Pre-hydraulic fracturing water quality data summary

W11 Milestone 7 report
May 2018

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Cover Photo

Dogwood Creek, Condabri, Queensland.

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List of Abbreviations

Acroynm	Meaning
ANZECC	Australia and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
BTEX	Benzene, toluene, ethylbenzene and xylene
HF	Hydraulic fracturing
NATA	National Association of Testing Authorities
PAH	Polycyclic aromatic hydrocarbons
TDS	Total dissolved solids
TRH	Total recoverable hydrocarbons

Acknowledgements

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The authors thank Origin Energy for allowing unrestricted access to their environmental monitoring data for the Condabri and Comababula gas fields.

Executive summary

CSIRO is currently undertaking a detailed study of the impacts of hydraulic fracturing (HF) on air, soil and water quality at two locations in the Surat Basin, QLD. The air component of the study is being conducted by CSIRO Oceans & Atmosphere and the water/soil component is being conducted by CSIRO Land & Water.

The aims of the water and soil study are as follows:

(i) To quantify the impacts of HF operations on the concentrations of contaminants in nearby surface waters, groundwater and soils.

(ii) To assess the concentrations of HF chemicals and geogenic contaminants in flowback and produced waters resulting from CSG HF operations.

(iii) To check compliance of contaminant concentrations in the collected water and soil samples with relevant Australian water and soil quality guidelines.

(iv) To conduct a laboratory assessment of various spill scenarios involving spillage of hydraulic fracturing fluid and produced waters onto various soils types representative of the Surat Basin.

During the planning phase of the study, two sites were selected in the Surat Basin, Queensland, at Condabri and Combabula. Both gas fields are operated by Origin Energy. A sampling and monitoring plan for waters and soils was subsequently developed (Apte et al. 2017).

In October 2016, Origin Energy secured the permission of landholders, and engaged SGS Leeder to undertake surface and groundwater sampling in the vicinity of the proposed study sites. The collected water samples were then analysed for a comprehensive range of inorganic and organic contaminants. The generated data sets provide useful information on baseline water quality before the commencement of HF in the study region.

This report provides a collation of the monitoring data and gives some preliminary interpretation of the data. The datasets will be used as an aid to interpret the results generated by the main part of the study which involves comprehensive sampling of surface waters and groundwater during and after HF operations.

Samples were collected from Dogwood Creek, the main surface water feature draining the Condabri study site in October 2016 and from three groundwater bores at the Combabula site in April 2017. The samples were subsequently analysed for a comprehensive range of water quality parameters including inorganic ions, organic chemicals, trace metals and radioactivity. The analytical data were supplied to CSIRO for checking and interpretation. The main findings were:

1. Water quality data for Dogwood Creek in October 2016, the major surface water feature draining the Condabri study site, indicated that the creek water was turbid, of low hardness and slightly acidic. The water samples were monitored for 128 organic contaminants and all were below the limits of detection. Most dissolved trace metal concentrations were in the low µg/L

range. Dissolved aluminium, copper and zinc concentrations exceeded the ANZECC/ARMCANZ water quality guideline values that apply in Australia (95% species protection values). The elevated concentrations of these metals in the Creek waters may reflect natural mineralisation in the catchment and/or anthropogenic inputs from upstream locations.

2. Groundwater samples collected from the Combabula study site in April 2017 indicated that the bore water was alkaline, moderately saline, of high alkalinity and low hardness. Total dissolved solids (TDS) concentrations were typically ~1000 mg/L. The water samples were monitored for 28 organic contaminants (including BTEX, TRHs, PAHs) and all were below the limit of detection aside from ethanol (2 mg/L). Ethanol is an unlikely groundwater contaminant and this result is believed to be an error (e.g. resulting from sample contamination). Trace metal concentrations were present at low µg/L or lower concentrations and were below levels of regulatory concern.

3. The baseline water quality data compiled in this report will be used to aid the assessment and interpretation of the water quality data obtained during hydraulic fracturing operations and thereafter.

1 Introduction

CSIRO is currently undertaking a detailed study of the impacts of hydraulic fracturing (HF) on air, soil and water quality at two locations in the Surat Basin, Queensland. The air component of the study is being conducted by CSIRO Oceans & Atmosphere and the water/soil component is being conducted by CSIRO Land & Water.

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2 Details of the study sites

As foreshadowed in the sampling and monitoring plan (Apte et al. 2017), field activities were focussed around two rural sites (Condabri and Combabula) in Central Queensland which were scheduled to undergo hydraulic fracturing operations in the second half of 2017. Both sites were grazing properties. This section provides background information on both sites.

2.1 Study site 1: Condabri

Site 1 (WAP2) is a farmland property of approximately 1030 ha located between Miles and Condamine (26°45’21’’ S, 150°10’49’’E). The property is predominantly flat, semi-arid open grassland with stands of native tree vegetation (Figure 1). Dogwood Creek, an ephemeral surface waterway, borders the western boundary of the property and the Leichhardt Highway borders the eastern boundary.

In total, six soil types were noted to be present across the project area. These included Dermosol, Sodosol, Hydrosol, Kandosol, Rudosol and Vertosol (Figure 2). The majority of soils present in the project area have formed from quaternary alluvium containing sand, silt mud and gravel.

The property contains 19 CSG wells, grid spaced at ~ 600 – 700 m intervals. Rig release dates provided by Origin Energy indicated that the wells were drilled and constructed between August and September 2015, with an additional well constructed in August 2016 (Source: Qld Globe). Well depths range from 740 – 860 m and target the Walloon Coal Measures. The wells were scheduled to undergo some form of well bore stimulation in June and July 2017 after which they were brought on-line and connected to the gas and water pipeline network. Twelve of the wells will undergo HF.

Dogwood Creek runs along the western boundary of the property and is the most significant surface water feature in the area. The area to the west of Dogwood Creek is dominated by farmland with ~ 5 CSG wells within a 5 km radius of the boundary. In contrast, the area to the east of the property, bounded by the Leichhardt Highway, is dominated by farmland with a high density of CSG wells (grid spaced ~ 600 – 700 m) (Figure 1). The wells in this area are serviced by a network of pipelines and vents, which connect to the Condabri Central Gas Processing Facility which is approximately 5 km to the south of the study site.

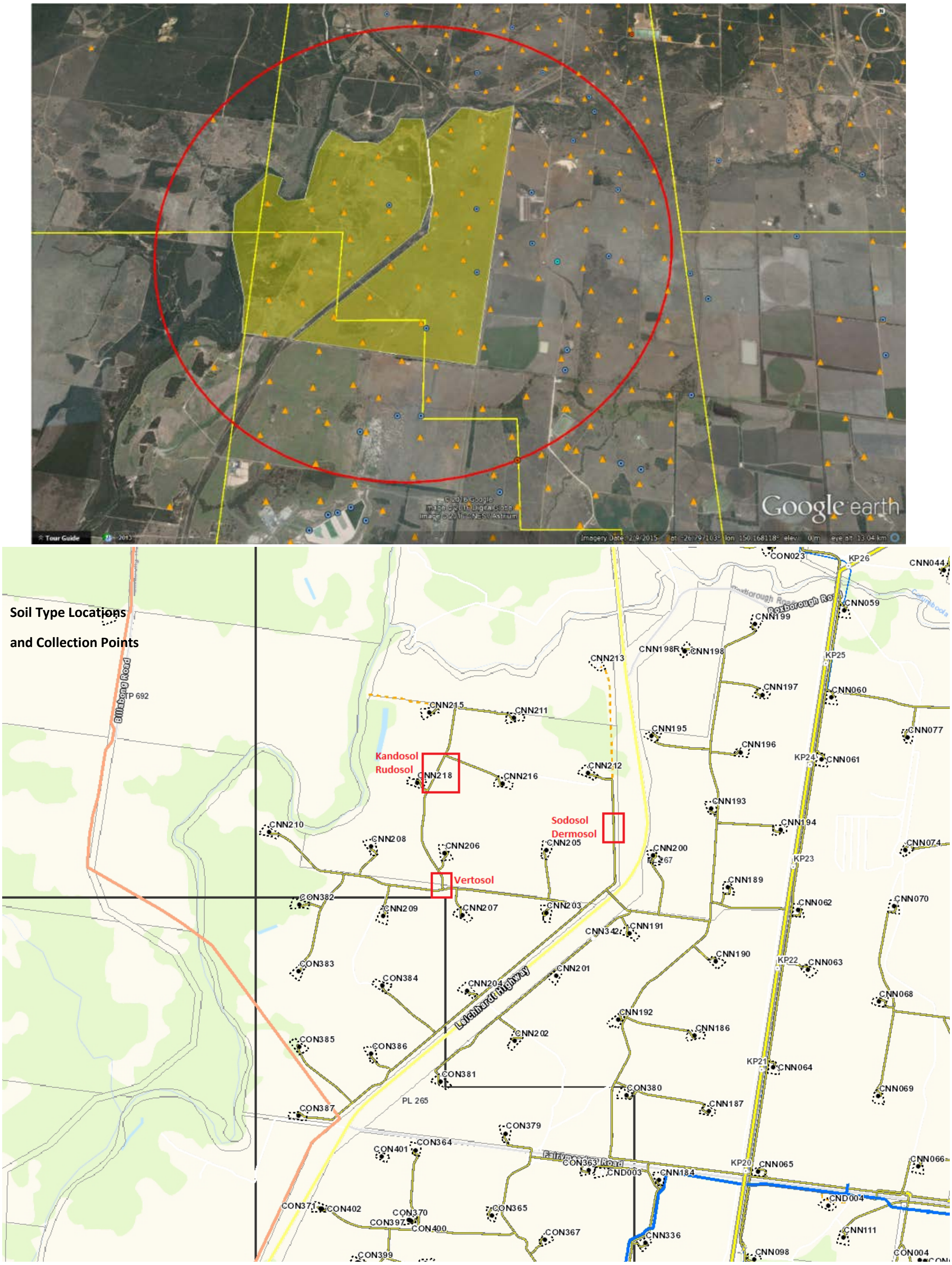

Figure 1. Google Earth image showing the location of the Condabri field site (WAP2); shaded in yellow (top map). The orange triangles are the CSG wells and the blue dots denote registered water boreholes. The lower map shows the locations and names of the CSG wells.

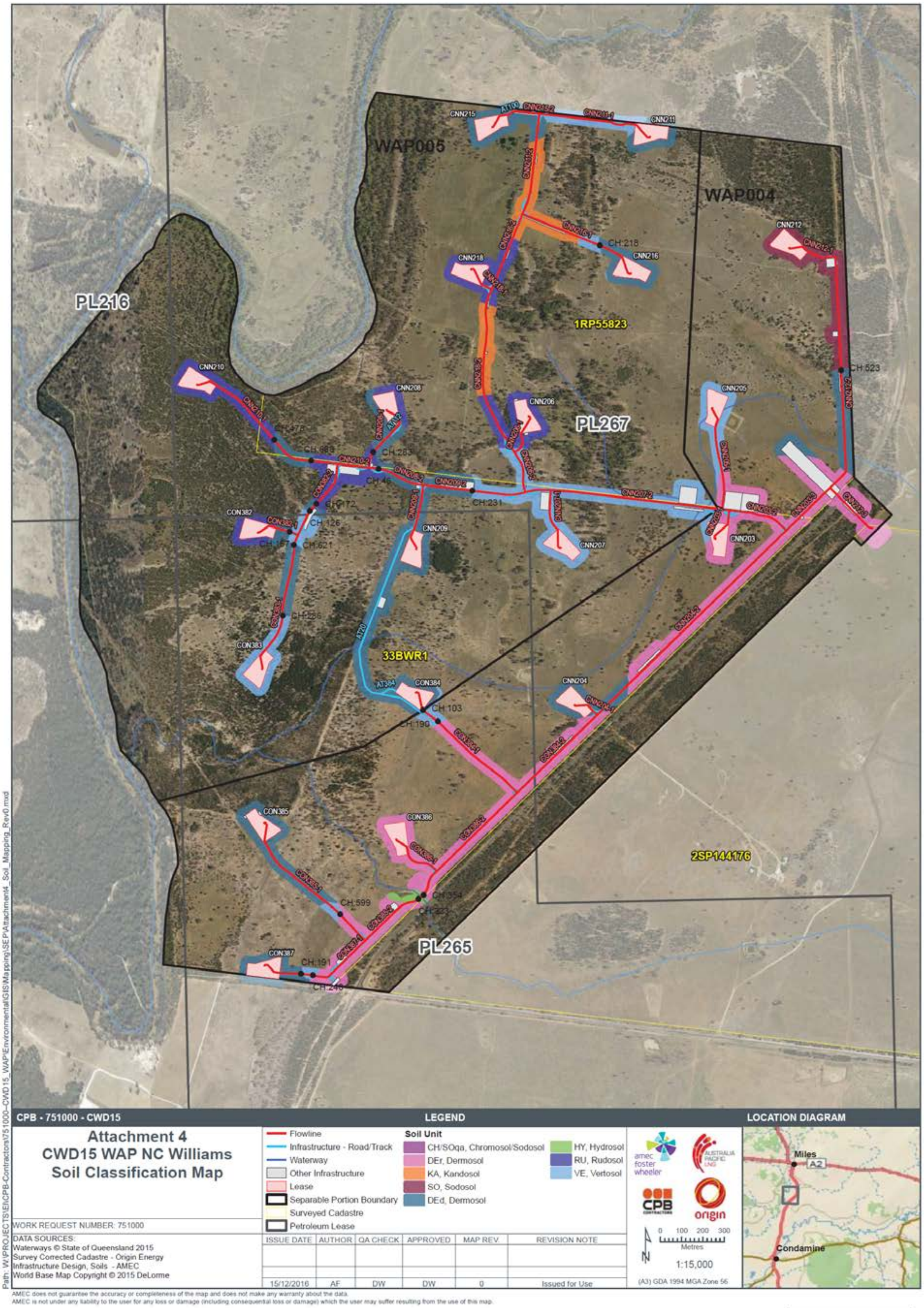

Figure 2. Soil classification map of the Condabri study area

2.2 Study site 2 - Combabula

Site 2 (Combabula) is a farmland property located approximately 100 km northwest of Miles (26°16’46’’ S, 149°33’22’’E) (Figure 3). Similar to Site 1, the property is predominantly semi-arid open grassland with stands of native tree vegetation. An ephemeral creek runs through the property, but surface water features are generally absent. Three landowner groundwater bores are present on the site.

The property has over 30 drilled wells, grid spaced at ~ 600 – 700 m intervals. Twenty-three of the wells were scheduled to undergo some form of well bore stimulation in the second half of 2017 after which they will be brought on-line and connected to the gas and water pipeline network. The wells in this area are serviced by a network of pipelines and vents, which connect to the nearby Reedy Creek central Gas Processing Facility.

3 Water sampling prior to HF operations

Surface water and groundwater samples from sites at the Combabula and Condabri study areas were taken by SGS Leeder Consulting using their standard operating procedures for the collection of surface water and groundwater samples. Sampling was conducted in October 2016 (Dogwood Creek, Condabri) and April 2017 (three groundwater bores, Combabula). The samples were subsequently shipped to their NATA-accredited laboratory in Brisbane where they were analysed for a comprehensive range of water quality parameters (see Table A1). The analytical data were reported to Origin Energy and then supplied to CSIRO.

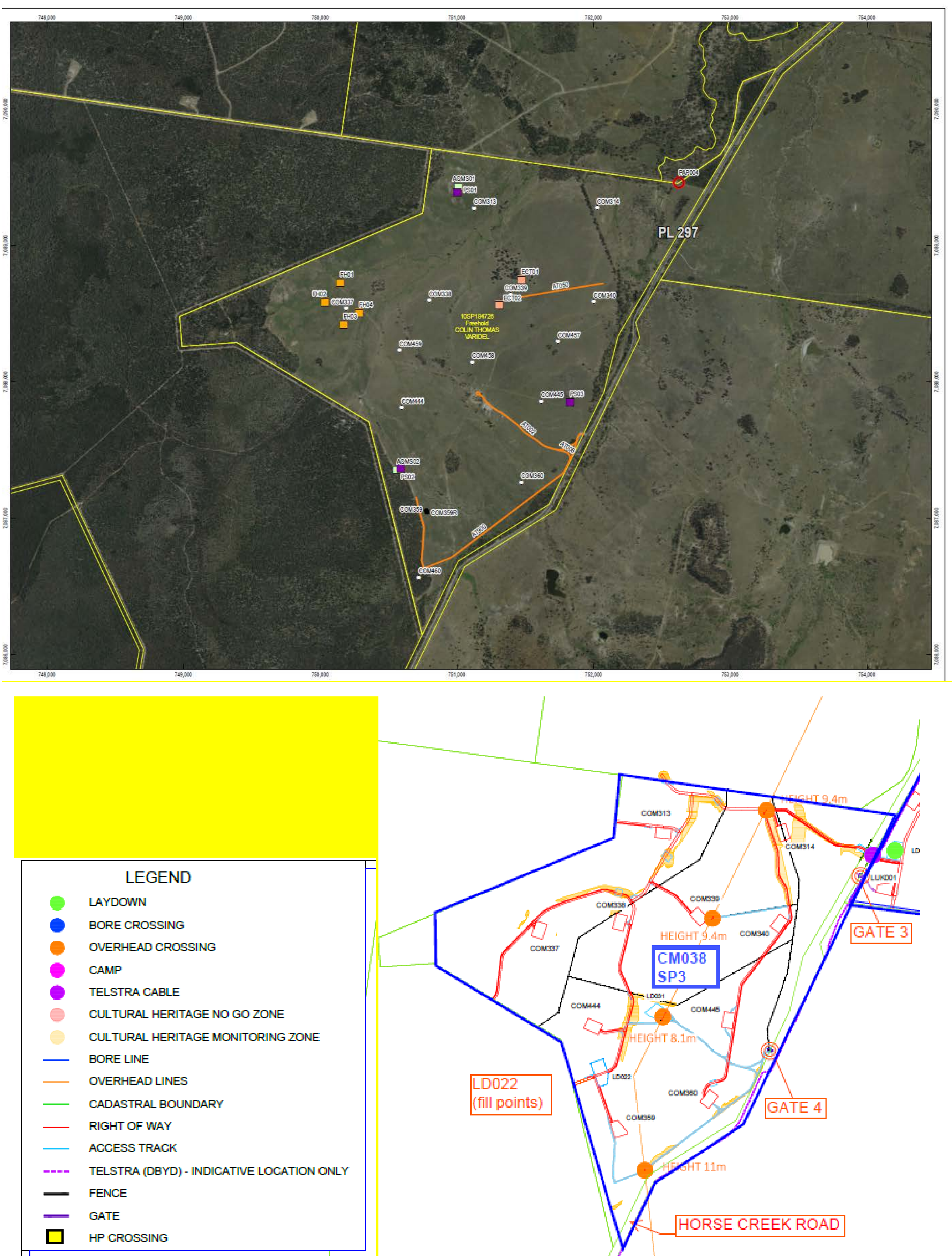

Figure 3. Google Earth image and map showing the location of the Combabula field site

4 Data acquisition and checking

Water quality data were provided by Origin Energy for surface water and groundwater samples taken across the Combabula and Condabri study areas. They comprised summary spreadsheets and the original laboratory test reports supplied by the SGS analytical laboratory. The data were reviewed for suitability and non-relevant data (e.g. sites at non-relevant locations) eliminated. The following data sets remained:

- Dogwood Creek: October 2016 (3 sites)
- Combabula landowner bore samples: April 2017 (3 bores)

The selected data sets were then put through the following checks:

(i) Transcription errors: spreadsheet summary data checked against individual laboratory reports.

(ii) Laboratory quality control data (e.g. blanks, duplicates and recoveries) reviewed and checked for any irregularities.

(iii) Dissolved elemental concentration data checked to ensure they were less than or equal to the total element concentrations. Note that it is not possible for the dissolved elemental concentration to exceed the total elemental concentration.

(iv) Laboratory reporting limits checked for fitness for purpose – i.e. sufficient sensitivity for monitoring contaminants in natural waters.

(v) Checking for outliers and anomalies using professional judgement and knowledge of typical analyte concentrations found in natural waters.

Pre-HF operations data on soil quality at the two study sites were not available. However, this was not regarded as a serious data gap as the sampling plan for soils used in the main study involves taking cores from impacted and non-impacted areas at the same time. The soil samples from the area well beyond the well leased areas (impacted by site operations) are a better indicator of baseline soil quality. Given the known spatial heterogeneity of soil types in this region of Queensland, this approach offers a more accurate assessment of impacts compared to before and after sampling. The soils investigations also involve a scenario study on the impacts of HF fluid spills conducted under laboratory conditions.

5 Condabri surface water data

Dogwood Creek, the major surface water feature draining the Condabri study site, was sampled at two locations upstream of the proposed hydraulic fracturing operations and one site below on 14 October 2016. The sampling sites were: Dogwood Creek at Miles, Gil Weir Campsite and DCL, a site downstream of the planned HF operations located near Miles airport. A map showing the sampling locations is presented in Figure 4. It should be noted that Dogwood Creek is not a pristine waterbody and receives domestic sewage inputs and industrial inputs from locations around the town of Miles.

The water quality data for the three sampling sites are presented in Table A1. The parameters measured included physico-chemical parameters (e.g. pH and conductivity) inorganic constituents, nutrients, trace elements (total and dissolved concentrations), radionuclides and 128organic compounds including TRHs, BTEX, and PAHs.

The key features of the data were as follows:

(i) Dogwood Creek was characterised by low hardness, slightly acidic waters (pH 6.6 to 6.9) having high natural turbidity (140 to 160 NTU).

(ii) The concentrations of all of the 128 trace organic chemicals measured were below the limits of reporting.

(iii) Most dissolved trace metal concentrations were in the low µg/L range or lower and below levels of regulatory concern. The exceptions were dissolved aluminium, copper and zinc (see below).

(iv) Nutrient (nitrogen and phosphorus) concentrations were low. Oxidised nitrogen species (nitrate and nitrite) were the only detectable nitrogen species. Ammonia and phosphate concentrations were below the limit of reporting.

(v) Gross alpha and beta (excluding K-40) activities were below the ANZECC/ARMCANZ guideline values for livestock watering and irrigational uses of 0.5 Bq/L (ANZECC/ARMCANZ 2000).

In order to identify any contaminants of potential concern, the analytical data was screened against the ANZECC/ARMCANZ water quality guidelines that apply in Australia (ANZECC/ARMCANZ 2000). The 95% species protection values for surface waters were used as benchmarks. Three exceedances were detected. Dissolved aluminium, copper and zinc had dissolved concentrations exceeding the 95% species protection guideline values (Table 1). Dissolved zinc marginally exceeded the 95% guideline value at the DCL site. Given the elevated concentrations were only detected at the downstream site, the elevated zinc concentrations may reflect local mineralisation. This issue will be investigated further in the main part of the study. Dissolved aluminium concentrations were typically 8 times the guideline value of 55 µg/L. It should be noted that the aluminium guideline value is conservative as it does not take into account the speciation of aluminium which markedly affects its bioavailability and toxicity. Further investigations are required to determine the chemical forms of aluminium in the creek water. Dissolved copper concentrations ranged from 3 to 4 µg/L and were over double the water quality guideline value of 1.4 µg/L. It is highly likely that a large proportion of copper is present as non-toxic complexes with natural dissolved organic matter as this is a well-known phenomenon in natural waters (Apte et al. 2005). Given the high turbidity of the system, it is highly likely that many metals are associated with colloids which renders them less bioavailable than the free metal ion. This issues surrounding the speciation and bioavailability of aluminium, copper and zinc will be investigated further in the main part of the study.

Table 1. Dogwood Creek: ANZECC/ARMCANZ surface water quality guideline value exceedances

Constituent	Units	Miles	Gil Weir	DCL	Guideline value[a]
Dissolved aluminium	µg/L	460	390	440	55
Dissolved copper	µg/L	3	3	4	1.4
Dissolved zinc	µg/L			9	8

[a]Value for 95% species protection

Given the presence of elevated concentrations of Al, Cu and Zn found in the Miles area which are not associated with hydraulic fracturing operations, the sampling plan for Dogwood Creek during HF operations will include samples taken upstream and downstream of WAP2 taken on the same day (typically within 1 hour of each other) (Apte et al. 2018). This will allow an assessment of contaminants originating from sources other than HF operations and minimises the effects of non HF-associated variations in water quality.

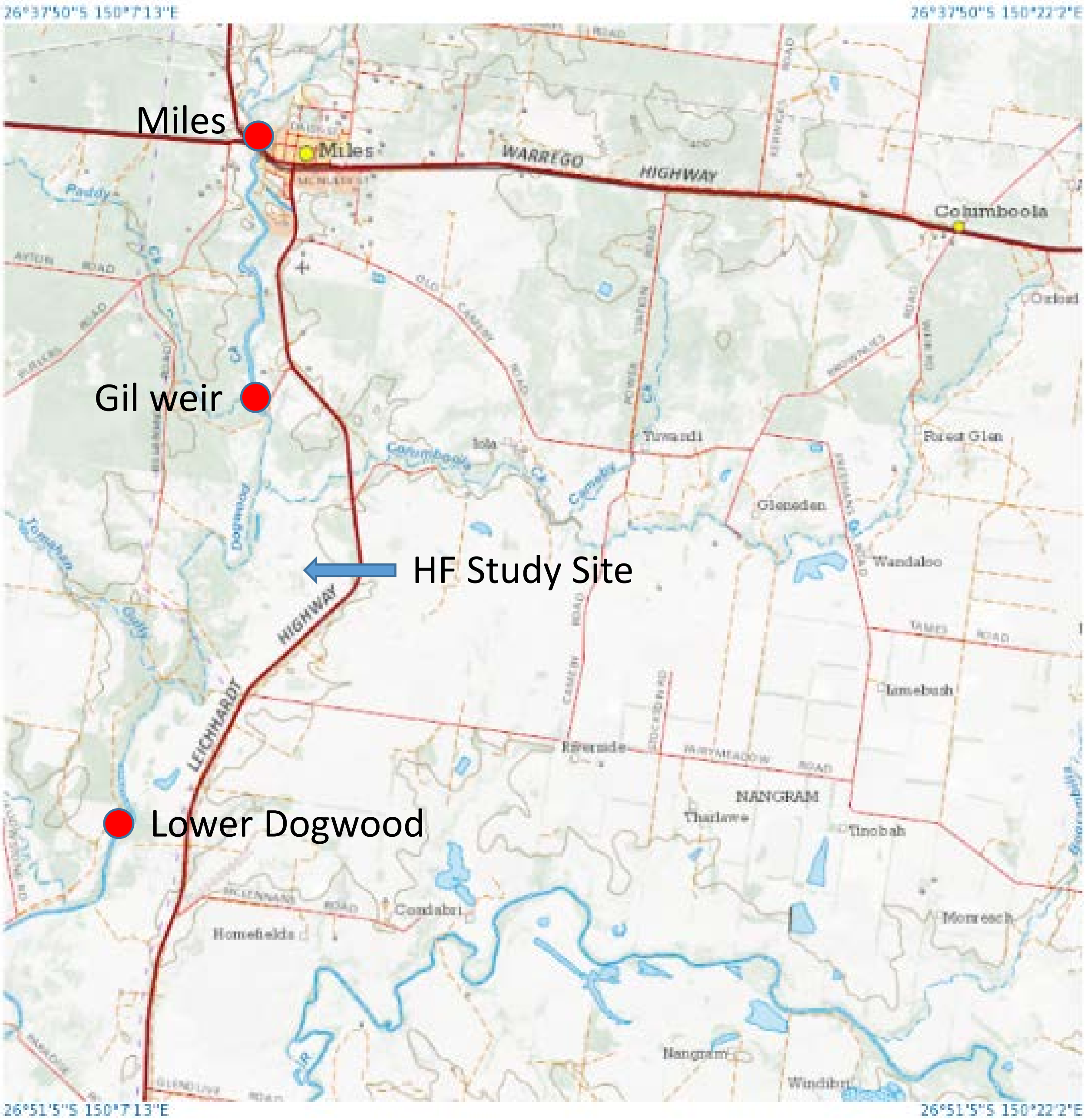

Figure 4. Map showing the locations of the Dogwood Creek sampling sites

6 Combabula groundwater data

Water quality data for the groundwater bores: LB012, LB037, and LB038 data are shown in Table A2. The bores were sampled on 21 April 2017 which was prior to the commencement of HF operations at this location. A map showing the sampling locations is presented in Figure 5.

The parameters measured included physico-chemical parameters (e.g. pH and conductivity) inorganic constituents, nutrients, trace elements (total and dissolved concentrations), radionuclides and organic compounds including TRHs, BTEX, and PAHs. The key features of the data are as follows:

(i) Groundwater chemistry was fairly consistent across the three bores and was characterised by alkaline pH, low hardness, high alkalinity, moderate salinity (950-1100 mg/L total dissolved solids) and low dissolved organic carbon concentrations.

(ii) The water samples were monitored for 28 organic contaminants (including BTEX, TRHs, PAH) and all were below the limit of detection with the exception of ethanol (2 mg/L). The appearance of ethanol as a single contaminant in a rural groundwater supply in the absence of other organic chemicals is very unlikely and these results are believed to be in error (e.g. resulting from sample contamination).

(iii) Dissolved trace metal concentrations were in the low µg/L range or lower and below levels of regulatory concern.

(v) Gross alpha and beta (excluding K-40) activities were below the ANZECC/ARMCANZ guideline values for livestock watering and irrigational uses of 0.5 Bq/L (ANZECC/ARMCANZ 2000).

Figure 5. Location of the Combabula groundwater bores that were sampled

7 Conclusions

1. Water quality data for Dogwood Creek in October 2016, the major surface water feature draining the Condabri study site, indicated that the creek water was turbid, of low hardness and slightly acidic. The water samples were monitored for 128 organic contaminants, all were below the limits of detection. Most dissolved trace metal concentrations were in the low µg/L range. Dissolved aluminium, copper and zinc concentrations exceeded the water quality guideline values that apply in Australia for 95% species protection. The elevated concentrations of these metals in the creek waters may reflect natural mineralisation in the catchment and/or anthropogenic inputs from upstream locations.

2. Groundwater samples collected from the Combabula study site in April 2017 indicated the bore water was alkaline, moderately saline, high alkalinity and of low hardness. Total dissolved solids concentrations were typically ~1000 mg/L. The water samples were monitored for 28 organic contaminants (including BTEX, TRHs and PAHs) and all were below the limit of detection aside from ethanol (2 mg/L). Ethanol is an unlikely groundwater contaminant and this result is believed to be in error (e.g. resulting from sample contamination). Trace metal concentrations were present at low µg/L or lower concentrations and were below levels of regulatory concern.

3. The water quality data compiled in this report will be used later in the study and will be compared to the water quality data obtained during hydraulic fracturing operations and thereafter.

8 References

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Appendix: Water quality monitoring data

Table A1. Dogwood Creek water quality data

	Units	Miles	Gil Weir	Lower Dogwood	Total or Filtered
Sampling date		14-Oct-16	14-Oct-16	14-Oct-16	
General physicochemical parameters					
Conductivity @ 25 C	µS/cm	91	84	93	T
Temperature	°C	22.6	23	22.3	F
Dissolved Oxygen	mg/L	8.1	7.9	8.1	F
Turbidity	NTU	150	140	160	T
Inorganics					
pH	pH Units	6.7	6.6	6.9	T
Total Alkalinity as $CaCO_3$	mg/L	18	16	19	T
Bicarbonate Alkalinity as $CaCO_3$	mg/L	18	16	19	T
Carbonate Alkalinity as $CaCO_3$	mg/L	< 5	< 5	< 5	T
Hydroxide Alkalinity as $CaCO_3$	mg/L	< 5	< 5	< 5	T
Fluoride by ISE	mg/L	< 0.1	< 0.1	< 0.1	F
Chloride, Cl	mg/L	18	16	17	F
Sulfate, SO_4	mg/L	3	2	2	F
Total Hardness	mg $CaCO_3$/L	15	15	18	T
Nutrients					
Nitrate, as NO_3	mg NO_3/L	0.29	0.21	0.07	F
Nitrite, as NO_2	mg NO_2/L	< 0.05	0.1	0.22	F
Nitrite Nitrogen, NO_2 as N	mg N/L	< 0.005	0.03	0.066	F
Nitrate Nitrogen, NO_3 as N	mg N/L	0.066	0.047	0.015	F
Ammonia Nitrogen, NH_3 as N	mg N/L	< 0.05	< 0.05	< 0.05	F
Ammonia, NH_3	mg NH_3/L	< 0.05	< 0.05	< 0.05	F
Filterable Reactive Phosphorus	mg/L	< 0.005	< 0.005	< 0.005	F
Dissolved trace elements					
Aluminium	mg/L	0.46	0.39	0.44	F
Antimony	mg/L	< 0.001	< 0.001	< 0.001	F
Arsenic	mg/L	0.0008	0.0006	0.0009	F
Bismuth	mg/L	<0.01	<0.01	< 0.01	F
Boron	mg/L	0.023	0.036	< 0.001	F
Barium	mg/L	0.076	0.063	0.085	F
Beryllium	mg/L	< 0.001	< 0.001	< 0.001	F
Cadmium	mg/L	< 0.00005	< 0.00005	< 0.00005	F
Calcium	mg/L	2.8	2.6	3.1	F

	Units	Miles	Gil Weir	Lower Dogwood	Total or Filtered
Chromium	mg/L	0.0007	< 0.0005	0.0005	F
Cobalt	mg/L	0.0012	0.0009	0.001	F
Copper	mg/L	0.003	0.003	0.004	F
Gold	mg/L	< 0.001	< 0.001	< 0.001	F
Iron	mg/L	1.9	1.1	1.2	F
Lead	mg/L	0.0033	0.0024	0.0029	F
Magnesium	mg/L	1.9	1.8	2.2	F
Manganese	mg/L	0.059	0.055	0.059	F
Mercury	mg/L	< 0.0001	< 0.0001	< 0.0001	F
Molybdenum	mg/L	< 0.001	< 0.001	< 0.001	F
Nickel	mg/L	0.0025	0.0024	0.003	F
Potassium	mg/L	2.6	2.4	2.7	F
Selenium	mg/L	< 0.001	< 0.001	0.002	F
Silicon	mg/L	7.3	6.2	8.3	F
Silver	mg/L	< 0.001	< 0.001	< 0.001	F
Sodium	mg/L	15	13	15	F
Strontium	mg/L	0.047	0.041	0.052	F
Thallium	mg/L	< 0.001	< 0.001	< 0.001	F
Tin	mg/L	0.004	0.002	< 0.001	F
Titanium	mg/L	< 0.001	< 0.001	< 0.001	F
Uranium	mg/L	< 0.001	< 0.001	< 0.001	F
Vanadium	mg/L	< 0.001	< 0.001	0.002	F
Zinc	mg/L	0.006	0.003	0.009	F
Total trace elements					
Total Aluminium	mg/L	5.3	6.8	2.6	T
Total Antimony	mg/L	< 0.001	< 0.001	< 0.001	T
Total Arsenic	mg/L	0.0009	0.001	0.0011	T
Total Barium	mg/L	0.088	0.068	0.089	T
Total Beryllium	mg/L	< 0.001	< 0.001	< 0.001	T
Total Bismuth	mg/L	< 0.001	< 0.001	< 0.001	T
Total Boron	mg/L	0.029	0.012	0.023	T
Total Calcium	mg/L	2.4	2.3	2.7	T
Total Cadmium	mg/L	< 0.0002	< 0.0002	< 0.0002	T
Total Chromium	mg/L	0.0034	0.0042	0.002	T
Total Cobalt	mg/L	0.0018	0.0018	0.0016	T
Total Copper	mg/L	0.002	0.003	0.003	T
Total Gold	mg/L	< 0.001	< 0.001	< 0.001	T
Total Iron	mg/L	3.8	3.6	2.9	T
Total Lead	mg/L	0.028	0.0028	0.0028	T
Total Manganese	mg/L	0.063	0.064	0.065	T
Total Mercury	mg/L	< 0.0005	< 0.0005	< 0.0005	T
Total Molybdenum	mg/L	< 0.001	< 0.001	< 0.001	T

	Units	Miles	Gil Weir	Lower Dogwood	Total or Filtered
Total Nickel	mg/L	0.0029	0.0029	0.0036	T
Total Selenium	mg/L	< 0.005	< 0.005	< 0.005	T
Total Silicon	mg/L	13	9.4	14	T
Total Silver	mg/L	< 0.005	< 0.005	< 0.005	T
Total Sodium	mg/L	15	13	15	T
Total Strontium	mg/L	0.048	0.045	0.056	T
Total Potassium	mg/L	2.6	2.6	2.9	T
Total Magnesium	mg/L	2	2	2.4	T
Total Thallium	mg/L	< 0.001	< 0.001	< 0.001	T
Total Tin	mg/L	< 0.001	< 0.001	< 0.001	T
Total Titanium	mg/L	0.2	0.29	0.05	T
Total Uranium	mg/L	< 0.001	< 0.001	< 0.001	T
Total Vanadium	mg/L	0.013	0.012	0.01	T
Total Zinc	mg/L	0.007	0.007	0.013	T
Radionuclides					
Gross alpha	Bq/L	0.066	0.064	0.049	F
Gross beta (excluding K-40)	Bq/L	< 0.066	< 0.071	0.104	F
Gross beta (including K-40)	Bq/L	< 0.15	< 0.16	0.184	F
Uranium-238	Bq/L	0.0046	< 0.01	< 0.0071	F
Radium-226	Bq/L	< 0.068	< 0.052	< 0.044	F
Thorium-230	Bq/L	< 1.8	< 1.7	< 1.2	F
Uranium-234	Bq/L	< 0.0096	0.0058	< 0.0091	F
Alkanes (C<4)					
Methane	mg/L	< 0.001	< 0.001	< 0.001	T
Ethane	mg/L	< 0.001	< 0.001	< 0.001	T
Propane	mg/L	< 0.001	< 0.001	< 0.001	T
Butane	mg/L	< 0.001	< 0.001	< 0.001	T
BTEX					
Benzene	µg/L	< 0.5	< 0.5	< 0.5	T
Toluene	µg/L	< 0.5	< 0.5	< 0.5	T
Ethylbenzene	µg/L	< 0.5	< 0.5	< 0.5	T
m/p-xylene	µg/L	< 1	< 1	< 1	T
o-xylene	µg/L	< 0.5	< 0.5	< 0.5	T
Naphthalene	µg/L	< 0.5	< 0.5	< 0.5	T
Total Xylenes	µg/L	< 1.5	< 1.5	< 1.5	T
Total BTEX	µg/L	< 3	< 3	< 3	T
Trace organics					
Dichlorodifluoromethane (CFC-12)	µg/L	< 5	< 5	< 5	T

	Units	Miles	Gil Weir	Lower Dogwood	Total or Filtered
Chloromethane	µg/L	< 5	< 5	< 5	T
Vinyl chloride (Chloroethene)	µg/L	< 0.3	< 0.3	< 0.3	T
Bromomethane	µg/L	< 10	< 10	< 10	T
Chloroethane	µg/L	< 5	< 5	< 5	T
Trichlorofluoromethane	µg/L	< 1	< 1	< 1	T
Acetone (2-propanone)	µg/L	< 10	< 10	< 10	T
1,1-dichloroethene	µg/L	< 0.5	< 0.5	< 0.5	T
Iodomethane	µg/L	< 5	< 5	< 5	T
Acrylonitrile	µg/L	< 0.5	< 0.5	< 0.5	T
Dichloromethane (Methylene chloride)	µg/L	< 5	< 5	< 5	T
Allyl chloride	µg/L	< 2	< 2	< 2	T
Carbon disulfide	µg/L	< 2	< 2	< 2	T
trans-1,2-dichloroethene	µg/L	< 0.5	< 0.5	< 0.5	T
1,1-dichloroethane	µg/L	< 0.5	< 0.5	< 0.5	T
MtBE (Methyl-tert-butyl ether)	µg/L	< 0.5	< 0.5	< 0.5	T
Vinyl acetate	µg/L	< 10	< 10	< 10	T
MEK (2-butanone)	µg/L	< 10	< 10	< 10	T
cis-1,2-dichloroethene	µg/L	< 0.5	< 0.5	< 0.5	T
Bromochloromethane	µg/L	< 0.5	< 0.5	< 0.5	T
Chloroform (THM)	µg/L	< 0.5	< 0.5	< 0.5	T
2,2-dichloropropane	µg/L	< 0.5	< 0.5	< 0.5	T
1,2-dichloroethane	µg/L	< 0.5	< 0.5	< 0.5	T
1,1,1-trichloroethane	µg/L	< 0.5	< 0.5	< 0.5	T
1,1-dichloropropene	µg/L	< 0.5	< 0.5	< 0.5	T
Carbon tetrachloride	µg/L	< 0.5	< 0.5	< 0.5	T
Dibromomethane	µg/L	< 0.5	< 0.5	< 0.5	T
1,2-dichloropropane	µg/L	< 0.5	< 0.5	< 0.5	T
Trichloroethene (Trichloroethylene,TCE)	µg/L	< 0.5	< 0.5	< 0.5	T
Bromodichloromethane (THM)	µg/L	< 0.5	< 0.5	< 0.5	T
cis-1,3-dichloropropene	µg/L	< 0.5	< 0.5	< 0.5	T
MIBK (4-methyl-2-pentanone)	µg/L	< 5	< 5	< 5	T
trans-1,3-dichloropropene	µg/L	< 0.5	< 0.5	< 0.5	T
1,1,2-trichloroethane	µg/L	< 0.5	< 0.5	< 0.5	T
1,3-dichloropropane	µg/L	< 0.5	< 0.5	< 0.5	T
Dibromochloromethane (THM)	µg/L	< 0.5	< 0.5	< 0.5	T
2-hexanone (MBK)	µg/L	< 5	< 5	< 5	T
1,2-dibromoethane (EDB)	µg/L	< 0.5	< 0.5	< 0.5	T
Tetrachloroethene (Perchloroethylene,PCE)	µg/L	< 0.5	< 0.5	< 0.5	T
1,1,1,2-tetrachloroethane	µg/L	< 0.5	< 0.5	< 0.5	T
Chlorobenzene	µg/L	< 0.5	< 0.5	< 0.5	T
Bromoform (THM)	µg/L	< 0.5	< 0.5	< 0.5	T
cis-1,4-dichloro-2-butene	µg/L	< 1	< 1	< 1	T
Styrene (Vinyl benzene)	µg/L	< 0.5	< 0.5	< 0.5	T

	Units	Miles	Gil Weir	Lower Dogwood	Total or Filtered
1,1,2,2-tetrachloroethane	µg/L	< 0.5	< 0.5	< 0.5	T
1,2,3-trichloropropane	µg/L	< 0.5	< 0.5	< 0.5	T
trans-1,4-dichloro-2-butene	µg/L	< 1	< 1	< 1	T
Bromobenzene	µg/L	< 0.5	< 0.5	< 0.5	T
n-propylbenzene	µg/L	< 0.5	< 0.5	< 0.5	T
2-chlorotoluene	µg/L	< 0.5	< 0.5	< 0.5	T
4-chlorotoluene	µg/L	< 0.5	< 0.5	< 0.5	T
1,3,5-trimethylbenzene	µg/L	< 0.5	< 0.5	< 0.5	T
tert-butylbenzene	µg/L	< 0.5	< 0.5	< 0.5	T
1,2,4-trimethylbenzene	µg/L	< 0.5	< 0.5	< 0.5	T
sec-butylbenzene	µg/L	< 0.5	< 0.5	< 0.5	T
1,3-dichlorobenzene	µg/L	< 0.5	< 0.5	< 0.5	T
1,4-dichlorobenzene	µg/L	< 0.3	< 0.3	< 0.3	T
p-isopropyltoluene	µg/L	< 0.5	< 0.5	< 0.5	T
1,2-dichlorobenzene	µg/L	< 0.5	< 0.5	< 0.5	T
n-butylbenzene	µg/L	< 0.5	< 0.5	< 0.5	T
1,2-dibromo-3-chloropropane	µg/L	< 0.5	< 0.5	< 0.5	T
1,2,4-trichlorobenzene	µg/L	< 0.5	< 0.5	< 0.5	T
Hexachlorobutadiene	µg/L	< 0.5	< 0.5	< 0.5	T
1,2,3-trichlorobenzene	µg/L	< 0.5	< 0.5	< 0.5	T
2,2-Dichloropropionic acid	mg/L	< 0.001	< 0.001	< 0.001	T
Bromochloroacetic acid	mg/L	< 0.001	< 0.001	< 0.001	T
Bromodichloroacetic acid	mg/L	< 0.001	< 0.001	< 0.001	T
Chlorodibromoacetic acid	mg/L	< 0.001	< 0.001	< 0.001	T
Dibromoacetic acid	mg/L	< 0.001	< 0.001	< 0.001	T
Dichloroacetic acid	mg/L	0.001	< 0.001	0.001	T
Bromoacetic acid (Mono)	mg/L	0.002	< 0.001	0.001	T
Chloroacetic acid (Mono)	mg/L	< 0.001	< 0.001	< 0.001	T
Tribromoacetic acid	mg/L	< 0.001	< 0.001	< 0.001	T
Trichloroacetic acid	mg/L	< 0.001	< 0.001	< 0.001	T
HAA6	mg/L	0.003	< 0.001	0.002	T
Monochloroacetonitrile	µg/L	< 0.1	< 0.1	< 0.1	T
Dichloroacetonitrile	µg/L	< 0.1	< 0.1	< 0.1	T
Trichloroacetonitrile	µg/L	< 0.1	< 0.1	< 0.1	T
Monobromoacetonitrile	µg/L	< 0.1	< 0.1	< 0.1	T
Dibromoacetonitrile	µg/L	< 0.1	< 0.1	< 0.1	T
Bromochloroacetonitrile	µg/L	< 0.1	< 0.1	< 0.1	T
Total recoverable hydrocarbons					
TRH C6-C10	µg/L	< 50	< 50	< 50	T
TRH C6-C9	µg/L	< 40	< 40	< 40	T
Benzene (F0)	µg/L	< 0.1	< 0.1	< 0.1	T
TRH C6-C10 minus BTEX (F1)	µg/L	< 50	< 50	< 50	T

	Units	Miles	Gil Weir	Lower Dogwood	Total or Filtered
TRH C10-C14	µg/L	< 50	< 50	< 50	T
TRH C15-C28	µg/L	< 200	< 200	< 200	T
TRH C29-C36	µg/L	< 200	< 200	< 200	T
TRH C37-C40	µg/L	< 200	< 200	< 200	T
TRH C10-C36	µg/L	< 450	< 450	< 450	T
TRH C10-C40	µg/L	< 400	< 400	< 400	T
TRH >C10-C16 (F2)	µg/L	< 60	< 60	< 60	T
TRH >C16-C34 (F3)	µg/L	< 500	< 500	< 500	T
TRH >C34-C40 (F4)	µg/L	< 500	< 500	< 500	T
TRH Total C6-C36	µg/L	< 500	< 500	< 500	T
PAHs					
Naphthalene	µg/L	< 0.1	< 0.1	< 0.1	T
2-methylnaphthalene	µg/L	< 0.1	< 0.1	< 0.1	T
1-methylnaphthalene	µg/L	< 0.1	< 0.1	< 0.1	T
Acenaphthylene	µg/L	< 0.1	< 0.1	< 0.1	T
Acenaphthene	µg/L	< 0.1	< 0.1	< 0.1	T
Fluorene	µg/L	< 0.1	< 0.1	< 0.1	T
Phenanthrene	µg/L	< 0.1	< 0.1	< 0.1	T
Anthracene	µg/L	< 0.1	< 0.1	< 0.1	T
Fluoranthene	µg/L	< 0.1	< 0.1	< 0.1	T
Pyrene	µg/L	< 0.1	< 0.1	< 0.1	T
Perylene	µg/L	< 0.1	< 0.1	< 0.1	T
Benzo(a)anthracene	µg/L	< 0.1	< 0.1	< 0.1	T
Coronene	µg/L	< 0.1	< 0.1	< 0.1	T
Chrysene	µg/L	< 0.1	< 0.1	< 0.1	T
Benzo(b&j)fluoranthene	µg/L	< 0.1	< 0.1	< 0.1	T
Benzo(k)fluoranthene	µg/L	< 0.1	< 0.1	< 0.1	T
Benzo(b&j&k)fluoranthene	µg/L	< 0.2	< 0.2	< 0.2	T
Benzo(a)pyrene	µg/L	< 0.1	< 0.1	< 0.1	T
Indeno(1,2,3-cd)pyrene	µg/L	< 0.1	< 0.1	< 0.1	T
Dibenzo(ah)anthracene	µg/L	< 0.1	< 0.1	< 0.1	T
Benzo(ghi)perylene	µg/L	< 0.1	< 0.1	< 0.1	T
Total PAH (18)	µg/L	< 1	< 1	< 1	T
Phenols					
Phenol	µg/L	< 0.5	< 0.5	< 0.5	T
2-methyl phenol (o-cresol)	µg/L	< 0.5	< 0.5	< 0.5	T
3/4-methyl phenol (m/p-cresol)	µg/L	< 1	< 1	< 1	T
2-chlorophenol	µg/L	< 0.5	< 0.5	< 0.5	T
2,4-dimethylphenol	µg/L	< 0.5	< 0.5	< 0.5	T
2,6-dichlorophenol	µg/L	< 0.5	< 0.5	< 0.5	T
2,4-dichlorophenol	µg/L	< 0.5	< 0.5	< 0.5	T

	Units	Miles	Gil Weir	Lower Dogwood	Total or Filtered
2,4,6-trichlorophenol	µg/L	< 0.5	< 0.5	< 0.5	T
2-nitrophenol	µg/L	< 0.5	< 0.5	< 0.5	T
4-nitrophenol	µg/L	< 1	< 1	< 1	T
2,4,5-trichlorophenol	µg/L	< 0.5	< 0.5	< 0.5	T
2,3,4,6-tetrachlorophenol	µg/L	< 0.5	< 0.5	< 0.5	T
Pentachlorophenol	µg/L	< 0.5	< 0.5	< 0.5	T
2,4-dinitrophenol	µg/L	< 2	< 2	< 2	T

Table A2. Groundwater monitoring data (Combabula)

Substance	Units	Reporting Limit	LB038	LB037	LB012
Sampling Date			21/04/2017	21/04/2017	21/04/2017
Inorganics					
pH**	pH Units	0.1	8.8	8.8	8.7
Conductivity @ 25 C	µS/cm	2	1600	1600	1700
Turbidity	NTU	0.5	<0.5	<0.5	1.1
Total Dissolved Solids	mg/L	10	950	1000	1100
Total Organic Carbon	mg/L	1	<1	<1	<1
Total Alkalinity as $CaCO_3$	mg/L	5	440	420	480
Bicarbonate Alkalinity as $CaCO_3$	mg/L	5	440	420	480
Carbonate Alkalinity as $CaCO_3$	mg/L	5	<5	<5	<5
Hydroxide Alkalinity as $CaCO_3$	mg/L	5	<5	<5	<5
Residual Alkali	meq/L	0.1	8.7	8.3	9.5
Aggressive CO_2 in Water	mg CO_2/L	0.5	9.9	7.7	11
Chloride, Cl	mg/L	1	240	280	280
Fluoride, F	mg/L	0.1	0.3	0.2	0.3
Sulfate, SO_4	mg/L	1	31	16	60
Bromide	mg/L	0.05	0.56	0.70	0.64
Sulfide	mg/L	0.01	0.03	0.02	<0.01
Hydrogen Sulfide	mg/L	0.01	0.03	0.02	0.01
Methane	mg/L	0.001	0.025	0.32	0.007
Sodium Adsorption Ratio	No unit	0.2	71	71	69
Anion-Cation Balance	%	-100	-1.1	-1.1	-3.1
Sum of Ions	mg/L	10	1070	1090	1220
Dissolved trace elements					
Aluminium	mg/L	0.001	0.009	0.001	0.002
Antimony	mg/L	0.001	<0.001	<0.001	<0.001
Arsenic	mg/L	0.0005	<0.0005	<0.0005	<0.0005
Barium	mg/L	0.001	0.020	0.019	0.022
Boron	mg/L	0.001	0.12	0.11	0.11
Cobalt	mg/L	0.0002	<0.0002	<0.0002	<0.0002

Substance	Units	Reporting Limit	LB038	LB037	LB012
Cadmium	mg/L	0.00005	<0.00005	<0.00005	<0.00005
Chromium	mg/L	0.0005	<0.0005	<0.0005	<0.0005
Copper	mg/L	0.001	0.004	<0.001	<0.001
Iron	mg/L	0.001	0.021	0.030	0.015
Lead	mg/L	0.0002	<0.0002	<0.0002	<0.0002
Manganese	mg/L	0.0005	0.0071	0.0062	0.0068
Molybdenum	mg/L	0.001	0.002	0.002	0.002
Nickel	mg/L	0.0005	<0.0005	<0.0005	<0.0005
Selenium	mg/L	0.001	<0.001	<0.001	<0.001
Strontium	mg/L	0.001	0.049	0.052	0.059
Tin	mg/L	0.001	<0.001	<0.001	<0.001
Vanadium	mg/L	0.001	<0.001	<0.001	<0.001
Zinc	mg/L	0.001	<0.001	<0.001	<0.001
Silver	mg/L	0.001	<0.001	<0.001	<0.001
Mercury	mg/L	0.0001	<0.0001	<0.0001	<0.0001
Calcium, Ca	mg/L	0.2	1.8	1.9	2.2
Magnesium, Mg	mg/L	0.1	0.1	0.1	0.2
Potassium, K	mg/L	0.1	0.9	0.9	1.0
Sodium, Na	mg/L	0.5	360	370	400
Total trace elements					
Total Aluminium	mg/L	0.001	0.005	0.004	0.004
Total Antimony	mg/L	0.001	<0.001	<0.001	<0.001
Total Arsenic	mg/L	0.0005	<0.0005	<0.0005	<0.0005
Total Barium	mg/L	0.001	0.020	0.019	0.022
Total Boron	mg/L	0.001	0.13	0.12	0.094
Total Cobalt	mg/L	0.0002	<0.0002	<0.0002	0.0002
Total Cadmium	mg/L	0.0002	<0.0002	<0.0002	<0.0002
Total Calcium	mg/L	0.2	1.8	1.8	2.2
Total Chromium	mg/L	0.0005	<0.0005	<0.0005	<0.0005
Total Copper	mg/L	0.001	<0.001	<0.001	<0.001
Total Iron	mg/L	0.001	0.020	0.033	0.016
Total Lead	mg/L	0.0002	<0.0002	0.0006	<0.0002
Total Magnesium	mg/L	0.1	0.1	0.1	0.2
Total Manganese	mg/L	0.0005	0.0070	0.010	0.015
Total Mercury	mg/L	0.0005	<0.0005	<0.0005	<0.0005

Substance	Units	Reporting Limit	LB038	LB037	LB012
Total Molybdenum	mg/L	0.001	0.002	0.002	0.002
Total Nickel	mg/L	0.0005	<0.0005	<0.0005	0.0005
Total Potassium	mg/L	0.1	0.9	0.8	1.0
Total Selenium	mg/L	0.005	<0.005	<0.005	<0.005
Total Silicon, Si	mg/L	0.02	2.0	1.2	1.5
Total Sodium	mg/L	0.5	360	370	400
Total Strontium	mg/L	0.001	0.049	0.052	0.059
Total Tin	mg/L	0.001	<0.001	<0.001	<0.001
Total Vanadium	mg/L	0.001	<0.001	<0.001	<0.001
Total Silver	mg/L	0.005	<0.005	<0.005	<0.005
Total Zinc	mg/L	0.001	<0.001	0.006	<0.001
Total Magnesium	mg/L	0.01	0.12	0.14	0.16
Total Potassium	mg/L	0.01	0.93	0.86	1.0
Total Sodium	mg/L	0.01	360	370	400
Total Calcium	mg/L	0.01	1.9	1.8	2.3
Hexavalent Chromium, Cr(VI)	mg/L	0.005	<0.005	<0.005	<0.005
Trivalent Chromium, Cr(III)	mg/L	0.005	<0.005	<0.005	<0.005
Radionuclides					
Gross alpha	Bq/L	0.02	0.114	0.034	0.045
Gross beta (excluding K-40)	Bq/L	0.05	0.083	0.064	0.060
Trace organics					
Benzene	µg/L	1	<1	<1	<1
Ethylbenzene	µg/L	1	<1	<1	<1
Toluene	µg/L	1	<1	<1	<1
m&p-Xylenes	µg/L	1	<1	<1	<1
o-Xylene	µg/L	1	<1	<1	<1
Naphthalene	µg/L	1	<1	<1	<1
Formaldehyde	mg/L	0.05	<0.05	<0.05	<0.05
Ethanol	mg/L	1	2.0	2.2	1.9
VPH in water					
C6-C10 (P&T)	mg/L	0.01	<0.01	<0.01	<0.01
C6-C10 (P&T) (less BTEX)	mg/L	0.01	<0.01	<0.01	<0.01

Substance	Units	Reporting Limit	LB038	LB037	LB012
C6-C9 (P&T)	mg/L	0.01	<0.01	<0.01	<0.01
TRH in water					
Total TRH C10-C36	mg/L	0.05	<0.05	<0.05	<0.05
Total TRH C6-C36	mg/L	0.05	<0.05	<0.05	<0.05
Total TRH C6-C40 (F)	mg/L	0.05	<0.05	<0.05	<0.05
TRH >C10-C16 (F2)	mg/L	0.01	<0.01	<0.01	<0.01
TRH >C10-C16 (F2) (less Naphthalene)	mg/L	0.01	<0.01	<0.01	<0.01
TRH >C10-C40 Total	mg/L	0.05	<0.05	<0.05	<0.05
TRH >C16-C34 (F3)	mg/L	0.05	<0.05	<0.05	<0.05
TRH >C34-C40 (F4)	mg/L	0.05	<0.05	<0.05	<0.05
TRH C10-C14	mg/L	0.01	<0.01	<0.01	<0.01
TRH C15-C28	mg/L	0.05	<0.05	<0.05	<0.05
TRH C29-C36	mg/L	0.05	<0.05	<0.05	<0.05
PAHs					
Acenaphthene	mg/L	0.001	<0.001	<0.001	<0.001
Acenaphthylene	mg/L	0.001	<0.001	<0.001	<0.001
Anthracene	mg/L	0.001	<0.001	<0.001	<0.001
Benzo(a)anthracene	mg/L	0.001	<0.001	<0.001	<0.001
Benzo(a)pyrene	mg/L	0.001	<0.001	<0.001	<0.001
Benzo(b&j)fluoranthene	mg/L	0.001	<0.001	<0.001	<0.001
Benzo(ghi)perylene	mg/L	0.001	<0.001	<0.001	<0.001
Benzo(k)fluoranthene	mg/L	0.001	<0.001	<0.001	<0.001
Chrysene	mg/L	0.001	<0.001	<0.001	<0.001
Dibenz(a&h)anthracene	mg/L	0.001	<0.001	<0.001	<0.001
7,12-Dimethylbenz(a)anthracene	mg/L	0.001	<0.001	<0.001	<0.001
Fluoranthene	mg/L	0.001	<0.001	<0.001	<0.001
Fluorene	mg/L	0.001	<0.001	<0.001	<0.001
Indeno(1,2,3-cd)pyrene	mg/L	0.001	<0.001	<0.001	<0.001
Naphthalene	mg/L	0.001	<0.001	<0.001	<0.001
Phenanthrene	mg/L	0.001	<0.001	<0.001	<0.001
Pyrene	mg/L	0.001	<0.001	<0.001	<0.001
Total PAH (18)	mg/L	0.02	<0.02	<0.02	<0.02
3-Methylcholanthrene	mg/L	0.001	<0.001	<0.001	<0.001

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