Shenandoah-1 Petroleum Well: Hydraulic Fracturing and Testing Program 2011 Water Quality Monitoring Results

1. Background

In 2011 AECOM Australia Pty Ltd conducted a water quality monitoring program on behalf of Falcon Oil and Gas Australia Limited (Falcon) at its Shenandoah-1 Well which is located in EP117 at Hayfield Station in the Beetaloo Sub-basin. The objective of Falcon's program was to hydraulically fracture (HF) and test the Shenandoah-1 Exploration Well. The HF activity was conducted in five stages in target reservoir zones between 1,555 m and 2,741 m total vertical depth on 10 October 2011. Approximately 1.20 ML of HF fluid (approximately 99% water and 1% chemicals) and 91,500 kg of sand was pumped into the target zones via the Shenandoah-1 vertical exploration petroleum well at a maximum pressure of 8,696 pounds-inch^{-2} (psi) in the HF treatment.

After completion of the HF process, plugs that had been placed in the well to hold in the pumped HF fluid and sand were drilled out and the fluid, under pressure in the target reservoir, allowed to flowback to surface and via a separator and flare into a holding tank. Flowback commenced on 20 October 2011 and was completed on 1 November 2011. The volume of flowback diminished over time and at the same time, an increase in hydrocarbons from the reservoir to surface were recorded and flared in a well testing procedure. Approximately 30% of the pumped HF fluid was recovered in the flowback period. The flowback water was pumped back into the well at the end of the well testing operation and the Shenandoah 1 Well was permanently plugged in accordance with regulatory requirements at that time.

A water quality monitoring program of flowback water (water produced from the following hydraulic fracturing) and groundwater from four monitoring bores that intersected the Gum Ridge aquifer surrounding the Shenandoah-1 Well site was conducted as part of this well testing program. Six water samples were taken from the flowback water during flowback and well testing period and tested for over 100 analytes as shown in Appendix 2. No HF fluid was tested.

The groundwater monitoring commenced prior to the HF operation on 23 September 2011 and finished on 14 November 2011. The monitoring bores were: RN035538, RN037384, RN037385 and RN028303. The latter three monitoring bores are approximately 600m +/- 50m downgradient (north) of the Shenandoah Well head while RN035538 is located 80 m north west of it. Figure 1 depicts the monitoring bores in relation to the petroleum Shenandoah-1 exploration petroleum well. Eight groundwater samples were taken from the Gum Ridge aquifer at each water bore for laboratory analysis during the monitoring period and tested for over 100 analytes as shown in Appendix 1.

The reports for the Shenandoah1 Well activity, referred to as Well Completion Report Shenandoah-1A (Re-entry, Completion and Stimulation of Shenandoah-1A) EP98 Beetaloo Basin Northern Territory Australia including the water quality monitoring program results complied in this report is available at https://geoscience.nt.gov.au/gemis/ntgsjspui/handle/1/79502 .

The groundwater quaity results of particular interest from an environmental impact perspective include chloride, and electrical conductivity (E.C.) because these analytes are present in high concentrations in drilling fluids, hydraulic fracturing fluids, well suspension fluids and flowback. Concentrations may be orders of magnitude (100s~1000s) times higher than found in potable (drinkable) water.

Produced waters (including flowback following hydraulic fracturing) that come out of a petroleum well are characterised by high concentrations and mixtures of inorganic salts, organic compounds and other materials. They may contain Naturally-Occurring Radionuclide Material (NORM) from uranium and thorium decay in concentrations higher than routinely observed in environmental water samples. This decay is measured in Becquerels (Bq). One Becquerel is defined as the activity of a quantity of radioactive material in which one nucleus decays per second.

Other useful tracers include barium, boron and strontium which are also typically in higher concentrations in water from hydraulic fracturing activities and well above background values normally seen in groundwater. Dissolved methane is important to monitor as a baseline and over the longer term to confirm petroleum well integrity. There is no guideline drinking water standard for methane, which may be naturally present in groundwater, because it is not toxic.

Drinking water guideline standards provide a useful reference point for groundwater quality baseline data. They are based on annual ingested volume of drinking-water, assumed to be 730 litres/year, and are generally a health safety-factor of ten lower than what is considered an intervention level which is that level at which authorities will then need to make a decision regarding the need to implement remedial measures or to place some restriction on the continued use of the water supply for drinking purposes. Certain standards such as chloride are based on aesthetic rather than health measures.

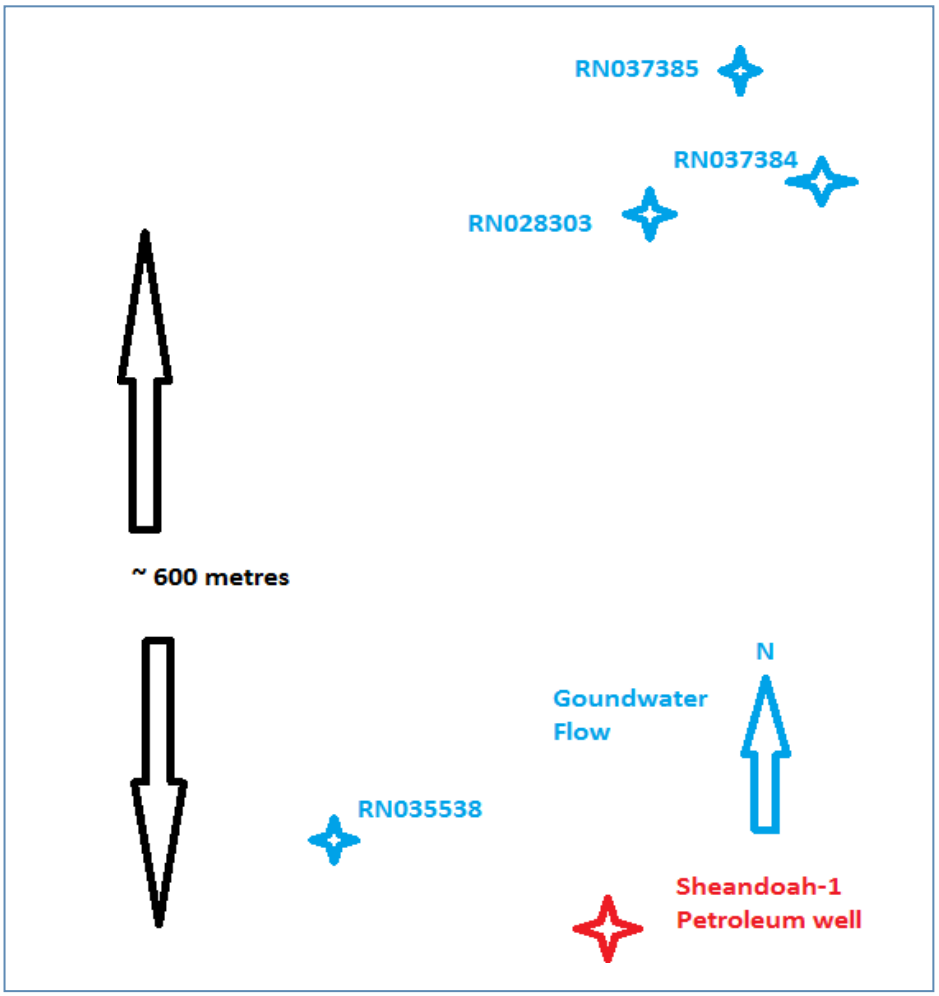

Figure 1: Groundwater monitoring bores in relation to Shenandoah-1 exploration petroleum well. Groundwater in the Gumridge aquifer flows approximately north in this location

2. Summary of results

Tables 1 and 2 lists a summary of results for groundwater at each monitoring bore in comparison to flowback water.

Table 1: Average **±** standard deviation for key analytes in groundwater at each bore during monitoring program from eight sampling events 23 September 2011 to 14 November 2011 in comparison to flowback water quality.

Key analyte	RN037384	RN037385	RN028303	RN035538	Flowback water
Electrical Conductivity (µS/cm)	842 ± 79	663 ± 135	1,185 ± 30	520 ± 21	65,383 ± 37,245
Chloride (mg/L)	91 ± 27	57 ± 28	151 ± 7.0	N.A.	29,433 ± 19,626
Barium (mg/L)	0.17 ± 0.19	<0.001	0.07 ± 0.05	0.313 ± 0.17	215 ± 239
Boron (mg/L)	0.16 ± 0.04	0.12 ± 0.05	0.21 ± 0.048	<0.05	4 ± 3.3

Table 2: Average, minimum and maximum for key analytes in flowback water at Shenandoah-1 petroleum well from six sampling events 20 October 2011 to 1 November 2011.

Key analyte	Average	Minimum	Maximum
Electrical Conductivity (µS/cm)	65,383	23,800	132,000
Chloride (mg/L)	29,433	8,100	66,200
Barium (mg/L)	215	0.6	595
Boron (mg/L)	4	0	8

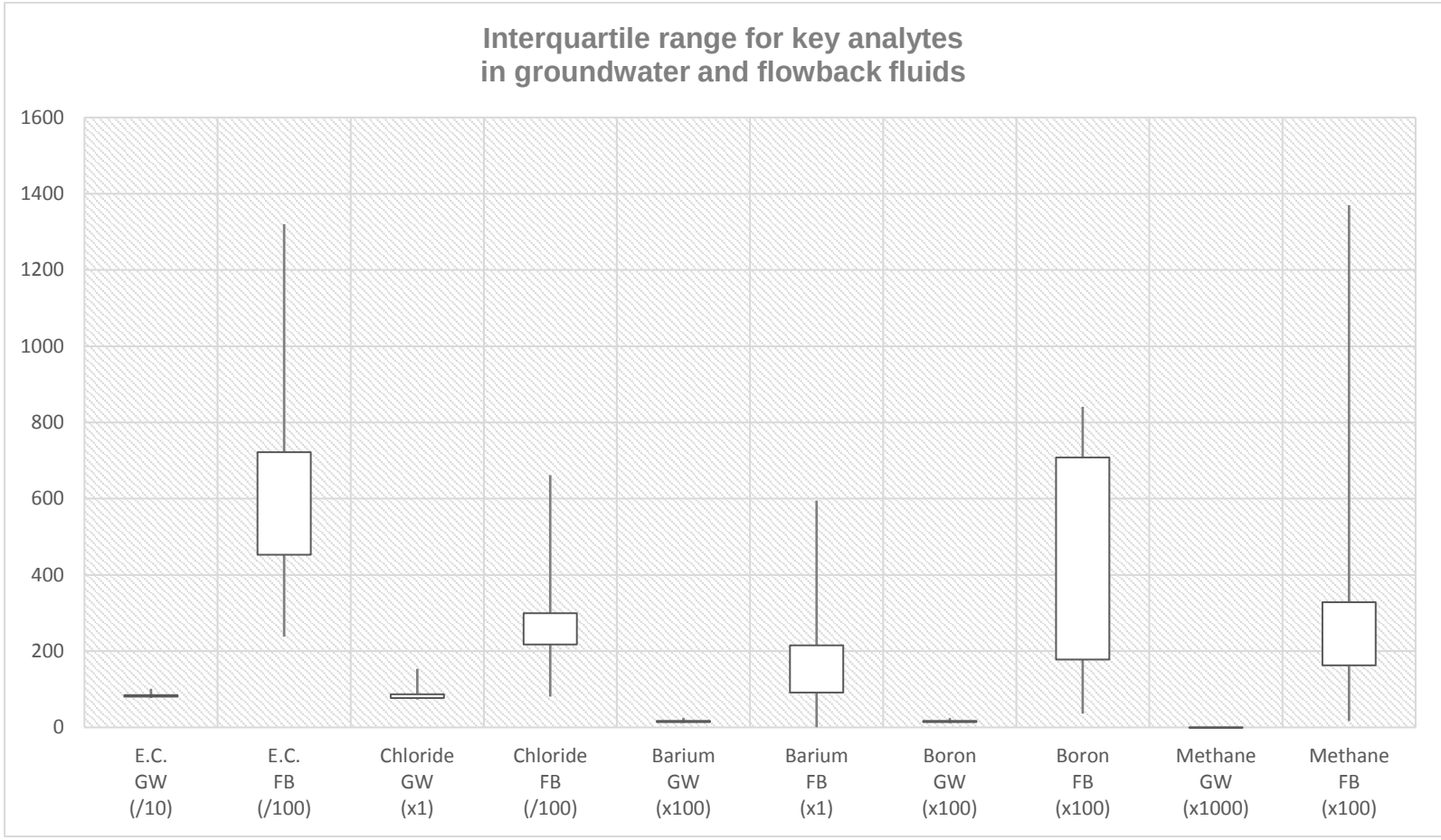

Figure 2: Interquartile range for key analytes in groundwater (GW) and flow back (FB) at Shenadoah petroleum well. Note the scale factor for each analyte and source.

3. Interpretation of results

Groundwater quality

The four groundwater quality monitoring bores (RN037384, RN037385, RN028303 and RN035538) near the Shenandoah Well site all intersect the Gum Ridge aquifer which is the principle regional aquifer of the Cambrian Limestone Aquifer system. Although RN037385, RN037384 and RN028303 are downgradient of the Shenandoah Well head (Figure 1) it is unlikely that they could provide an early detection of potential groundwater contamination from the Shenandoah Well during the activity, due to distance from the well head. However the groundwater monitoring data acquired at Shenandoah-1 in 2011 prior to and during Shenandoah well operations provides a useful baseline data set in the Gum Ridge aquifer at this location for a wide range of inorganic and organic analytes of interest.

Comparison of data acquired at these monitoring bores in subsequent years for the same analytes with the 2011 baseline data may provide a level of surety that the activity conducted in 2011 has not resulted in residual impact to the Gum Ridge aquifer in this location. One groundwater sample was taken at RN037385 on 10 November 2018. All hydrocarbons remained below detection limits. DENR has recommended that the full suite of analytes required for groundwater monitoring in the Code of Practice: Petroleum Activities in the NT (2019) be tested and reported on samples from these bores by the interest holder, Origin Energy, in 2019 to further assess this potential impact.

In the data reported in Appendix 1 for the four groundwater monitoring bores at Shenandoah, chloride varied from 42 mg/L to 161 mg/L. Corresponding E.C. monitoring data, which correlates with chloride as a proxy, ranged from 486 µS/cm to 1230 µS/cm. The US EPA recommends chloride levels no higher than 250 mg/L to avoid salty tastes and undesirable odors.

Barium varied from below detection limit of 0.001 mg/L to as high as 0.545 mg/L in the water bores. Recommended maximum level of barium in drinking water is 0.7 mg/L.

Contaminants of potential concern including heavy metals, hydrocarbons including methane, polyaromatic hydrocarbons (PAH) and BTEX were all below limits of reporting (LoR), i.e. not detectable, in the 2011 data set from these four bores.

Flowback fluid

Flowback water was sampled at the well head prior to flaring and discharge into the holding tank. Results are shown in Appendix 2, and key analytes summarised in Table 2. By comparison E.C. was approximately 60 times higher than bore water; chloride 200 times higher than bore water and barium 700 times higher than bore water.

The analysis shows pH was only slightly acidic with pH > 6.4 throughout the flowback period. E.C. increased from 23,800 µS/cm to 132,000 µS/cm during the flowback period. Similarly, chloride increased from 8,100 mg/L to 66,200 mg/L during flowback. This is much higher than permitted drinking water or wastewater effluent standards and therefore needs to be appropriately managed.

This trend of increasingly extreme salinity (brine) and corresponding reduction in flowback volume over the twelve days of flowback is typical of shale reservoirs following hydraulic fracturing. The reason for this elevated salinity in flowback water is that the target “source-rock” shale (mudstone), in which the organic matter that forms petroleum was deposited and subsequently buried, occurred in a depositional nearshore marine environment; over one billion years ago in the case of the Beetaloo Sub-basin shales. It is also noted that chloride in seawater averages approximately 18,980 mg/L by comparison.

Barium is also typically elevated in flowback water from shale gas reservoirs and serves, among other metals (e.g. strontium and boron), as an additional useful tracer. Marine deposition of barium is reported to be as barite which is released into the deep ocean during the breakdown and mineralization of organic matter during the sediment burial process and hence is typically elevated

in petroleum source- rock shales. Barium increased from 0.6 mg/L to 595 mg/L in the flowback. This is much higher than permitted drinking water or wastewater effluent standards and therefore needs to be appropriately managed. Similarly, boron and manganese are also elevated above guideline values in the flowback water.

As expected in flowback from a hydrocarbon reservoir, volatile organic carbon (VOC) levels were reported (Appendix 2) including dissolved methane, which varied from 1.2 mg/L to 13.7 mg/L, and benzene which varied from 1 mg/L to 94 mg/L were reported in the flowback but prior to flaring. In addition a range of total petroleum hydrocarbons (TPH) were also reported. However, no sampling of the composite total flowback water was conducted.

Range Comparison of Key analytes in Groundwater and Flowback

A range comparison of key analytes in groundwater (GW) and flow back (FB) at Shenandoah-1 petroleum well is shown graphically in Figure 2. Note the scale factor for each analyte and source. For example chloride range for FB is divided by 100 whereas GW has a scale factor of 1. The interpretation of results using this graphical method is helpful in visually exploring the data by comparing ranges and range overlap for each analyte in GW and FB. For example the range of electrical conductivity and chloride values measured in groundwater at the well site before during and after (years) the Shenandoah-1 well operations is orders of magnitude lower than FB fluid indicating that contamination of the groundwater at the well site from the HF operations is not detectable. A similar pattern can be seen for other key analytes in Figure 2. The conclusion from this data analysis is that there has been no material change detected in background values of groundwater quality attributable to well operations at the Shenandoah-1 wellsite from 2011 to 2018.

Approximate Composition of Flowback fluid

In terms of approximate composition, the flowback was found to be comprised of approximately 91% sodium chloride, 8% calcium carbonate, 0.58% barium sulphate and iron 0.22% which accounts for 99.84% of the flowback constituents (Fig. 3).

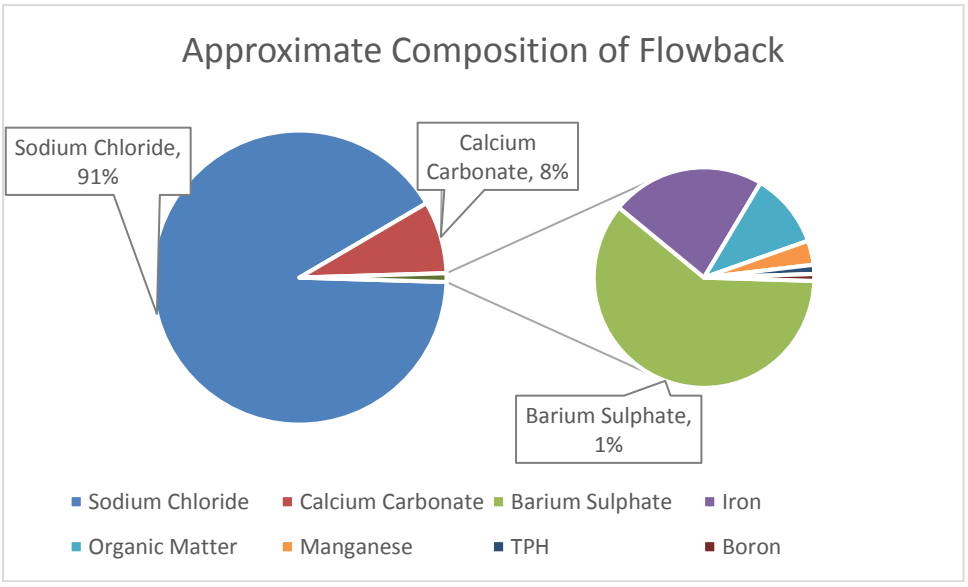

Figure 3: Approximate composition of Shenandoah flowback water

Contaminants of potential concern in the flowback water, due to their persistence and higher toxicity in the environment, including heavy metals (such as arsenic, cadmium, chromium and mercury), polyaromatic hydrocarbons (such as Benzo(a)pyrene) were all below limits of reporting (LoR), i.e. not detectable.

DENR has requested the interest holder to conduct further monitoring at the groundwater bore at Shenandoah-1 petroleum exploration well site in 2019 for the range of inorganic and organic

analytes specified in the Code of Practice: Onshore Petroleum Activities in the Northern Territory (the Code) (2019) to confirm no residual impact from the 2011 HF activities.

This flowback water quality data is consistent with flowback water quality data provided by Origin Energy from the nearby Amungee NW 1-H HF program in the Beetaloo Sub-basin in 2016.

The Shenadoah-1 results are similar to those reported in major studies of flowback from shale plays in North America (Hayes, 2009; Gandhi et al, 2018). These studies concluded that spills of flowback to ground were unlikely to pose a significant risk to aquatic ecosystems provided they were contained and cleaned up. The residue following evaporation of flowback water is considered a listed waste and therefore must be managed under listed waste provisions of the Waste Management and Pollution Control Act (1998).

4. Concluding summary points

- HF activities were conducted at the Shenandoah-1 petroleum exploration vertical well in October, 2011. A total of approximately 1.20 ML of HF fluid and 91.5 tons of sand were pumped into the target reservoir more than 1.5 km below the surface.
- Flowback water from the target reservoir in HF operation was tested for more than 100 analytes during the 3-week flowback period in November 2011.
- Results indicated that flowback water had approximately 200 times the level of chloride, 700 times the level of barium and 20 times the level of boron detected in groundwater at the well site.
- Groundwater from the Gum Ridge aquifer was tested for over 70 analytes at four bores, three of which were approximately 600 m down-gradient of Shenandoah-1 petroleum well, between September – November 2011. Further monitoring was conducted at one bore in 2018. No significant changes in groundwater quality were observed in the groundwater quality at any of the bores.
- The conclusion from graphical range analysis of key analytes in groundwater and flowback fluid is that there has been no material change detected in background values of groundwater quality attributable to well operations at the Shenandoah-1 petroleum well site.
- Contaminants of potential concern in the flowback water, due to their persistence and higher toxicity in the environment, including heavy metals (such as arsenic, cadmium, chromium and mercury) and polyaromatic hydrocarbons (such as Benzo-a-pyrene) were all below limits of reporting i.e. not detectable.
- In terms of approximate composition among the more than 100 analytes tested in the flowback, it was found to be comprised of approximately 91% sodium chloride, 8% calcium carbonate, 0.58% barium sulphate and 0.22% iron which accounts for 99.84% of the flowback water constituents.
- DENR has requested the interest holder to conduct further monitoring at the groundwater bores down-gradient of the Shenandoah well site in 2019 for the range of inorganic and organic analytes specified in the Code of Practice: Onshore Petroleum Activities in the Northern Territory (the Code) (2019) to confirm no residual impact from the 2011 HF activities.

References

Hayes, T, 2009, *Sampling and Analysis of Water Streams Associated with the Development of Marcellus Shale Gas Final Report* (www.**water**-research.net/naturalgasPA/pdffiles/MSCommission-Report.pdf (PDF file)).

Gandhi, H R, Sadiq, G, Hu and K Hewage, 2018, *Ecological risk assessment of accidental release of flowback water: A conceptual framework. Journal Human and Ecological Risk Assessment* 24(2): 398 to 426.

Acronyms, initialisms and glossary

HF	Hydraulic fracture
LoR	Limits of Reporting
NORM	Naturally Occurring Radionuclide Material
NTU	Nephelometric turbidity units
PAH	Poly-aromatic hydrocarbons
VOC	Volatile Organic Carbon

Units and symbols

%	
mg/L	Milligrams per litre
µg/L	Micrograms per litre
ML	megalitres
psi	Pounds per square inch
µS/cm	Micro Siemens/centimetre

Appendix 1: Shenandoah-1 Petroleum Well – Groundwater quality monitoring

Analyte	LoR	Unit	RN037384	RN037384	RN037384	RN037384	RN037384	RN037384	RN037384	RN037384	RN037385	RN037385
			23-09-11	05-10-11	10-10-11	17-10-11	31-10-11	31-10-11	08-11-11	14-11-11	05-10-11	10-10-11
Electrical Conductivity @ 25°C	1	µS/cm	-	1010	773	814	853	837	813	793	583	604
Alkalinity (Hydroxide) as CaCO3		mg/L	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000
Alkalinity (total) as CaCO3		NTU	360	259	230	234	216	263	258	259	181	194
Ammonia as N			10	<10	20	<10	<10	10	20	20	<10	<10
Anions Total		mg/L	14	9.8	8.19	8.03	7.41	8.86	8.63	8.63	5.86	6.34
Alkalinity (Bicarbonate as CaCO3)		mg/L	360	259	230	234	216	263	258	259	181	194
Cations Total		mg/L	14.2	10.1	8.66	8.58	7.24	8.28	8.76	8.37	6	6.84
Chloride		mg/L	154	105	81	77	80	80	76	73	45	54
Ionic Balance		mg/L	0.55	1.66	2.77	3.31	1.13	3.42	0.74	1.51	1.15	3.86
Nitrate (as N)		mg/L	0.07	0.14	0.05	0.03	0.02	0.04	0.04	0.03	0.29	0.01
Nitrite (as N)		mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Nitrogen (Total Oxidised)		mg/L	0.07	0.14	0.05	0.03	0.02	0.04	0.04	0.03	0.29	0.01
Free Carbon Dioxide as CO2		mg/L	17	-	4	16	11900	10	7	18	-	4
pH (Lab)		mg/L	7.62	7.39	8.11	7.47	8.03	7.73	7.88	8.11	7.56	8.01
Sodium (Filtered)		mg/L	110	78	61	62	59	54	58	55	39	46
Sulphate		mg/L	119	80	63	57	40	65	64	67	47	45
Sulphide		mg/L	<0.1	-	-	-	-	-	-	-	-	-
Total Suspended Solids		mg/L	1010	<5	<5	<5	<5	<5	<5	24	<5	<5
METALS												
Aluminium	0.01	mg/L	0.05	0.05	0.01	0.02	0.02	0.05	0.01	0.02	0.04	0.02
Arsenic	0.001	mg/L	0.005	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
Beryllium	0.001	mg/L	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.045	0.036
Barium	0.001	mg/L	0.545	0.048	0.034	0.037	-	-	-	-	<0.001	<0.001
Boron	0.05	mg/L	0.19	0.25	0.12	0.14	0.14	0.13	0.16	0.14	0.16	0.1
Cadmium	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium (III+VI)	0.001	mg/L	<0.0001	<0.0001	<0.001	<0.001	0.001	<0.001	<0.001	0.001	<0.001	<0.001
Cobalt	0.001	mg/L	<0.0001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Copper	0.001	mg/L	0.009	0.002	0.003	0.006	0.006	0.007	<0.001	<0.001	0.001	<0.001
Iron	0.05	mg/L	0.19	0.14	<0.05	0.08	<0.05	0.06	0.16	0.44	0.3	0.08
Lead	0.001	mg/L	0.007	0.002	0.002	0.002	0.002	0.001	<0.001	<0.001	<0.001	<0.001
Manganese	0.001	mg/L	<0.0001	<0.0001	<0.001	<0.001	<0.001	0.001	0.001	0.002	0.004	0.002
Mercury	0.0001	mg/L	<0.001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Molybdenum	0.001	mg/L	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	0.003	0.002
Nickel	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Phosphorus	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	0.16	<0.01	0.22
Selenium	0.001	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Uranium	0.01	mg/L	<1	<1	<1	<1	1	<1	1	<1	<1	<1
Vanadium	0.005	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc	0.01	mg/L	<0.005	<0.005	<0.005	0.011	0.015	0.018	<0.005	<0.005	<0.005	<0.005
HYDROCARBONS												
Methane	10	µg/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Acenaphthene	1	µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Acenaphthylene	1	µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Anthracene	1	µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Benz(a)anthracene	1	µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Benzo(a) pyrene	1	µg/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Benzo(b)fluoranthene	1	µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Benzo(g,h,i)perylene	1	µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Benzo(k)fluoranthene	1	µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chrysene	1	µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Dibenz(a,h)anthracene	1	µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Fluoranthene	0.5	µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Fluorene	1	µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Indeno(1,2,3-c,d)pyrene	1	µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Naphthalene	1	µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Phenanthrene	1	µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Pyrene	0.5	µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
TPH C6 - C9	20	µg/L	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
TPH C10 - C14	50	µg/L	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
TPH C15 - C28	100	µg/L	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
TPH C29-C36	50	µg/L	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
TPH+C10 - C36 (Sum of total)	50	µg/L	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
TPH C10 - C40 (Sum of total)	100	µg/L	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
TPH C10-C16	0.1	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
TPH C16-C34	0.1	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
TPH C34-C40	0.1	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
TPH C6-C10	0.02	mg/L	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Benzene	1	µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Toluene	2	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Ethylbenzene	2	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
meta- & para-Xylene	2	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
ortho-Xylene	2	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
^ Total Xylenes	2	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2

= Analytes of interest in groundwater monitoring at petroleum well sites due to their naturally high levels in petroleum reservoirs and flowback

Appendix 1: Shenandoah-1 Petroleum Well – Groundwater quality monitoring

Analyte	LoR	Unit	RN037385	RN037385	RN037385	RN037385	RN037385	RN037385	RN028303	RN028303	RN028303
			17-10-11	24-10-11	31-10-11	08-11-11	14-11-11	10-Nov-18	23-09-2011	5-Oct-11	10-Oct-11
Electrical Conductivity @ 25°C	1	µS/cm	632	-	663	611	585	962	1140	1200	1160
Alkalinity (Hydroxide) as CaCO3		mg/L	<1000	-	<1000	<1000	<1000	<1000	<1000	<1000	<1000
Alkalinity (total) as CaCO3		NTU	199	-	214	212	201		330	306	210
Ammonia as N			30	<10	<10	<10	<10		20	180	<10
Anions Total		mg/L	6.37	-	6.71	6.54	6.34		12.9	12.7	11.6
Alkalinity (Bicarbonate as CaCO3)		mg/L	199	-	214	212	201		330	306	210
Cations Total		mg/L	7.15	-	6.72	6.77	6.25		13.3	12.6	12.8
Chloride		mg/L	53	-	51	42	49	102	141	156	157
Ionic Balance		mg/L	5.81	-	0.05	1.69	0.67	4.41	1.7	0.29	5.17
Nitrate (as N)		mg/L	<0.01	0.01	0.02	0.02	<0.01	0.03	0.08	0.05	0.07
Nitrite (as N)		mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Nitrogen (Total Oxidised)		mg/L	<0.01	0.01	0.02	0.02	<0.01		0.08	0.05	0.07
Free Carbon Dioxide as CO2		mg/L	11	-	5	8	7		14	-	4
pH (Lab)		mg/L	7.57	-	7.95	7.74	8.05	7.60	7.66	7.23	8.03
Sodium (Filtered)		mg/L	47	44	42	42	39		100	99	98
Sulphate		mg/L	43	-	48	54	45	73	110	106	141
Sulphide		mg/L	-	-	-	-	-		<0.1	-	-
Total Suspended Solids		mg/L	<5	<5	<5	<5	8		<5	<5	<5
METALS											
Aluminium	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	0.02		<0.01	0.02	0.03
Arsenic	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Beryllium	0.001	mg/L	0.036	-	-	-	-	-	<0.001	<0.001	<0.001
Barium	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	-	0.08	0.11	0.087
Boron	0.05	mg/L	0.12	0.11	0.11	0.12	0.1	-	0.2	0.32	0.17
Cadmium	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	-	<0.0001	<0.0001	<0.0001
Chromium (III+VI)	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cobalt	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	<0.001	<0.001
Copper	0.001	mg/L	0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001
Iron	0.05	mg/L	<0.05	<0.05	0.16	0.3	0.28	0.27	0.08	0.6	<0.05
Lead	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Manganese	0.001	mg/L	0.001	0.002	0.004	0.009	0.012	0.026	0.034	0.071	0.038
Mercury	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	-	<0.0001	<0.0001	<0.0001
Molybdenum	0.001	mg/L	0.002	0.002	0.002	<0.001	0.002	-	<0.001	<0.001	<0.001
Nickel	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	<0.001	<0.001
Phosphorus	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	<0.01	<0.01
Selenium	0.001	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	-	0.001	0.001	0.001
Uranium	0.01	mg/L	<1	<1	<1	<1	<1	-	<0.01	<0.01	<0.01
Vanadium	0.005	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.005	<0.005	<0.005
Zinc	0.01	mg/L	0.033	<0.005	<0.005	<0.005	0.009	-	0.02	0.18	<0.01
HYDROCARBONS											
Methane	10	µg/L	<10	<10	<10	<10	<10	<10	<10	<10	<10
Acenaphthene	1	µg/L	<1	<1	<1	<1	<1	<1	<1.0	<1.0	<1.0
Acenaphthylene	1	µg/L	<1	<1	<1	<1	<1	<1	<1.0	<1.0	<1.0
Anthracene	1	µg/L	<1	<1	<1	<1	<1	<1	<1.0	<1.0	<1.0
Benz(a)anthracene	1	µg/L	<1	<1	<1	<1	<1	<1	<1.0	<1.0	<1.0
Benzo(a) pyrene	1	µg/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<1.0	<1.0	<1.0
Benzo(b)fluoranthene	1	µg/L	<1	<1	<1	<1	<1	<1	<1.0	<1.0	<1.0
Benzo(g,h,i)perylene	1	µg/L	<1	<1	<1	<1	<1	<1	<1.0	<1.0	<1.0
Benzo(k)fluoranthene	1	µg/L	<1	<1	<1	<1	<1	<1	<1.0	<1.0	<1.0
Chrysene	1	µg/L	<1	<1	<1	<1	<1	<1	<1.0	<1.0	<1.0
Dibenz(a,h)anthracene	1	µg/L	<1	<1	<1	<1	<1	<1	<1.0	<1.0	<1.0
Fluoranthene	0.5	µg/L	<1	<1	<1	<1	<1	<1	<0.5	<0.5	<0.5
Fluorene	1	µg/L	<1	<1	<1	<1	<1	<1	<1.0	<1.0	<1.0
Indeno(1,2,3-c,d)pyrene	1	µg/L	<1	<1	<1	<1	<1	<1	<1.0	<1.0	<1.0
Naphthalene	1	µg/L	<1	<1	<1	<1	<1	<1	<1.0	<1.0	<1.0
Phenanthrene	1	µg/L	<1	<1	<1	<1	<1	<1	<1.0	<1.0	<1.0
Pyrene	0.5	µg/L	<1	<1	<1	<1	<1	<1	<0.7	<0.5	<0.5
TPH C6 - C9	20	µg/L	<20	<20	<20	<20	<20	<20	<20	<20	<20
TPH C10 - C14	50	µg/L	<50	<50	<50	<50	<50	<50	<50	<50	<50
TPH C15 - C28	100	µg/L	<100	<100	<100	<100	<100	<100	<100	<100	<100
TPH C29-C36	50	µg/L	<50	<50	<50	<50	<50	<50	<50	<50	<50
TPH+C10 - C36 (Sum of total)	50	µg/L	<50	<50	<50	<50	<50	<50	<50	<50	<50
TPH C10 - C40 (Sum of total)	100	µg/L	<100	<100	<100	<100	<100	<100	<20	<20	<20
TPH C10-C16	0.1	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<20	<20	<20
TPH C16-C34	0.1	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<100	<100	<100
TPH C34-C40	0.1	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<100	<100	<100
TPH C6-C10	0.02	mg/L	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<100	<100	<100
Benzene	1	µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1
Toluene	2	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2
Ethylbenzene	2	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2
meta- & para-Xylene	2	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2
ortho-Xylene	2	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2
^ Total Xylenes	2	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2
	= Analytes of inte										

Appendix 1: Shenandoah-1 Petroleum Well – Groundwater quality monitoring

Analyte	LoR	Unit	RN028303	RN028303	RN028303	RN028303	RN028303	RN035538	RN035538	RN035538	RN035538
			17-Oct-11	24-10-11	31-10-11	08-11-11	14-11-11	23-09-2011	11-10-05	11-10-10	11-10-17
Electrical Conductivity @ 25°C	1	µS/cm	1210	1230	1190	1190	1160	521	552	514	520
Alkalinity (Hydroxide) as CaCO3		mg/L	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000
Alkalinity (total) as CaCO3		NTU	307	261	332	343	330	294	270	270	272
Ammonia as N			20	<10	10	20	10	20	<10	<10	30
Anions Total		mg/L	12.7	11.6	13.1	13.2	13	6.1	5.66	5.64	5.69
Alkalinity (Bicarbonate as CaCO3)		mg/L	307	261	332	343	330	294	270	270	272
Cations Total		mg/L	13.4	10.8	12.3	12.7	12.7	6.67	5.83	6.32	5.95
Chloride		mg/L	161	152	150	147	143	-	-	-	-
Ionic Balance		mg/L	2.79	3.86	3.23	1.83	1.34	4.52	1.53	5.73	2.26
Nitrate (as N)		mg/L	0.08	0.05	0.08	0.07	0.06	0.08	0.34	0.08	0.06
Nitrite (as N)		mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Nitrogen (Total Oxidised)		mg/L	0.08	0.05	0.08	0.07	0.06	0.08	0.34	0.08	0.06
Free Carbon Dioxide as CO2		mg/L	39	22300	19	12	26	6	-	4	20
pH (Lab)		mg/L	7.2	7.83	7.55	7.74	7.92	7.97	7.5	8.13	7.43
Sodium (Filtered)		mg/L	105	87	92	95	95	2	2	2	2
Sulphate		mg/L	98	102	108	106	114	4	6	5	4
Sulphide		mg/L	-	-	-	-	-	<0.1	-	-	-
Total Suspended Solids		mg/L	<5	<5	<5	<5	8	<5	<5	<5	<5
METALS											
Aluminium	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.02	0.02
Arsenic	0.001	mg/L	<0.001	<0.01	<0.01	<0.01	<0.01	0.002	0.003	0.003	0.003
Beryllium	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002
Barium	0.001	mg/L	0.087	<0.001	<0.001	<0.001	0.001	0.279	0.363	0.31	0.301
Boron	0.05	mg/L	0.2	0.18	0.18	0.23	0.2	<0.05	<0.05	<0.05	<0.05
Cadmium	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Chromium (III+VI)	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cobalt	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Copper	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	0.003	0.033	0.024	0.05	0.017
Iron	0.05	mg/L	<0.05	<0.05	<0.05	0.46	0.82	<0.05	<0.05	<0.05	<0.05
Lead	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Manganese	0.001	mg/L	0.035	0.046	0.03	0.016	0.016	0.108	0.113	0.063	0.113
Mercury	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Molybdenum	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nickel	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001
Phosphorus	0.01	mg/L	<0.01	<0.01	0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01
Selenium	0.001	mg/L	0.001	<0.01	<0.01	<0.01	<0.01	<0.001	<0.001	<0.001	<0.01
Uranium	0.01	mg/L	<0.01	1	1	1	1	<0.01	<0.01	<0.01	<1
Vanadium	0.005	mg/L	<0.005	<0.01	<0.01	<0.01	<0.01	0.103	0.158	0.111	<0.01
Zinc	0.01	mg/L	0.02	<0.005	<0.005	<0.005	0.007	0.103	0.158	0.111	1.87
HYDROCARBONS											
Methane	10	µg/L	<10	<10	<10	<10	<10	<10	<10	<10	<10
Acenaphthene	1	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Acenaphthylene	1	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Anthracene	1	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Benz(a)anthracene	1	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Benzo(a) pyrene	1	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Benzo(b)fluoranthene	1	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Benzo(g,h,i)perylene	1	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Benzo(k)fluoranthene	1	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Chrysene	1	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Dibenz(a,h)anthracene	1	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Fluoranthene	0.5	µg/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Fluorene	1	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Indeno(1,2,3-c,d)pyrene	1	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Naphthalene	1	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Phenanthrene	1	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Pyrene	0.5	µg/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
TPH C6 - C9	20	µg/L	<20	<20	<20	<20	<20	<20	<20	<20	<20
TPH C10 - C14	50	µg/L	<50	<50	<50	<50	<50	<50	<50	<50	<50
TPH C15 - C28	100	µg/L	<100	<100	<100	<100	<100	<100	<100	<100	<100
TPH C29-C36	50	µg/L	<50	<50	<50	<50	<50	<50	<50	<50	<50
TPH+C10 - C36 (Sum of total)	50	µg/L	<50	<50	<50	<50	<50	<50	<50	<50	<50
TPH C10 - C40 (Sum of total)	100	µg/L	<20	<20	<20	<20	<20	<20	<20	<20	<20
TPH C10-C16	0.1	mg/L	<20	<20	<20	<20	<20	<20	<20	<20	<20
TPH C16-C34	0.1	mg/L	<100	<100	<100	<100	<100	<100	<100	<100	<100
TPH C34-C40	0.1	mg/L	<100	<100	<100	<100	<100	<100	<100	<100	<100
TPH C6-C10	0.02	mg/L	<100	<100	<100	<100	<100	<100	<100	<100	<100
Benzene	1	µg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1
Toluene	2	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2
Ethylbenzene	2	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2
meta- & para-Xylene	2	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2
ortho-Xylene	2	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2
^ Total Xylenes	2	µg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2
	= Analytes of inte										

Appendix 1: Shenandoah-1 Petroleum Well – Groundwater quality monitoring

Analyte	LoR	Unit	RN035538	RN035538	RN035538	RN035538
			24-10-11	31-10-11	08-11-11	14-11-11
Electrical Conductivity @ 25°C	1	µS/cm	544	523	500	486
Alkalinity (Hydroxide) as CaCO3		mg/L	<1000	<1000	<1000	<1000
Alkalinity (total) as CaCO3		NTU	230	287	286	280
Ammonia as N			10	10	20	<10
Anions Total		mg/L	4.92	5.96	5.91	5.79
Alkalinity (Bicarbonate as CaCO3)		mg/L	230	287	286	280
Cations Total		mg/L	4.83	5.88	6.02	5.73
Chloride		mg/L	-	-	-	-
Ionic Balance		mg/L	0.97	0.61	0.9	0.47
Nitrate (as N)		mg/L	0.05	0.05	0.06	0.05
Nitrite (as N)		mg/L	0.02	<0.01	<0.01	0.02
Nitrogen (Total Oxidised)		mg/L	0.07	0.05	0.06	0.07
Free Carbon Dioxide as CO2		mg/L	4	7	4	7
pH (Lab)		mg/L	8.04	7.9	8.14	8.28
Sodium (Filtered)		mg/L	2	2	2	2
Sulphate		mg/L	9	4	4	4
Sulphide		mg/L	-	-	-	-
Total Suspended Solids		mg/L	11	<5	<5	14
METALS						
Aluminium	0.01	mg/L	0.02	0.01	0.01	0.01
Arsenic	0.001	mg/L	0.003	0.004	0.004	005
Beryllium	0.001	mg/L	<.001	<.001	<.001	<0.001
Barium	0.001	mg/L	-	-	-	-
Boron	0.05	mg/L	<.0.05	<0.05	<0.05	<0.05
Cadmium	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001
Chromium (III+VI)	0.001	mg/L	<0.001	<0.001	<0.001	<0.001
Cobalt	0.001	mg/L	<0.001	<0.001	<0.001	<0.001
Copper	0.001	mg/L	0.006	0.015	0.021	0.009
Iron	0.05	mg/L	<0.05	0.14	0.08	0.16
Lead	0.001	mg/L	<0.001	<0.001	<0.001	<0.001
Manganese	0.001	mg/L	0.143	0.097	0.048	0.034
Mercury	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001
Molybdenum	0.001	mg/L	<0.001	<0.001	<0.001	<0.001
Nickel	0.001	mg/L	<0.001	<0.001	<0.001	<0.001
Phosphorus	0.01	mg/L	<0.01	0.05	<0.01	<0.01
Selenium	0.001	mg/L	<0.01	<0.01	<0.01	<0.01
Uranium	0.01	mg/L	<1	<1	<1	<1
Vanadium	0.005	mg/L	<0.01	<0.01	<0.01	<0.01
Zinc	0.01	mg/L	0.08	0.093	0.086	0.066
HYDROCARBONS						
Methane	10	µg/L	<10	<10	<10	<10
Acenaphthene	1	µg/L	<1.0	<1.0	<1.0	<1.0
Acenaphthylene	1	µg/L	<1.0	<1.0	<1.0	<1.0
Anthracene	1	µg/L	<1.0	<1.0	<1.0	<1.0
Benz(a)anthracene	1	µg/L	<1.0	<1.0	<1.0	<1.0
Benzo(a) pyrene	1	µg/L	<1.0	<1.0	<1.0	<1.0
Benzo(b)fluoranthene	1	µg/L	<1.0	<1.0	<1.0	<1.0
Benzo(g,h,i)perylene	1	µg/L	<1.0	<1.0	<1.0	<1.0
Benzo(k)fluoranthene	1	µg/L	<1.0	<1.0	<1.0	<1.0
Chrysene	1	µg/L	<1.0	<1.0	<1.0	<1.0
Dibenz(a,h)anthracene	1	µg/L	<1.0	<1.0	<1.0	<1.0
Fluoranthene	0.5	µg/L	<0.5	<0.5	<0.5	<0.5
Fluorene	1	µg/L	<1.0	<1.0	<1.0	<1.0
Indeno(1,2,3-c,d)pyrene	1	µg/L	<1.0	<1.0	<1.0	<1.0
Naphthalene	1	µg/L	<1.0	<1.0	<1.0	<1.0
Phenanthrene	1	µg/L	<1.0	<1.0	<1.0	<1.0
Pyrene	0.5	µg/L	<0.5	<0.5	<0.5	<0.5
TPH C6 - C9	20	µg/L	<20	<20	<20	<20
TPH C10 - C14	50	µg/L	<50	<50	<50	<50
TPH C15 - C28	100	µg/L	<100	<100	<100	<100
TPH C29-C36	50	µg/L	<50	<50	<50	<50
TPH+C10 - C36 (Sum of total)	50	µg/L	<50	<50	<50	<50
TPH C10 - C40 (Sum of total)	100	µg/L	<20	<20	<20	<20
TPH C10-C16	0.1	mg/L	<20	<20	<20	<20
TPH C16-C34	0.1	mg/L	<100	<100	<100	<100
TPH C34-C40	0.1	mg/L	<100	<100	<100	<100
TPH C6-C10	0.02	mg/L	<100	<100	<100	<100
Benzene	1	µg/L	<1	<1	<1	<1
Toluene	2	µg/L	<2	<2	<2	<2
Ethylbenzene	2	µg/L	<2	<2	<2	<2
meta- & para-Xylene	2	µg/L	<2	<2	<2	<2
ortho-Xylene	2	µg/L	<2	<2	<2	<2
^ Total Xylenes	2	µg/L	<2	<2	<2	<2

= Analytes of inte

Appendix 2: Shenandoah-1 Flow back analysis

Analyte	Units	EQL	ANZECC (2000) Ecosystems Freshwater	ANZECC (2000) Stock Watering	Dutch (2000) Interventions Value	NHRMC (2004) Drinking Water Health	Sample 1 16/10/2011	Sample 2 17/10/2011	Sample 3 21/10/2011	Sample 4 21/10/2011	Sample 5 31/10/2011	Sample 6 2/11/2011
INORGANICS												
Electrical Conductivity	uS/cm	1					23800	58300	61400	75800	41000	132000
Turbidity	NTU	0.1					46.2	1.8	584	462	12.4	150
Alkalinity (Hydroxide) as CaCO3	µg/L	1000					<1000	<1000	<1000	<1000	<1000	<1000
Alkalinity (total) as CaCO3	mg/L	1					290	259	201	223	111	56
Ammonia as N	µg/L	10					47,800	73,500	48,100	55,000	64,600	1880
Anions Total	meq/L	0.01					237	719	704	893	587	-
Alkalinity (Bicarbonate as CaCO	mg/L	1					290	259	201	223	111	56
Cations Total	meq/L	0.01					259	641	766	882	580	-
Chloride	mg/L	1					8100	25,300	24,800	31,500	20,700	66,200
Ionic Balance	%	0.01					4.32	5.75	4.26	0.6	0.57	-
Nitrate (as N)	mg/L	0.01					0.23	0.25	0.13	0.1	0.27	0.24
Nitrite (as N)	mg/L	0.01					0.14	0.02	<0.01	<0.01	0.03	<0.01
Nitrogen (Total Oxidised)	mg/L	0.01					0.37	0.27	0.13	0.1	0.3	0.24
pH (Lab)	pH_Units	0.01					6.59	6	6.87	6.68	6.41	6.13
Sodium (Filtered)	mg/L	1					5190	11,400	13,800	14,800	9150	21,500
Sulphate	mg/L	1		**2000**		**500**	141	<1	6	3	53	<1
Sulphide	mg/L	0.1					-	-	-	-	-	-
TSS	mg/L	5					28	13	115	440	50	306
METALS												
Aluminium	mg/L	0.01	**0.06**	**5.0**			0.78	0.37	<0.1	<0.1	0.06	<0.1
Arsenic	mg/L	0.001		**0.500**		**0.007**	0.001	<0.001	<0.01	<0.01	<0.001	<0.01
Barium	mg/L	0.001				**0.700**	0.634	50.6	-	-	-	595
Beryllium	mg/L	0.001					<0.001	<0.001	<0.01	<0.01	<0.001	<0.01
Boron	mg/L	0.05	**0.37**	**5.0**		**4.0**	3.33	5.32	7.67	8.41	0.36	1.26
Cadmium	mg/L	0.0001	**0.0002**	**0.0100**	**0.0002**	**0.0020**	0.0004	0.0001	<0.001	<0.001	0.0003	<0.001
Calcium (Filtered)	mg/L	1		**1000**			487	2280	2710	3970	2280	9180
Chromium (III+VI)	mg/L	0.001		**1.000**			0.102	0.144	0.083	0.097	0.007	<0.01
Cobalt	mg/L	0.001		**1.000**			0.002	0.004	<0.01	<0.01	0.012	0.021
Copper	mg/L	0.001		**0.400**		**2.000**	0.004	0.008	0.022	0.029	0.012	0.114
Iron	mg/L	0.05					32.8	78	81.5	98	70.3	236
Lead	mg/L	0.001	**0.003**	**0.100**		**0.010**	0.001	<0.001	<0.01	<0.01	0.003	<0.01
Manganese	mg/L	0.001	**1.900**			**0.500**	1.29	3.82	4.81	5.77	14	64.3
Mercury	mg/L	0.0001	**0.0006**	**0.0020**		**0.0010**	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Molybdenum	mg/L	0.001		**0.150**		**0.005**	0.007	0.008	<0.01	<0.01	0.007	<0.01
Nickel	mg/L	0.001	**0.011**	**1.0**		**0.002**	0.005	<0.001	<0.01	<0.01	0.072	<0.01
Phosphorus	mg/L	0.01					2.57	1.84	0.79	0.82	0.1	<0.25
Selenium	mg/L	0.01					<0.01	<0.01	<0.1	<0.1	0.02	-
Uranium	µg/L	1			**200**	**20**	<1	<1	<10	<10	<1	<10
Vanadium	mg/L	0.01					0.01	<0.01	<0.1	<0.1	<0.01	<0.1
Zinc	mg/L	0.005	**0.008**	**20.0**			0.104	0.427	0.063	0.213	0.056	0.497
HYDROCARBONS												
Methane	mg/L	1	**0.01**				1.26	2.75	0.169	13.7	3.07	3.36
BTEX												
Benzene	µg/L	1	**950**			**1**	1	6	<1	4	94	17
Ethylbenzene	µg/L	2				**300**	<2	<2	<2	<2	4	<2
Toluene	µg/L	2				**800**	2	14	<5	<5	106	24
Xylene (m & p)	µg/L	2					<2	<2	<2	<2	29	11
Xylene (o)	µg/L	2	**350**				<2	<2	<2	<2	14	4
Xylene Total	µg/L	2				**600**	<2	<2	<2	<2	43	15
Total Petroleum Hydrocarbons												
TPH C6 - C9	µg/L	20					<20	40	<20	<20	280	230
TPH C10 - C14	µg/L	50					1000	1400	510	420	870	1620
TPH C15 - C28	µg/L	100					240	160	240	<100	<100	3300
TPH C29-C36	µg/L	50					190	90	100	<50	<50	700
TPH+C10 - C36 (Sum of total)	µg/L	50			**600**		1430	1650	850	420	870	5620
TPH C10 - C40 (Sum of total)	µg/L	100					1160	1260	600	480	1440	7760
TPH C10-C16	mg/L	0.1					0.84	1.1	0.34	0.48	1.44	4.06
TPH C16-C34	mg/L	0.1					0.32	0.16	0.26	<0.1	<0.1	3.27
TPH C34-C40	mg/L	0.1					<0.1	<0.1	<0.1	<0.1	<0.1	0.43
TPH C6-C10	mg/L	0.02					<0.02	0.05	<0.02	<0.02	0.29	0.26
PAH/Phenols												
Acenaphthene	µg/L	1					<1	<1	<1	<1	<1	<1
Acenaphthylene	µg/L	1					<1	<1	<1	<1	<1	<1
Anthracene	µg/L	1					<1	<1	<1	<1	<1	<1
Benz(a)anthracene	µg/L	1					<1	<1	<1	<1	<1	<1
Benzo(a) pyrene	µg/L	0.5				**0.01**	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Benzo(b)fluoranthene	µg/L	1					<1	<1	<1	<1	<1	<1
Benzo(g,h,i)perylene	µg/L	1					<1	<1	<1	<1	<1	<1
Benzo(k)fluoranthene	µg/L	1					<1	<1	<1	<1	<1	<1
Chrysene	µg/L	1					<1	<1	<1	<1	<1	<1
Dibenz(a,h)anthracene	µg/L	1					<1	<1	<1	<1	<1	<1
Fluoranthene	µg/L	1					<1	<1	<1	<1	<1	<1
Fluorene	µg/L	1					<1	<1	<1	<1	<1	<1
Indeno(1,2,3-c,d)pyrene	µg/L	1					<1	<1	<1	<1	<1	<1
Naphthalene	µg/L	1	**16**				<1	<1	<1	<1	<1	<1
Phenanthrene	µg/L	1					<1	<1	<1	<1	<1	<1
Pyrene	µg/L	1					<1	<1	<1	<1	<1	<1

water monitoring at petroleum well sites due to their naturally high levels in petroleum reservoirs and flowback