GISERA
Gas Industry Social and Environmental Research Alliance

Assessing the impacts of hydraulic fracturing on soil and water quality in the Surat Basin, Queensland

Simon Apte | Senior Principal Research Scientist

CSIRO | Australia Pacific LNG | QGC | origin | Santos | NSW Government | Australian Government Department of Industry, Innovation and Science | Supported by Government of South Australia | Queensland Government | Northern Territory Government | Pangaea Resources Pty Ltd

Introduction

- Considerable public concern about the environmental impacts of hydraulic fracturing (HF) operations undertaken as part of unconventional gas extraction in both Australia and internationally
- Concerns especially around chemical contaminants
- Scepticism around the veracity of industry-generated data
- Need for an independent study that examines chemical concentrations in waters and soils from areas impacted by HF operations

Sources of chemicals

Process chemicals

- Constituents of HF fluids, drilling muds, other additives

Geogenic chemicals

- Mobilised during the process of HF and delivered to the surface in produced waters during well operation.
- Includes: organic compounds, trace elements, radionuclides

Study objectives

(i) Assess the concentrations of HF chemicals and geogenic contaminants in flowback and produced waters resulting from CSG HF operations

(ii) Quantify the impacts of HF operations on the concentrations of contaminants in nearby surface waters, groundwater and soils

(iii) Assess contaminant concentrations in the collected water and soil samples with relevant Australian water and soil quality guideline values

Study location

- Origin gas fields in the Surat Basin Central Queensland (Miles, Reedy Creek)
- Two properties located at Condabri and Combabula. Three wells studied at each site

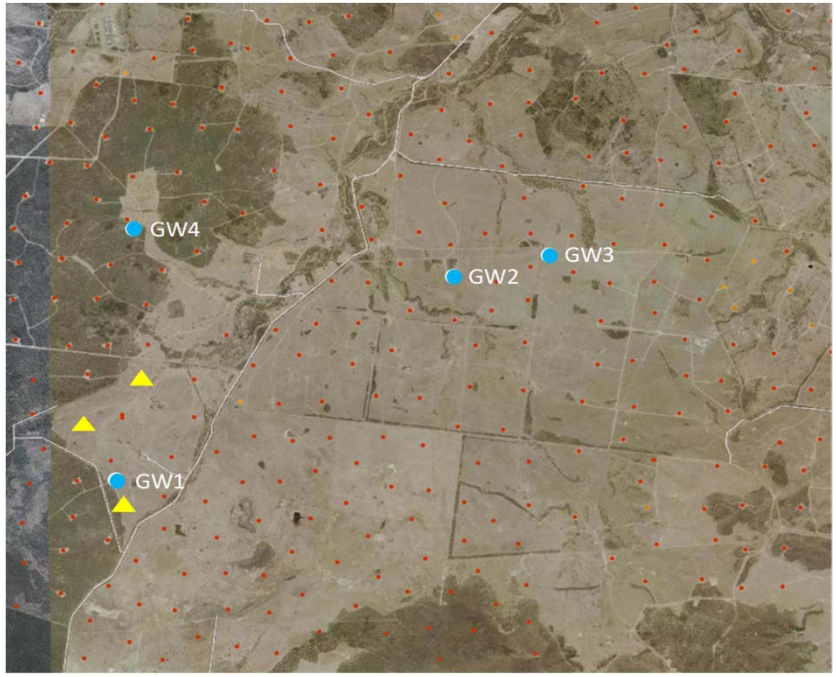
Approximate locations of the Condabri (blue) and Combabula (red) study sites

Sampling

- Sampling plan developed and peer reviewed. Published as a separate report
- Sampling campaign carried out successfully over a period of 9 months (July 2017 to April 2018)
- 6 Wells were followed from HF to 6 months after (time series)
- Samples comprised creek waters, groundwater, produced water flowback water, samples of HF fluid and soil cores from well pads
- 113 water samples and 40 soil samples were collected
- The list of contaminants to be analysed was developed following a review of recent relevant published literature on CSG operations and covered both inorganic and organic chemicals
- Analyses conducted in NATA accredited laboratories or at highly reputable institutions (e.g. ANSTO)
- Samples underwent 22 analytical procedures to determine the concentration of more than 150 potential contaminants including organics, inorganics and radionuclides

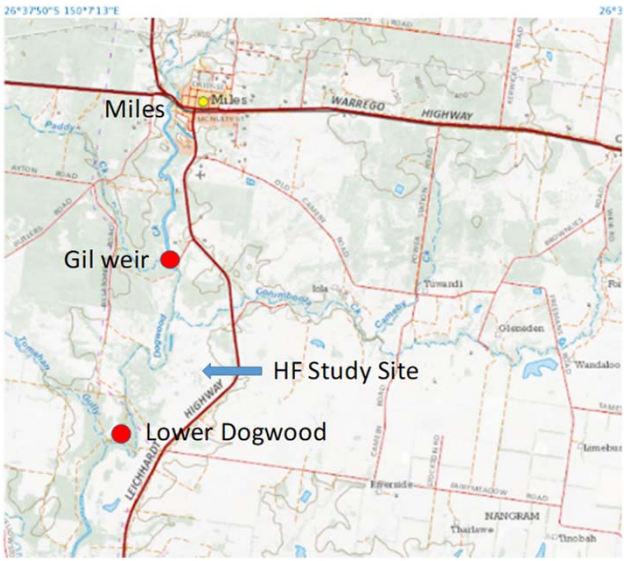
Sampling sites - bores

- Three registered bores at the Combabula study site were sampled on four occasions
- The first two sampling events were during HF operations and the last two after operations had ceased.
- Sampling was conducted by CSIRO staff with assistance from Origin Energy staff



Map showing the location of groundwater bores. The blue dots indicate the location of all CSG wells in the area and the yellow triangles the CSG wells that were sampled during the study

Creek sampling sites



Dogwood Creek, Condabri

- Upstream of the study site, Dogwood Creek flows through the township of Miles and receives inputs from the town's sewage treatment works
- Creek water samples were collected at sites upstream and downstream of the study area on the same day within one hour of each other. Paired sampling approach minimised the influence of any variations in upstream sample water quality.
- Five sampling events: three during HF operations, one shortly after the cessation of HF and one several months after operations had ceased
- Sampling of surface water dams at Condabri and Combabula - not undertaken owing to the lack of suitable sampling sites

Sampling – Reedy Creek water treatment facility

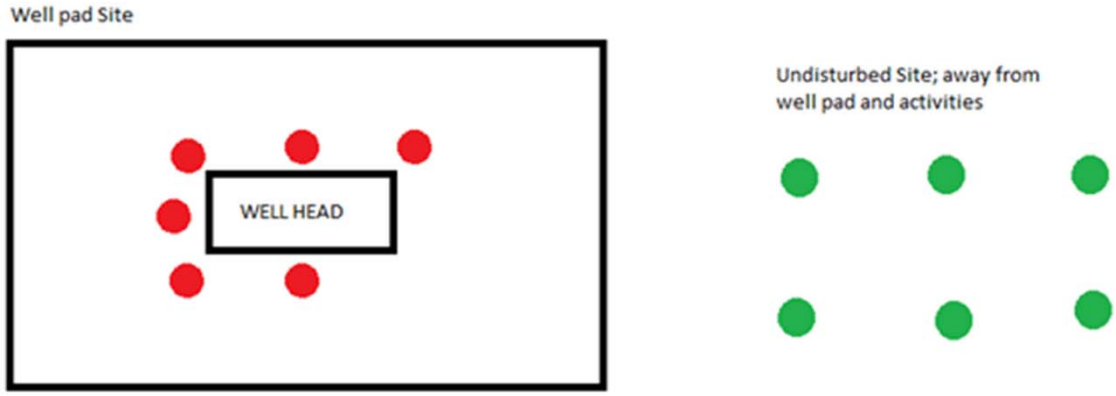
Treatment involves: screening and filtration, disinfection, membrane filtration, ion exchange and Reverse Osmosis (RO)

Samples of raw water, post-treatment water and reject brines were collected by CSIRO staff on three occasions over the study period

The WTF receives and treats water from a network of CSG wells situated across the Reedy Creek and Combabula gas fields. The samples therefore provided an integrated view of water quality across the gas fields

Soil sampling at Condabri

- Six wells were selected for soil sampling
- Soil cores were collected at six points around the well pad within the drill lease and also from a nearby reference sites
- The cores were sectioned into depths of 0-20 cm, 20-40 cm and 40-60 cm



Example of soil sample collection locations within well pad site (red dots) and undisturbed site (green dots) with same soil type

Inorganics analysis

Parameter	Description
Dissolved trace elements (63 elements)	Analysis by both inductively coupled plasma-mass spectrometry (ICP-MS) and inductively coupled plasma atomic emission spectrometry (ICP-AES)
Total trace elements (63 elements	Acid digestion and analysis by both inductively coupled plasma-mass spectrometry (ICP-MS) and inductively coupled plasma atomic emission spectrometry (ICP-AES)
Total Hg	Cold vapour atomic fluorescence spectrometry (CV-AFS)
Dissolved Organic Carbon (DOC)	Shimadzu Combustion Analyser
Alkalinity as $CaCO_3$	Titration
Sulfate and chloride	Ion chromatography
Phosphate, nitrate, nitrite, ammonia	Ion chromatography
Electrical conductivity, pH	Conductivity meter, ISE
Radionuclides: Ra-226, Ra-228, Th-230, Th-232, U-234, U-238, Gross alpha and beta	ANSTO - Environmental Radiochemistry
Total suspended sediment (TSS)	Gravimetry

Organics analysis

Parameter	Description
HF additives: e.g. fluorobenzoic acid tracers; biocides etc., depending on the HF fluid composition	Dissolved phase (filtration, solid phase extraction) liquid chromatography- quadrupole time of flight mass spectrometry (CSIRO Laboratory- LC-QTOF-MS)
Geogenic organic chemicals: Phenols (inc. phenol, methylphenols, dimethylphenols, chlorophenols, nitrophenol) PAHs (inc. naphthalene and substituted naphthalenes, acenaphthene, anthracene, benzopyrenes, fluoranthene, fluorene, phenanthrene) VOCs- Volatile organic carbons (including BTEX compounds) TRHs- Total recoverable hydrocarbons THMs –Trihalomethanes Miscellaneous organics e.g. oxygenated compounds	CSIRO Laboratory (LC-QTOF-MS) and GC-MS at NMI (NATA accredited laboratory), 108 compounds
Non-target compounds- unknowns (semi-quantitative):	Dissolved phase (filtration, solid phase extraction) gas chromatography-triple quadrupole mass spectrometry (GC-MSMS) full scan analysis and mass spectra library matching – at CSIRO Laboratory

Results: key features of the data

Hydraulic fracturing fluid composition

Consistent HF Fluid composition across the 6 wells

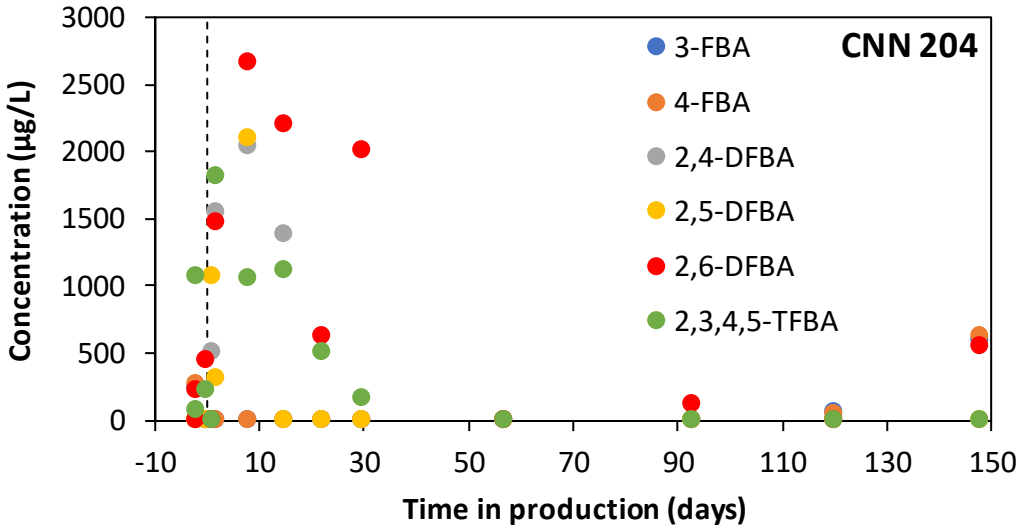
Chemical Constituents
J604 Crosslinker (ethylene glycol, sodium tetraborate, boric acid)
Hydrochloric acid (HCl)
J318 Breaker Aid (triethanolamine)
Potassium chloride (KCl) Clay Control
M275 Biocide (3:1 mixture of CMIT &MIT)
J218 Breaker (diammonium peroxidisulphate)
J479 Encapsulated breaker (diammonium peroxidisulphate)
J580 Guar gum
B499 Corrosion Inhibitor (gelatine)
Chemical tracers (selected wells): 2-FBA, 3-FBA, 4-FBA, 2,3-DFBA, 2,4-DFBA, 2,5-DFBA, 2,6-DFBA, 3,5-DFBA, 3,4-DFBA, 2,3,4,5-TTFBA

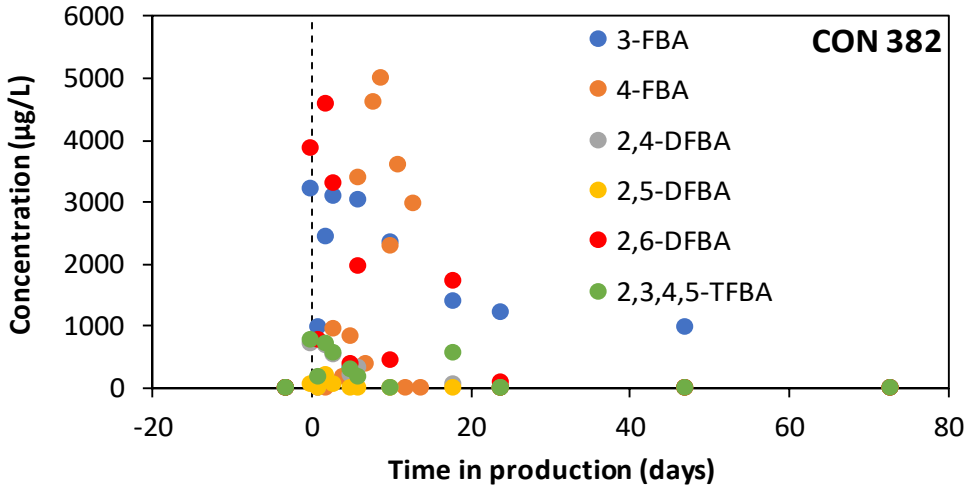
Well sampling – results snapshot

- Well samples have varied composition – high salts content
- HF chemicals mostly detected in early stages of well production (e.g. CMIT, MIT)
- High concentrations of ammonia in most samples (exceeds surface water quality guidelines)
- High organic carbon concentrations during the first few months of production
- Metals of greatest concern are: chromium, copper, mercury and zinc (consistently exceed surface water quality guidelines)
- High barium and boron concentrations in waters. Boron concentrations exceed water quality guidelines
- Radium-226 concentrations – highest following commencement of well production then a decline

Note: water quality guidelines in this context are used as a benchmark – not for regulation

Well data: Fluorobenzoic acid (FBA) tracers

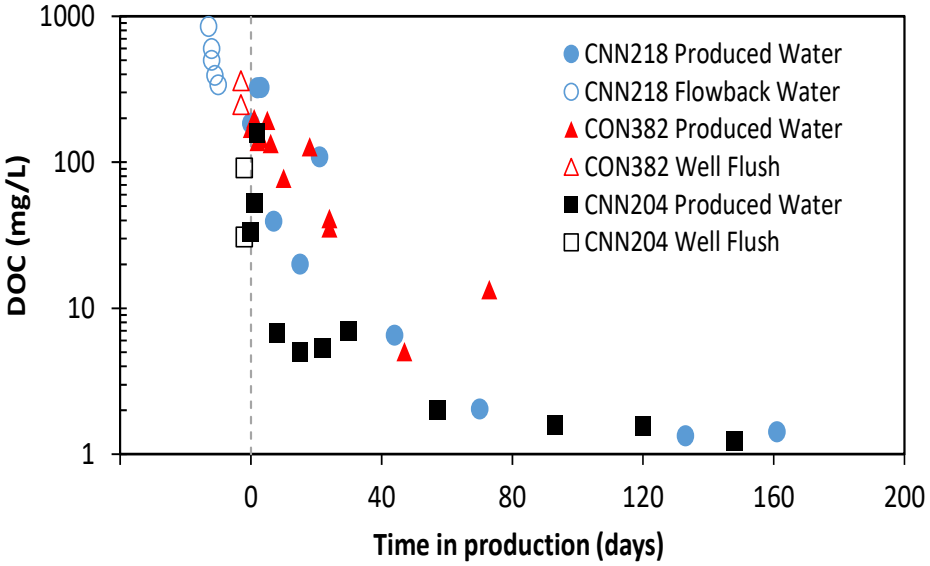




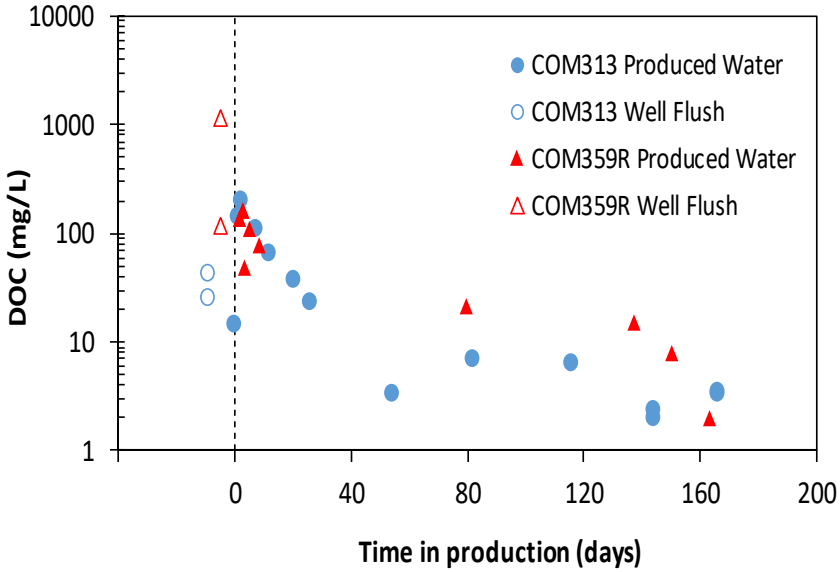
Mainly detected in the first 30 days of well operation

Well data: dissolved organic carbon

High dissolved organic carbon concentrations during the first 30 days of well production



Condabri

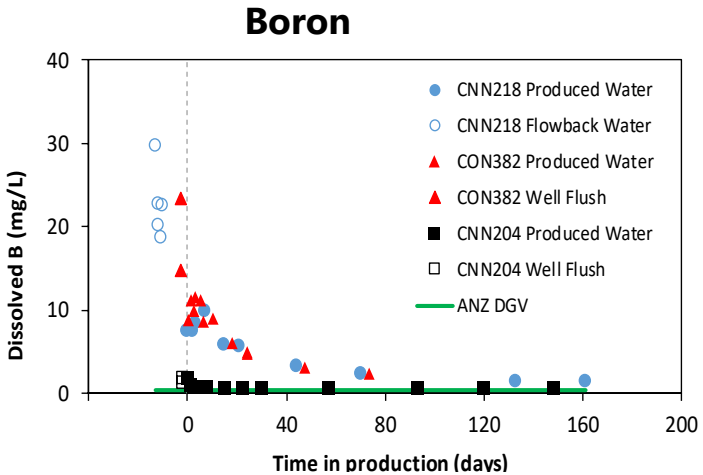


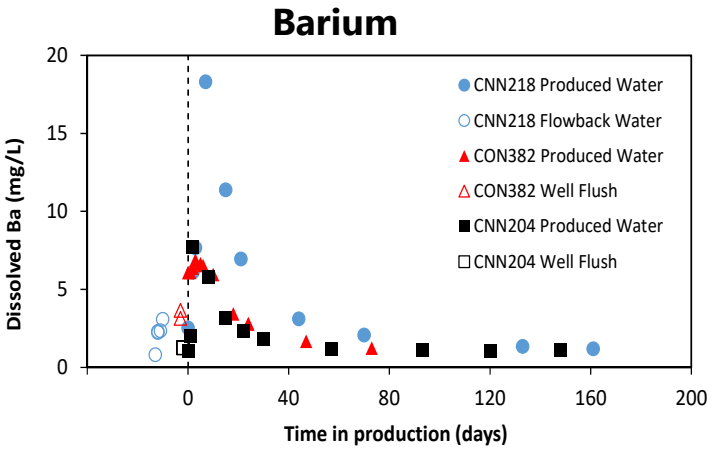
Combabula

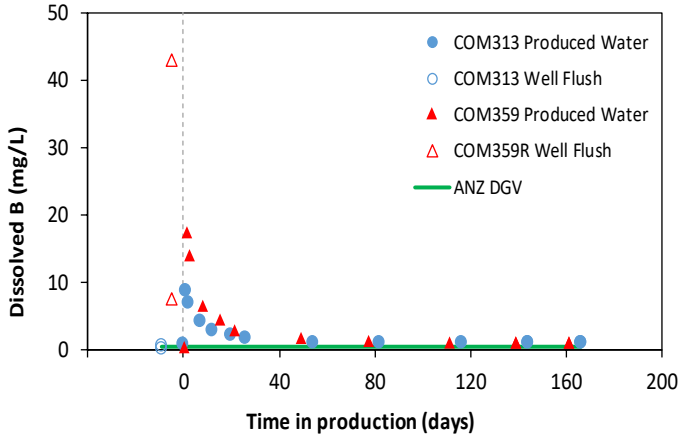
Well data: dissolved barium and boron

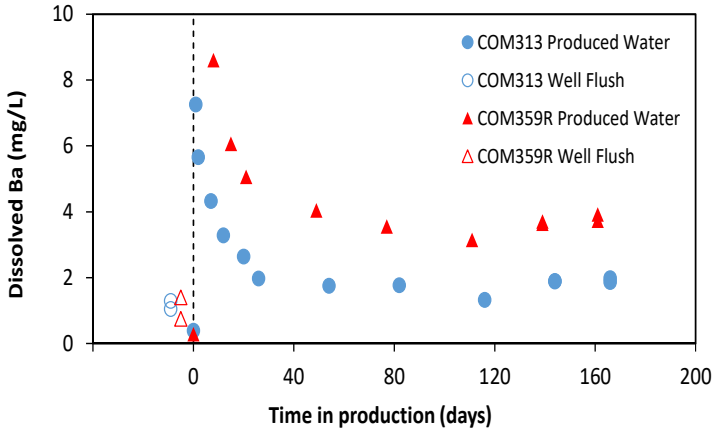
High concentrations of boron and barium in well water

ANZG guideline value for boron = 0.37 mg/L





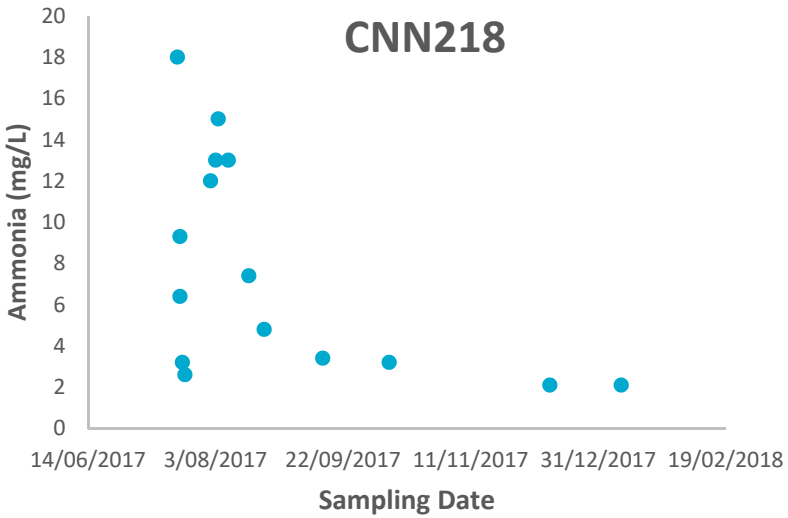


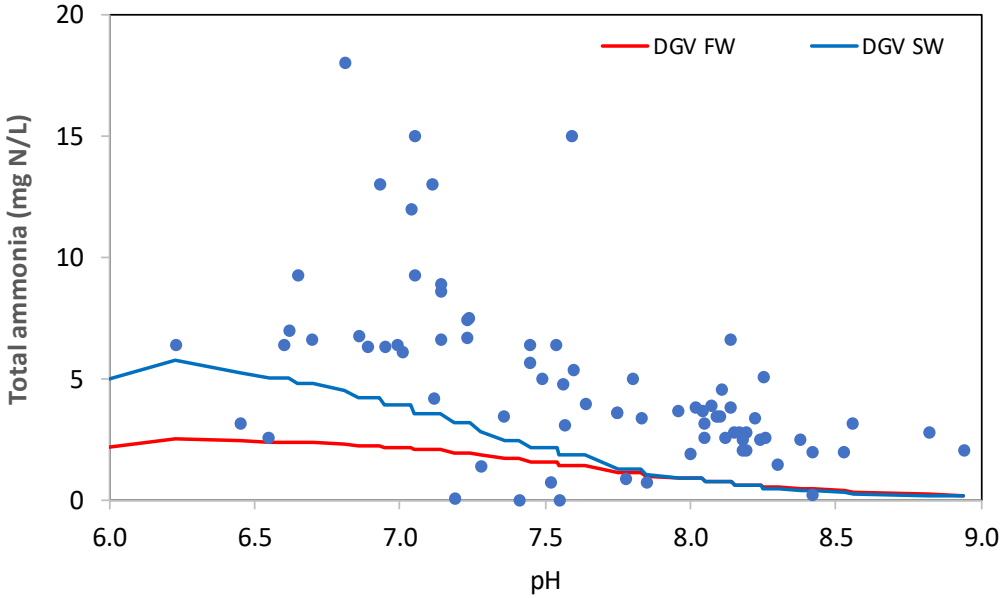


CSIRO GISERA
Gas Industry Social and Environmental Research Alliance

Well data: dissolved ammonia

- Unionised ammonia is very toxic to aquatic organisms
- ANZG guidelines for ammonia varies with pH
- 68 out of the 78 well samples exceeded the ANZG guideline values (DGV)

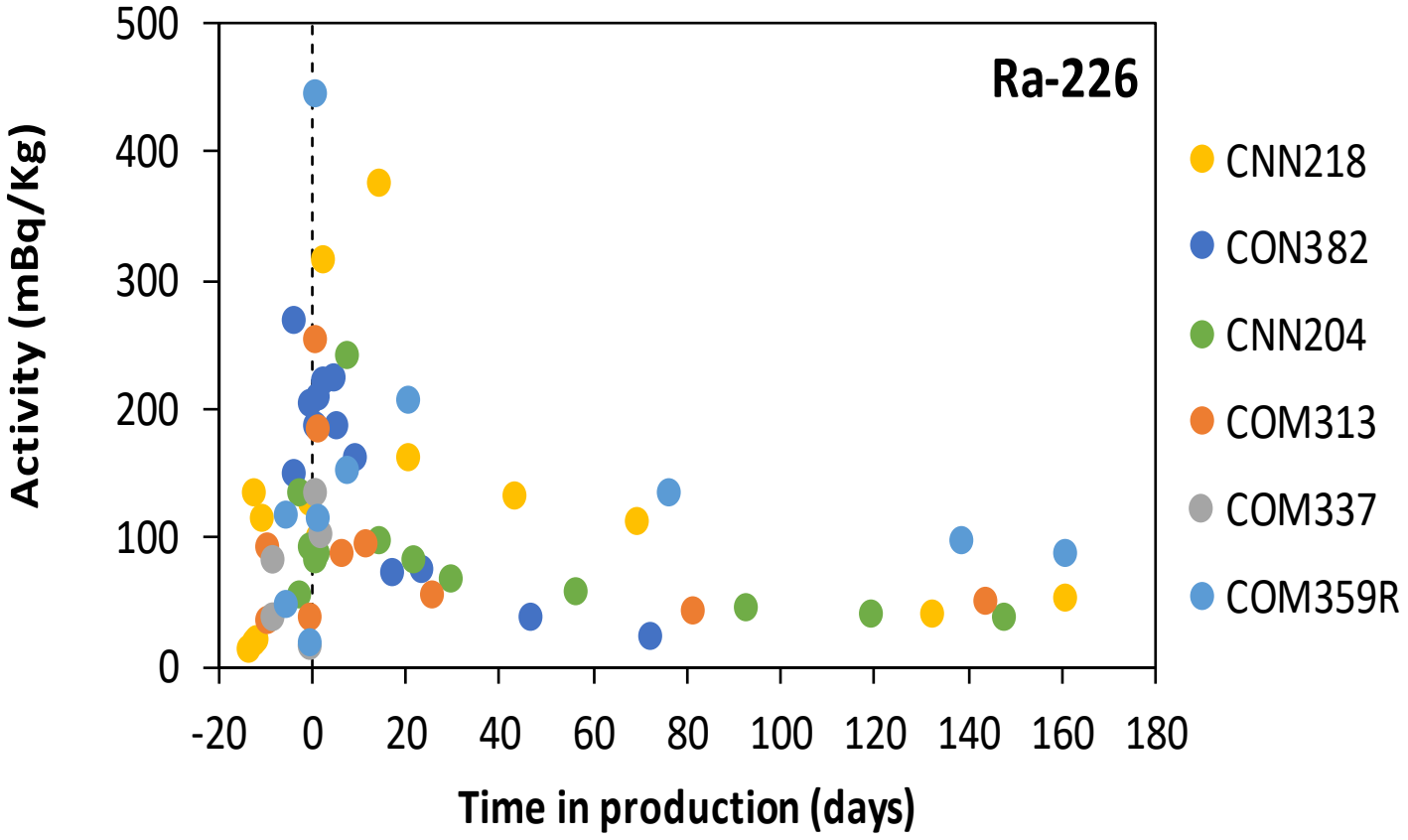




DGV FW – freshwater guideline
DGV SW – marine guideline

Well data: Radium-226

- Radium activity highest in post HF samples then decreases to very low activities
- For comparison: USEPA drinking water = 185 mBq/L



Soils

- Soil sampling from drill leases and nearby background sites did not reveal any contamination (inorganics, metals, organics, radionuclides) that could be associated with CSG activities during hydraulic fracturing operations
- This finding was expected as there were no spills of HF chemicals reported over the time of the study
- Given that the probability of capturing a spill event in the field is low, a companion laboratory study was conducted where spills of HF fluid chemicals and produced waters were simulated in the laboratory and residues measured over time

WTF results snapshot

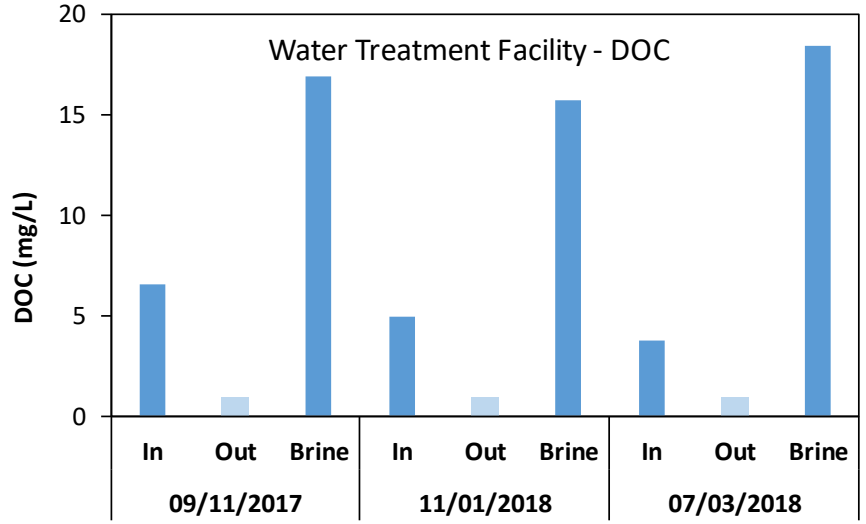
- Water sampling of a CSG water treatment facility indicated the current treatment procedure which incorporates reverse osmosis was effective in removing most CSG-related chemicals from the wastewater stream.

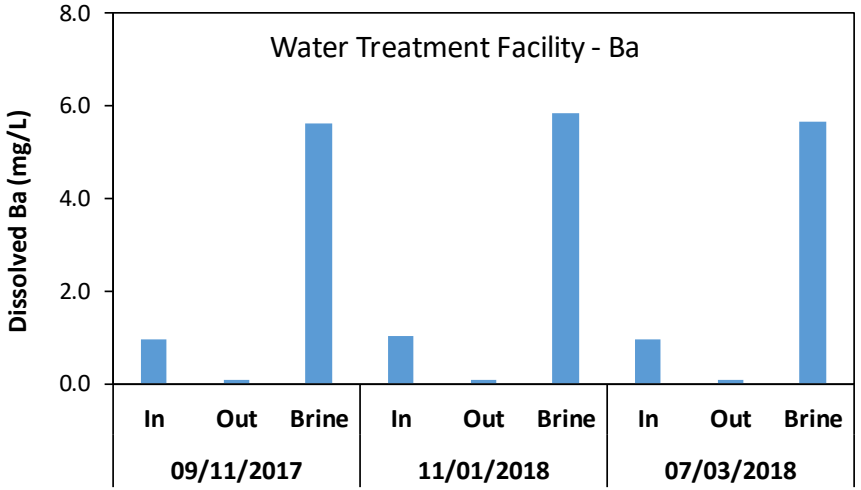
- Treated waters comply with relevant water quality guidelines

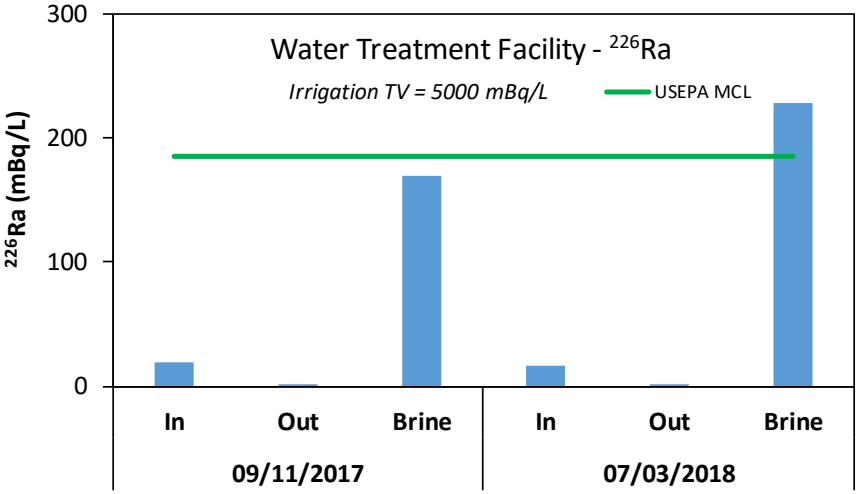
- Highest contaminant concentrations observed in reject brines>input waters

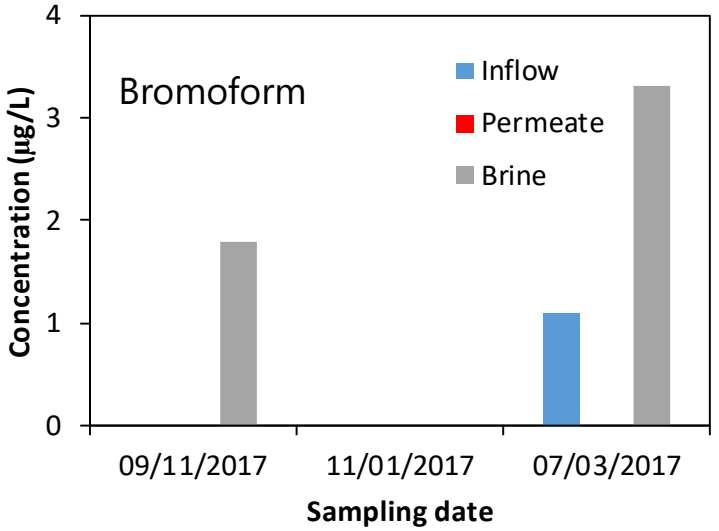
- Some organics observed in the treated waters (e.g. chloroform, bromoform) which may be related to the disinfection process, but below levels of regulatory concern

Water treatment facility samples









Surface waters and local ground water bores

Groundwater bore samples

- The concentrations of major cations, metals and metalloids were generally similar in samples taken from the same bore at different times, and between the different bores
- Four marginal exceedances of surface water quality guidelines, all at GW2; cadmium, copper and zinc and mercury. The source of these metals is uncertain but unlikely to be a signature of CSG-related contamination as other CSG-related elements such as boron and barium were not present at elevated concentrations
- The concentration of all organic compounds measured were below the limits of reporting. This indicated that the bores were free of any significant contamination by organic chemicals
- Radionuclide activities were generally very low, with Ra-226 and U-234 being the only two radionuclides consistently detected in samples. The measured activities in all samples analysed were well below the available guideline values for irrigation, livestock watering and human consumption

Dogwood Creek - results

- No evidence of consistently elevated of trace element concentrations downstream of the Condabri study site that could be linked to CSG runoff (i.e. increases in concentration of chemicals associated with drilling muds and HF fluids such as boron and barium)
- Dissolved copper chromium and zinc concentrations exceeded the guideline values in several samples at both upstream and downstream locations
- Radionuclide activities were generally very low. Measured activities in all samples analysed were well below the available guideline values for irrigation, livestock watering and human consumption
- The only organic compounds detected were some hydrocarbon fractions (>C10-C34) which were sporadically detected at low concentrations in both the upstream and downstream sites

Dogwood Creek – key results

Site	Date	Ba	Cr	Cu	Zn	TRH >C10 - C16	TRH >C16 - C34	^{238}U activity	^{226}Ra activity	Gross Alpha	Gross Beta
		mg/L	µg/L	µg/L	µg/L	mg/L	mg/L	mBq/kg	mBq/kg	Bq/L	Bq/L
Upstream	27/07/2017	0.034	2	1.1	5	<25	<100	2.2	4.1	0.07	0.14
	3/08/2017	0.15	1	2.1	<4	<25	**310**	---	---	---	---
	18/08/2017	0.12	2	3.2	---	---	---	---	---	---	---
	13/09/2017	0.039	<1	1.5	<4	<25	<100	---	---	---	---
	1/11/2017	0.059	5	1.5	17	<25	<100	3.6	6.1	0.15	0.12
Downstream	27/07/2017	0.045	2	1.1	9	<25	<100	2.6	6.2	0.15	0.11
	3/08/2017	0.12	2	1.9	<4	**31**	**610**	---	---	---	---
	18/08/2017	0.21	7	5.0	<4	---	---	---	---	---	---
	13/09/2017	0.044	1	1.6	<4	<25	<100	---	---	---	---
	1/11/2017	0.11	9	3.9	14	**71**	100	5.0	7.3	0.14	0.14
ANZG 2018		**-**	**1**	**1.4**	**8**	**-**	**-**	**200**	**5000**	**0.5**	**0.5**

Figures is red exceed ANZG surface water quality guideline values

Conclusions (I)

- Flowback and produced water composition was dominated mainly by geogenic chemicals with most HF fluid-derived chemicals (e.g. potassium chloride, CMIT and MIT) only being significant at the start of well operations.
- Chemical concentrations in the flowback and produced waters were dynamic and changed with time. The peak concentrations of many chemicals were observed during the flowback/early produced waters production phase at all wells. After this period, the concentrations of the chemicals declined rapidly with occasional spikes in concentrations.
- The chemicals occurring at concentrations above Australian default guideline values (DGV's) for surface water quality in well samples were ammonia, boron and seven trace metals: chromium, copper, manganese, mercury, nickel, silver and zinc.
- The activities of seven radionuclides were measured in water and soil samples. Radium-226 was the most abundant radionuclide in waters. All other radionuclides were below the existing levels of regulatory concern.
- Well samples were characterised by high concentrations of dissolved organic carbon which reached concentrations in excess of 100 mg C/L during the early stages of well production. Organic contaminants such as phenols, hydrocarbons, HF fluid chemicals typically comprised a small fraction (<5%) of the DOC and the remaining pool of carbon is currently uncharacterised.

Conclusions (II)

- Sampling of surface and groundwaters did not indicate any significant impacts of CSG operations on water quality. This finding was consistent with recent groundwater modelling which indicates that even under worst case conditions, contaminant migration from well bores to groundwater supplies is likely to occur on a timescale of decades to many hundreds of years.
- Water samples from a local creek adjacent to one of the study areas did not indicate signs of contamination relating to CSG activities. However, the creek's water quality showed evidence of contamination arising from other sources (e.g. sewage treatment works discharges) upstream of the CSG operations.
- Water sampling of a CSG water treatment facility indicated the current treatment procedure which incorporates reverse osmosis was effective in removing most CSG-related chemicals from the wastewater stream. The highest chemical concentrations were observed in the concentrated reject brine samples.
- Soil sampling from drill leases and nearby background sites did not reveal any contamination that could be associated with CSG activities during hydraulic fracturing operations. This finding was expected as there were no spills of HF chemicals reported over the time of the study.

GISERA
Gas Industry Social and Environmental Research Alliance

Thank you

Simon Apte
Senior Principal Research Scientist

t +61 2 9710 6838
e simon.apte@csiro.au
w gisera.csiro.au

Australian Government
Department of Industry, Innovation and Science
Supported by Government of South Australia
Queensland Government
NORTHERN TERRITORY GOVERNMENT
PANGAEA RESOURCES PTY Ltd.