



Impacts on Groundwater Quality from Abandoned Hydrocarbon Wells - Final Report

Groundwater Science Programme
Commissioned Report CR/18/061



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Contents

Contents	i
Acknowledgements	iv
Summary.....	v
1 Introduction	1
1.1 Site selection	2
2 Fieldwork campaigns	6
2.1 Logistics.....	6
2.2 Field Area Details	6
2.3 Sampling and analysis	14
3 Summary results.....	16
3.1 Organic chemistry.....	16
3.2 Inorganic chemistry	24
3.3 Dissolved gases.....	24
4 Further reconnaissance.....	28
4.1 Broughton	28
4.2 Calow	30
4.3 Eskdale.....	32
4.4 Everton.....	34
4.5 Ironville.....	36
4.6 Outcome of reconnaissance	38
5 Soil Gas Survey.....	39
5.1 Introduction.....	39
5.2 Monitoring site selection and supporting information.....	39
5.3 Monitoring data and processing activities	39
5.4 Results and discussion	39
5.5 Soil gas summary.....	47
6 Conclusions	48
References.....	49
Appendix 1 Hydrocarbon field factsheets.....	50

FIGURES

Figure 1. The location of selected abandoned fields.....	2
Figure 2. Geology, licensed areas and abandoned wells in the Nooks Farm study area.....	7
Figure 3. Potential sampling sites around Nooks Farm.	7
Figure 4. Sites sampled around Nooks Farm.	8
Figure 5. Geology and abandoned wells in the Ashdown study area.	9
Figure 6. Potential sampling sites around the Ashdown study area.....	9
Figure 7. Sites sampled around Ashdown.....	10
Figure 8. Geology, licensed areas and abandoned wells in the Hemswell study area	11
Figure 9. Potential sampling sites around the Hemswell study area.....	11
Figure 10. Sites sampled around Hemswell.....	12
Figure 11. Geology, licensed areas and abandoned wells in the Lomer study area.....	13
Figure 12. Potential sampling sites around the Lomer study area.	13
Figure 13. Sites sampled around Lomer	14
Figure 14. Piper diagram showing major-ion chemistry of the four study areas	25
Figure 15. Geology, licensed areas and abandoned wells around the Broughton oil field	29
Figure 16. Potential sampling sites around the Broughton oil field.....	29
Figure 17. Sites considered during a reconnaissance of the area around the Broughton oil field	30
Figure 18. Geology, licensed areas and abandoned wells around the Calow gas field.....	31
Figure 19. Potential sampling sites around the Calow gas field	31
Figure 20. Sites considered during a reconnaissance of the area around the Calow gas field	32
Figure 21. Geology, licensed areas and abandoned wells around the Eskdale gas field.....	33
Figure 22. Potential sampling sites around the Eskdale gas field.	33
Figure 23. Sites considered during a reconnaissance of the area around the Eskdale gas field.....	34
Figure 24. Geology, licensed areas and abandoned wells around the Everton gas field.....	35
Figure 25. Potential sampling sites around the Everton gas field	35
Figure 26. Sites considered during a reconnaissance of the area around the Everton gas field.....	36
Figure 27. Geology, licensed areas and abandoned wells around the Ironville gas field	37
Figure 28. Potential sampling sites around the Ironville gas field	37
Figure 29. Sites considered during a reconnaissance of the area around the Ironville gas field.....	38
Figure 30. Ashdown 1 soil gas survey area showing the location of the Ashdown 1 well (A), adjacent lane (B) and neighbouring equestrian jumps (C) course to the west	40
Figure 31. Ashdown 1 open path CO ₂ laser, CO ₂ flux and CO ₂ in soil gas.....	41
Figure 32. Ashdown 1 CO ₂ and O ₂ ratios in soil gas collected in January 2018 and November 2017.	42
Figure 33. Bolney 1 soil gas survey area and reported location of the Bolney 1 well.....	43
Figure 34. Figure 4. Open path CO ₂ laser surveying at Bolney 1	44
Figure 35. Bolney 1 open path CO ₂ laser, CO ₂ flux, and CO ₂ and CH ₄ in soil gas.	45

Figure 36. Bolney 1 CO ₂ and O ₂ ratios in soil gas collected in January 2018 (black points) and November 2017 (blue points)	46
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TABLES

Table 1. Assessment criteria for abandoned wells, Phase 2 highlighted in red	1
Table 2. Phase 2 assessment of the 27 HC fields in the study	3
Table 3. Sample analysis suite	15
Table 4. Round 1 organic chemistry summary for Nooks Farm.....	16
Table 5. Round 1 GC-MS and LC-MS summary for Nooks Farm.....	16
Table 6. Round 1 organic chemistry summary for Ashdown	17
Table 7. Round 1 GC-MS and LC-MS summary for Ashdown	17
Table 8. Round 1 organic chemistry summary for Hemswell	17
Table 9. Round 1 GC-MS and LC-MS summary for Hemswell.....	18
Table 10. Round 1 organic chemistry summary for Lomer	18
Table 11. Round 1 GC-MS and LC-MS summary for Lomer	19
Table 12. Round 2 organic chemistry summary for Nooks Farm.....	20
Table 13. Round 2 GC-MS and LC-MS summary for Nooks Farm.....	20
Table 14. Round 2 organic chemistry summary for Ashdown	21
Table 15. Round 2 GC-MS and LC-MS summary for Ashdown	21
Table 16 Round 2 organic chemistry summary for Hemswell	21
Table 17. Round 2 GC-MS and LC-MS summary for Hemswell.....	22
Table 18. Round 2 organic chemistry summary for Lomer	22
Table 19. Round 2 GC-MS and LC-MS summary for Lomer	23
Table 20. Summary of CH ₄ data	24
Table 21. Round 1 inorganic chemistry selected results.....	26
Table 22. Round 2 inorganic chemistry selected results.....	27
Table 23. Desk study summary of potential sites within 5km of field.....	28
Table 24. Summary of reconnaissance visits	38

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Summary

This report details a reconnaissance investigation carried out between 2016 and 2018 from a British Geological Survey (BGS)-Environment Agency (EA) collaboration on the impacts of abandoned hydrocarbon (HC) wells on groundwater quality in England. The investigation involved collation of a database of HC wells that were identified from records provided by DECC (Department of Energy & Climate Change; now BEIS: Business, Energy & Industrial Strategy) as being abandoned (as opposed to operational or unspecified), categorising according to factors such as oil or gas designation, depth of HC resource, time since abandonment, productive life, absence of active wells nearby, and occurrence and type of overlying aquifer(s). From this categorisation, a subset of 27 sites were shortlisted for further investigation and fact sheets were produced for each outlining regional geology, hydrogeology and potential groundwater monitoring points in the area. Using these factsheets, four study areas were assessed as being most suitable for further field investigation. These comprised two gas fields: Nooks Farm (Staffordshire), and Ashdown (Sussex), and two oil fields: Hemswell (Lincolnshire) and Lomer (Hampshire).

Groundwater sampling campaigns were conducted in 2016–2017 in the four study areas, with potential sampling points identified within a 5 km buffer zone around (downstream of) the HC well or HC field. In several areas, the number of sampling points was very limited as locations of HC wells do not necessarily have any relationship with locations of overlying aquifers. In others, large numbers of sites were deemed unsuitable for sampling, for reasons including disuse, decommissioning, safety or lack of access. This made representative sampling of groundwater a severe challenge. Suitable sites from the four study areas were sampled twice during the project, with a total of 48 groundwater samples being collected over the two campaigns.

Results from both sampling rounds have shown that the presence of hydrocarbons in the groundwater is limited. In the first sampling round, a maximum dissolved methane (CH_4) concentration of 407 $\mu\text{g/L}$ was recorded. However, this relatively high value was not repeated when the site was visited during the second round of groundwater sampling. The value was below the threshold required for $\delta^{13}\text{C}_{\text{CH}_4}$ isotopic analysis. Some groundwater samples showed detectable quantities of organic compounds including VOCs (volatile organic compounds) and PAHs (polycyclic aromatic hydrocarbons) as well as pesticides, herbicides, fungicides, surfactants, analgesics and veterinary compounds. These were, however, almost invariably present in low concentrations, none could be linked unequivocally to the presence of abandoned HC wells and many were clearly due to other anthropogenic activities.

As a result of the difficulties finding representative and suitable groundwater sampling sites, a further reconnaissance was undertaken in May 2017 to identify potential alternative gas and oil fields. This confirmed further the difficulties in finding suitable areas for investigating groundwater quality and further groundwater sampling was therefore not attempted. An alternative approach was used to investigate two abandoned HC well areas: Ashdown, one of the original study areas, and a new location at Bolney (also Sussex). A soil gas survey was completed at each of these locations in order to investigate whether soil gas proximal to the former well location contained any evidence of HC leakage. Due to poor ground conditions at the time of sampling, the results are ambiguous, but do show elevated concentrations of both CO_2 and CH_4 . Further work in dry ground conditions would be required to say with certainty that these concentrations are linked directly to the presence of the gas wells.

1 Introduction

This investigation made use of a database of hydrocarbon (HC) wells/fields, available from DECC (now BEIS), who hold the HC borehole logs and any additional geochemistry or logging information. The database lists some 1500 HC wells across England & Wales, from which a shortlist of 27 abandoned HC wells was selected across the country. These were shortlisted and prioritised in two Phases: in Phase 1 on HC well criteria including oil/gas prospectivity, depth, length of time since abandonment, absence of proximal active wells, and in Phase 2 on aquifer status and type, pre-existing HC and water data availability and sampling practicality (Table 1). For Phase 2, information on the aquifer type was collated from BGS and EA reports and geological data from BGS datasets. Where available, geological cross sections were included in the assessment.

Groundwater sampling practicalities involved an assessment of the EA's Groundwater Quality and Groundwater Level monitoring networks, the EA's National Abstraction Licence Database, and the BGS's Wellmaster database.

Table 1. Assessment criteria for abandoned wells with agreed priority (3: highest)

Order		Criterion	Priority	
PHASE 1	1	HC type	Gas Oil Coalbed methane (CBM)	1 2 0
	2	HC well history	Producing Non-producing	1 0
	3	Reason for abandonment	Economic Unproductive	1 0
	4	Time since abandonment	< 20 years 20–50 years > 50 years	1 2 2
	5	HC well depth (or depth to offset)	< 500 m 500–750 m 750–1500 m > 1500 m	0 1 2 2
	6	Proximity to existing wells	0–5 km 5–10 km > 10 km	3 2 1
Assess number of water wells				
PHASE 2	7	Aquifer type	Unconfined Confined Unproductive	1 1 0
	8	Data availability for HC wells	Well completion Monitoring data Abandonment/decommissioning	1 2 2
	9	Practicality	Accessibility Availability of monitoring well	2 1

The collated information was tabulated into a series of ‘factsheets’ for each of the 27 HC wells/fields. These included maps of potential sampling sites, stratigraphic logs and any hydrogeological information (e.g. groundwater level, flow directions). The 27 factsheets are included in Appendix 1.

1.1 SITE SELECTION

The location of the 27 shortlisted locations is shown in Figure 1. The factsheets were used to inform the selection of the four areas most suitable for further study. It was anticipated that a mixture of aquifer types, physical location and HC field type (oil/gas) would be valuable for comparison.

Each field was assessed according to the aquifer type, number of potential sampling sites and the HC resource present. This information was tabulated, with inputs from the EA and BGS, and colour coded to aid decision making (Table 2).

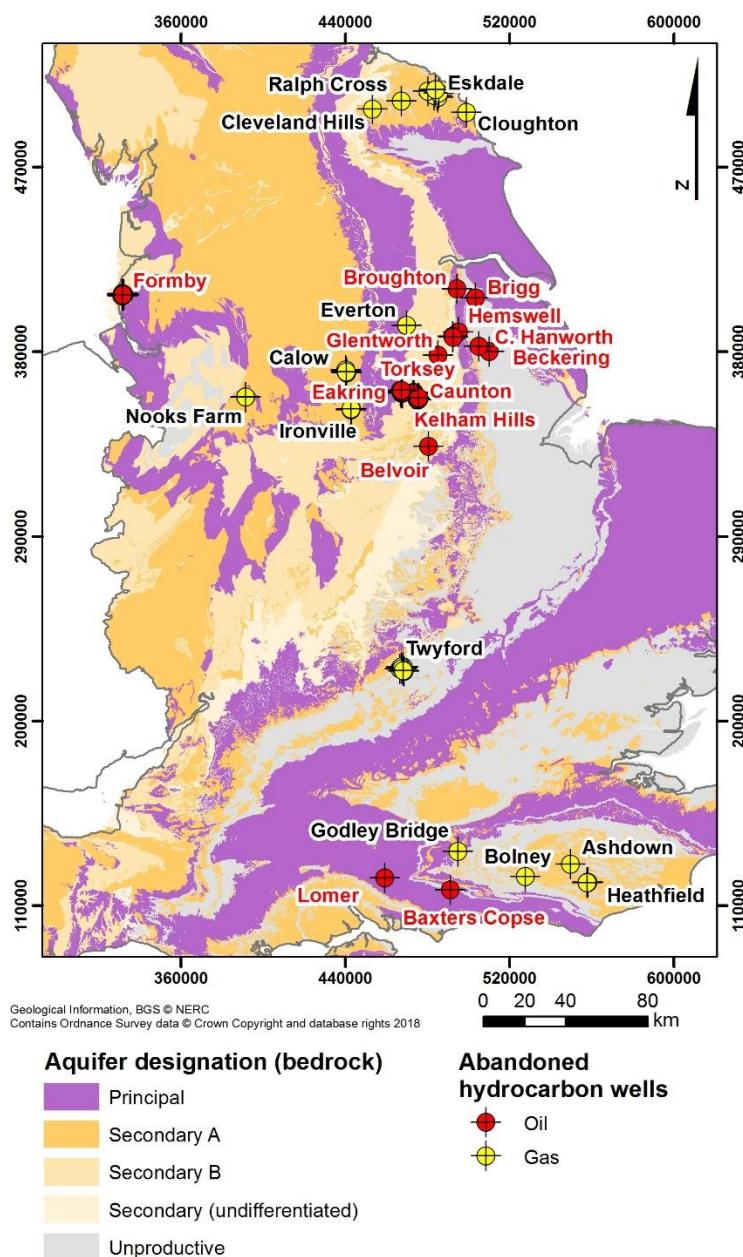
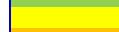


Figure 1. The location of selected abandoned fields

Table 2. Phase 2 assessment of the 27 HC fields in the study

Site	Location	Depth	Shows	Bedrock aquifer	Superficial aquifer	Wellmaster Field	1km	Comments	Environment Agency	BGS
GAS										
Ashdown	East Sussex	1383m	241-253 m 0.7 m3/day; 262 -288 m 1.3 m3/day; 327-336 m 17.3 m3/day; 896-904 m 90.9 m3/day	Ashdown Fm		1	4	Appears reasonable	Deep and shallow hydrocarbon source	
Bolney	West Sussex	2440m	@ ~132m, Purbeck, oil @ ~293m & ~400m oil seepage 322 – 628 m. Gas 148-154 m 78.6 m3/day; 220-230 m 572.8 m3/day; 220-241 m 2455 m3/day; 293-298 m 818 m3/day; 312-319 m 264 m3/day; 312-341 m 168 m3/day. No gas from 421-910m	Tunbridge Wells Sand secondary A		1	1	Insufficient mpts	Similar location/hydrogeology to Ashdown, but Ashdown has better potential for sampling	
Calow	Derbyshire	1130m		Lower Coal measures, Secondary A		2	5		Majority of potential sampling points are Well Master boreholes - aquifer is coal measures, likely to have elevated CH4	
Cleveland Hills	N Yorks	1915m	Gas seen at 1300, 1330, 1520 m bgl. At 1517 m bgl yielded 682 m3/day of gas	Ravenscar Group (Cloughton Fm), Secondary A		0	0	Insufficient mpts	Water quality issues	limited monitoring points
Cloughton	N Yorks	3078m	Gas show. Little gas recovered from Carboniferous sandstone or Magnesian Limestone	Ravenscar Group, Secondary A		0	0	Insufficient mpts	Water quality issues	limited monitoring points
Eskdale	N Yorks	1540m	Gas found at and below 1300 m	Ravenscar Group, Secondary A	Till, Secondary A	6	12	Water quality issues	Limited spread of groundwater monitoring points in the buffer zone.	
Everton	N Notts	1660m	abandoned without reaching target formation	Sherwood Sandstone, Principal aquifer	Peat, Secondary A, unproductive	0	1	Insufficient mpts	Target not reached	CBM target not met, but deeper oil target was. Limited monitoring points but principal aquifer with potentially enough samples for this project.
Godley Bridge	Sussex	2584m	Gas analysis for CH4, C2H6, C3H8, C4H10 in log. Just CH4 until 823 m. Highest concentrations of all gasses 1873 m	Weald Clay Formation, Secondary A	Alluvium	0	0	Insufficient mpts		Poor aquifer and limited monitoring points in the aquifer of interest
Heathfield	Sussex	115m	Well 4 produced 68200 m3/day enough to provide natural gas to a small number of houses.	Ashdown Formation, Secondary A		4	6	Gas source is within the formation to be monitored		Only shallow gas has been proven, not a deeper reservoir.
Ironville	Derbyshire	836m	Oil show 180 to 190m, 240m, 370m, 408m, 615m, 660m, 710m and 830m. Oil and gas shows 515 to 530m, 585m, 680m. Tested ~235m 0.3 m3/day water and trace gas. 36 to 60 m3/day gas between 510-535 m	Lower Coal Measures, Secondary A		3	10		Majority of potential sampling points are Well Master boreholes - aquifer is coal measures, likely to have elevated CH4	
Nooks Farm	Staffs	625m	Good gas production.	Millstone Grit Group, Secondary A	Till, Secondary Undiff	15	40		Status of the field is in flux, currently all wells are abandoned, but 7 Star are planning on re-instating a drill site for further exploration.	
Ralph Cross	N Yorks	1631m	Methane noted in log in 'considerable' amounts.	Jurassic Ravenscar Group, Secondary A		0	0	Insufficient mpts		Limited monitoring points
Twyford	Bucks	154m	No gas until 126 m then gas and water to 144 m.	Oxford Clay, unproductive		8	14	Bedrock unproductive		Unproductive bedrock aquifer
 Suitable Has potential Others are preferable Not suitable										

Site	Location	Depth	Shows	Bedrock aquifer	Superficial aquifer	Wellmaster		Comments	
						Field	1km	Environment Agency	BGS
<u>OIL</u>									
Baxters Copse	West Sussex	2365m	Some CH4, C2H6, C3H8, C4H10 seen during drilling, details on log. Borehole produced 150 BFPD (25% was 370 API oil, light crude oil).	Gault Formation, unproductive		0	6	Insufficient close mpts Bedrock unproductive	Unproductive bedrock aquifer
Beckering	Lincs	1699m	No details	Amphill Clay, unproductive	Glaciofluvial deposits – sands and gravels. Secondary A	0	0	Insufficient mpts Bedrock unproductive	Limited monitoring points and poor aquifer
Belvoir	Leics	960m	Presence of oil seen in the core description from about 560 m to 590m, 700 m, 860 m to 920 m	Lias Group/ (Charmouth Mudstone Fm), Secondary Undiff	Secondary Undiff	0	0	Insufficient mpts Bedrock undifferentiated	Limited monitoring points and poor aquifer
Brigg	Lincs	1937m	Oil shows from 1650 m to 1750 m and 1880 m to bottom of hole	Amphill Clay (Ancholme Clay), unproductive	Breighton Sand Fm, Secondary Undiff	1	4		Poor aquifer
Broughton	Lincs	1920m	Westphalian A and Upper Namurian moderate to good hydrocarbon shows but only Peniston Flags produced oil (40 bopd), others formations water and traces of oil and gas	Lincolnshire Limestone Formation, Principal	None	0	8	Insufficient close mpts Secondary B bedrock	Multiple oil fields in buffer zone, not many sampling points close to field.
Caunton	Notts	699m	Oil shows below 672 m	Mercia Mudstone, Secondary B	Unproductive / Secondary A	23	28	Insufficient hydrocarbon? Bedrock unproductive	Limited monitoring points and poor aquifer
Cold Hanworth	Lincs	1760m	Possibly but some of the information has been obscured. Oil staining, hydrocarbon odour and fluorescence tests noted in sample descriptions	West Walton Fm, unproductive	Secondary	1	2	Poor aquifer and not clear how much hydrocarbon Secondary B bedrock	Limited monitoring points and poor aquifer
Eakring	Notts	819m	Core samples show a little oil. Oil in borehole at 596 m, 632 m, 677 m	Mercia Mudstone Group, Secondary B	None	70	174		Poor aquifer, large numbers of abandoned wells in field
Formby	Merseyside	2340m	Free oil and oil staining 30 to 55 m; 104 – 113 m. Gas odour 711-712 m.	Mercia Mudstone, Secondary A	Peat, Unproductive superficial aquifer	16	25	Near surface peat may produce gas and confuse the monitoring Secondary B bedrock	Complicated area with shallow oil seeps.
Glentworth	Lincs	1666m	Traces, no production	Charmouth Mudstone Fm, Lower Lias, Secondary Undiff	Till, Secondary Undiff	1	5		Limited monitoring points and poor aquifer
Hemswell	Lincs	1669m	Oil ~1390 to 1410 m 1530 m and 1570 m. Gas shows throughout Coal Measures and Millstone Grit.	Lincolnshire Limestone Fm, Inferior Oolite Group. Principal	None	1	7	Potential but few close mpts Potential but poor near-surface aquifer conditions?	Appears good; gw thought to flow east where there appear to be a good number of wells Principal aquifer, monitoring points along the flow path.
Kelham Hills	Notts	768m	Oil 458m, 465 m, 476 m	Mercia Mudstone Group, Secondary B	None	21	70	Secondary B bedrock	Poor aquifer
Lomer	Hants		Oil shows from 1360 m to 1390 m. Intermittent gas shows, 872 m to end	Seaford Chalk (White Chalk Subgroup), Principal	None	3	10	Appears very good	Principal aquifer, plenty of monitoring points. In a similar area as licensed oil fields.
Torksey	Lincs	1427m	1360-1430 m 0.09 m3/day Gas 1410 – 1430 m 0.23 m3/day Gas and a trace of oil	Scunthorpe Mudstone Fm, Lower Lias, Secondary A	Holme Pierrepont Sand and Gravel Member. Secondary A	2	4		Well penetrates the Lower Lias, all monitoring points are in the SSG to the west.

 Suitable
 Has potential
 Others are preferable
 Not suitable

The criteria specified in Table 1 inform the selection of sites, as demonstrated in Table 2. For example Godley Bridge, Ralph Cross and Beckering were ruled out because of insufficient monitoring points, while Twyford and Baxters Copse were not chosen because the bedrock was unproductive. Formby had been a site of interest but was ruled out at this stage because the system was considered to be too complicated: it was thought that shallow oil seeps/peat could produce gas and confuse the monitoring results.

Ashdown and Everton were selected as the most suitable gas fields, while Hemswell and Lomer were considered the most suitable oil fields for further study. Once this decision had been made, however, concerns were raised about the Everton gas field. Although there were potential sampling points in the unconfined Sherwood Sandstone around Everton, the groundwater flow direction is towards the east, where it is confined by the Mercia Mudstone, and where there are limited groundwater abstractions downgradient of the abandoned well. Nooks Farm was selected as an alternative gas field. This is a large gas field with a large number of potential sampling points. The wells are currently being reinstated and put back into production, which presents a potential complication. Nonetheless, it was agreed that this should not preclude selection of the site and Nooks Farm was therefore selected as the fourth choice.

The aim of this project was to reconnoitre a selection of abandoned wells in different environmental settings to identify any impact on groundwater quality that is being caused by the well completions. As such, the selection of two gas and two oil fields was seen as a suitable way to assess the potential impacts of different types of HC fields and all four study areas are in locations underlain by different aquifers (Chalk, Millstone Grit, Sherwood Sandstone and Wealden Group) for comparison.

2 Fieldwork campaigns

2.1 LOGISTICS

The first round of sampling was planned to take place during September 2016, with subsequent sampling rounds due to take place at quarterly intervals. The aim was to secure ten sampling sites in each study area, and revisit these in order to obtain time-series data throughout a year. Potential groundwater sampling sites were identified using the EA monitoring network (which includes the Groundwater Quality Monitoring Network and Level Network), the EA National Abstraction Licence Database and the BGS Wellmaster database. Boreholes were identified as being of primary importance, with springs secondary due to additional complications with sampling for dissolved gases. Permissions letters were sent out to ca. 25 landowners in each area (100 in total). Discussions were also held with Alkane, the company currently operating at the Nooks Farm HC sites.

During this first fieldwork campaign, a total of 20 samples were collected; six samples were from Hemswell, five from Nooks Farm, seven from Lomer and two from Ashdown. These were lower numbers than had been anticipated, but were due to difficulties finding suitable boreholes to sample.

The second round of sampling took place during January 2017. Effort was made to find additional sites within each area. A total of 11 new groundwater sites were sampled. However, four could not be resampled, meaning that only 27 samples were collected across the four areas.

The challenges finding suitable sites were slightly different in each of the study areas, which will be discussed in more detail below.

2.2 FIELD AREA DETAILS

2.2.1 Nooks Farm

Nooks Farm is a large gas field in Staffordshire, underlain by the Carboniferous Millstone Grit Group and the Coal Measures (Figure 2). The Millstone Grit is classed as a Secondary A aquifer, with groundwater flow dominated by fractures. The location of the field and abandoned wells are shown in Figure 2, along with the UK Petroleum Exploration and Development Licences (PED Licences). There were a number of potential sampling sites within a 5 km buffer. Figure 3 shows these sites along with buffer zones at 1, 2, and 5 km around the Nooks Farm site.

Five samples were collected from this area during the September 2016 fieldwork, but 15 additional sites were visited as part of the visit. Many locations in the BGS Wellmaster groundwater database are springs, which were not sampled as part of this first round. Eleven sites were sampled during the second round of sampling. These included wells, springs, and a sample taken from a storage tank because of the lack of more suitable sites. The locations of these sites are shown in Figure 4.

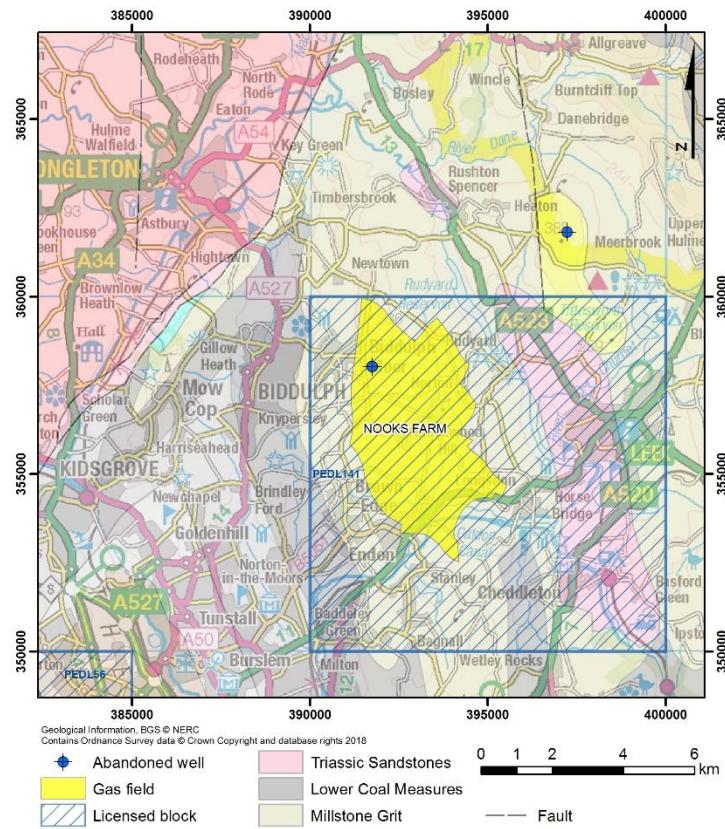


Figure 2. Geology, licensed areas and abandoned wells in the Nooks Farm study area.

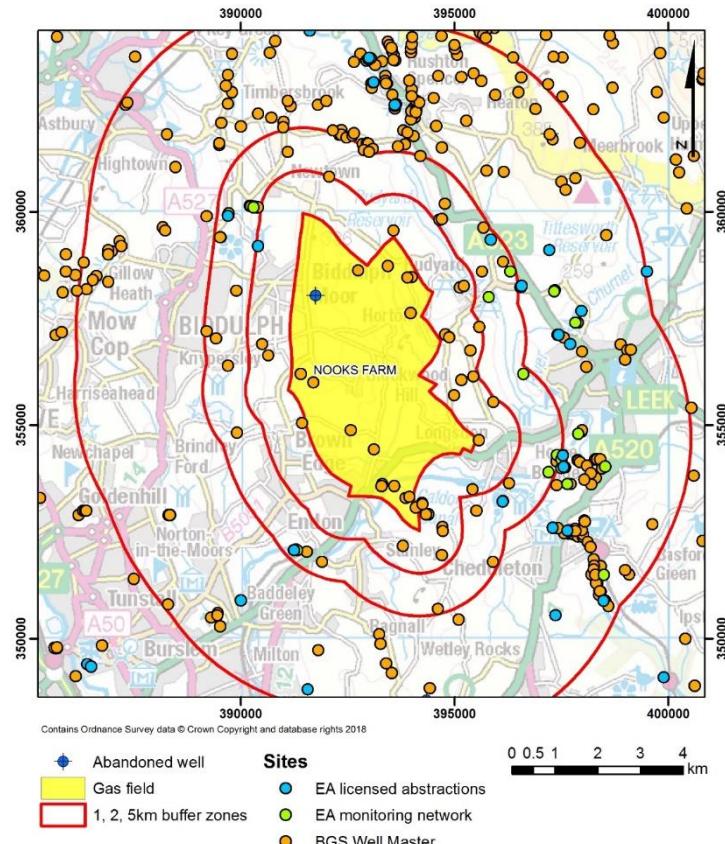


Figure 3. Potential sampling sites around Nooks Farm.

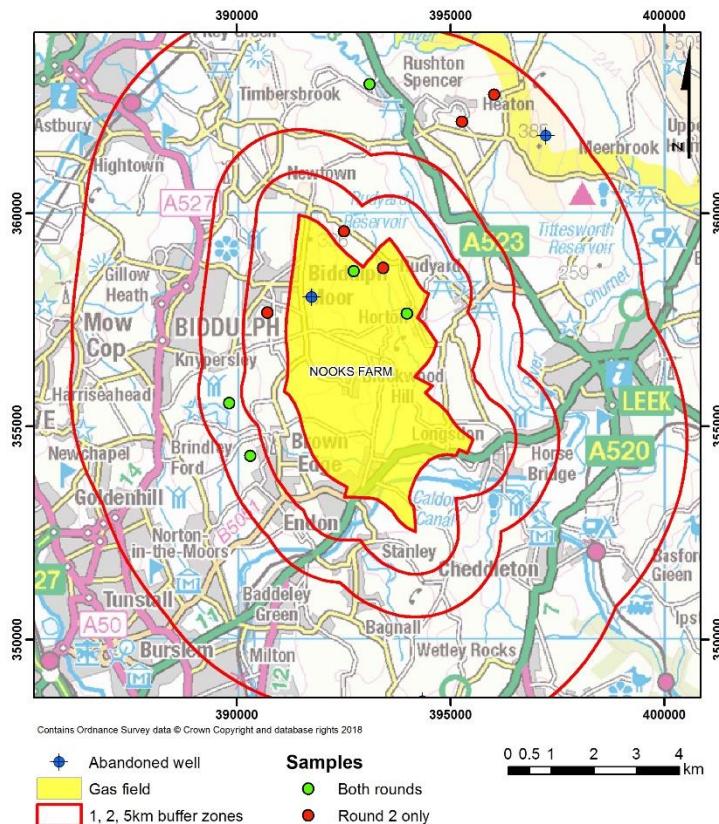


Figure 4. Sites sampled around Nooks Farm.

2.2.2 Ashdown

Ashdown is a small gas field in East Sussex, underlain by the Cretaceous Ashdown Formation, which is part of the Wealdon Group. The Wealdon Group is classified as a Secondary A aquifer. This aquifer is faulted and complex, with discontinuous layers. No current PED Licence is present in the area (Figure 5). The potential sample sites are shown in Figure 6 along with the 1, 2, and 5 km buffer zones around the Ashdown gas field.

Two samples were collected from this area during the September 2016 fieldwork, but a total of 17 sites was visited. Obtaining sample sites proved difficult as many boreholes had been built on or sealed; some sites were springs. During the second round of sampling (January 2017), three new sites were sampled. However, one of the sites from the first round could not be repeated as the flow from the borehole was intermittent. This meant a total of four samples was taken on the second sampling round. A further five sites were investigated but were considered unsuitable for reasons including broken pumps, disuse, and springs without visible upwellings. The locations of the sites sampled are shown in Figure 7.

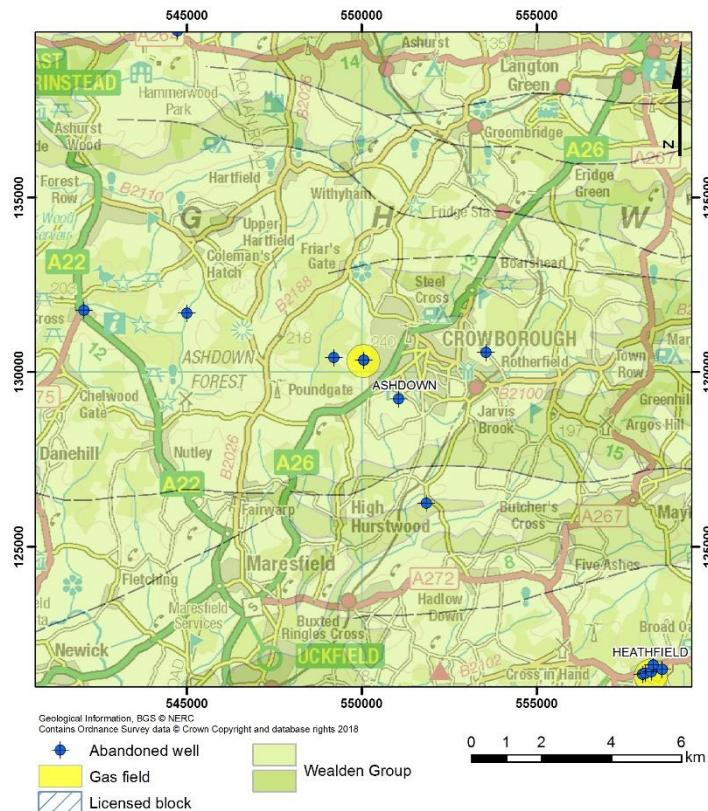


Figure 5. Geology and abandoned wells in the Ashdown study area.

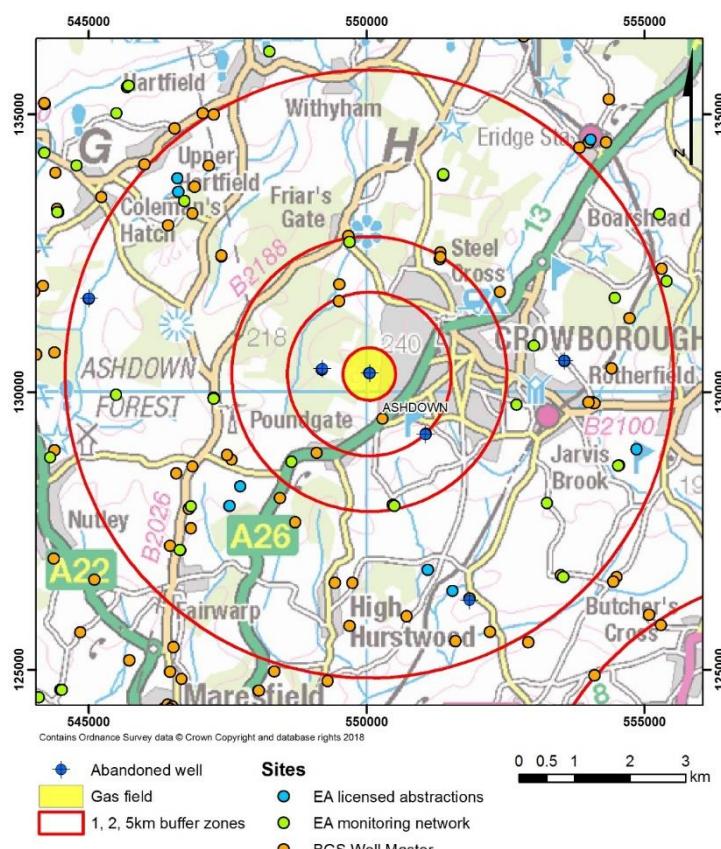


Figure 6. Potential sampling sites around the Ashdown study area.

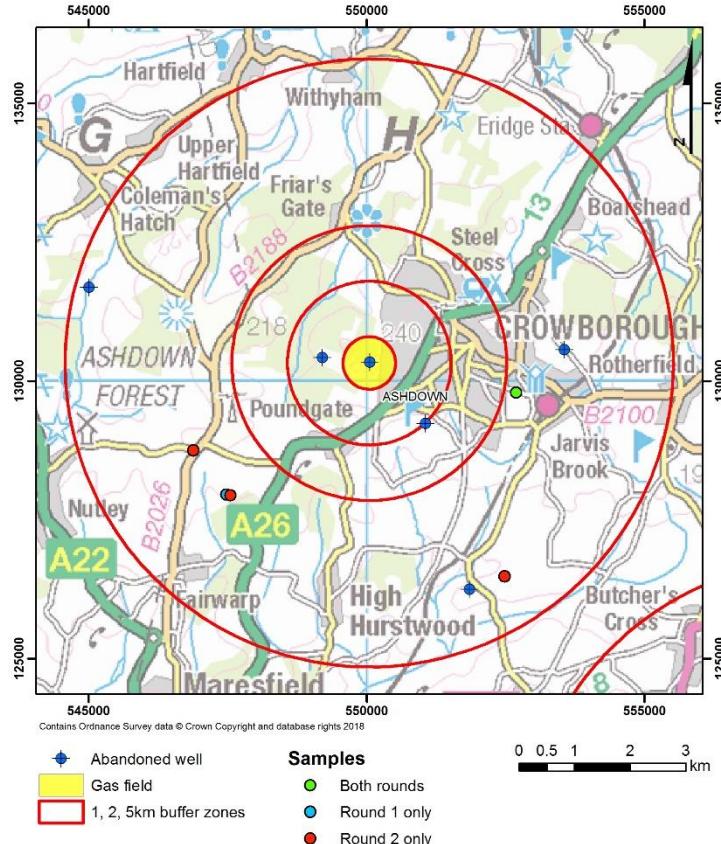


Figure 7. Sites sampled around Ashdown

2.2.3 Hemswell

Hemswell is a small oil field in Lincolnshire, underlain by the Lincolnshire Limestone Formation, which is part of the Jurassic Inferior Oolite Group and designated as a Principal aquifer (Figure 8). The field is in a current PED Licensed area and there are an additional four HC fields in close proximity. Groundwater flow is eastwards and dominated by fracture flow; the Lincolnshire Limestone is confined by the Lias Group. The potential sample sites are presented in Figure 9. While there are many potential sites within the 5 km buffer zone, they are mostly towards the east.

Six samples were collected from this area during the September 2016 fieldwork, but 25 sites were visited. Many locations in the Wellmaster database had been capped or abandoned so were not available for sampling. During the second sampling round (January 2017) four samples were collected. Two of the sites visited previously could not be sampled because of lower groundwater levels. The locations of sample sites are shown in Figure 10.

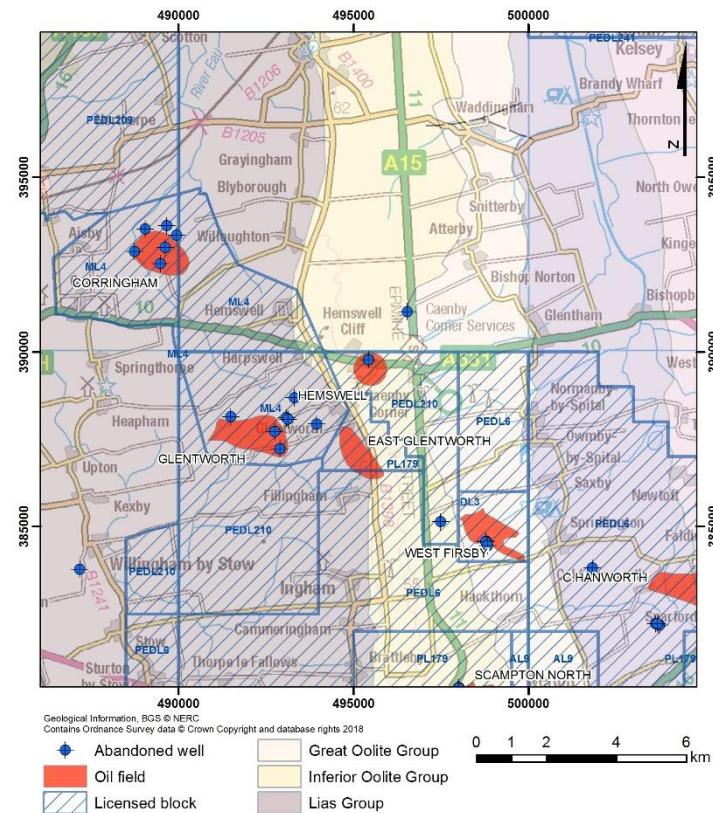


Figure 8. Geology, licensed areas and abandoned wells in the Hemswell study area

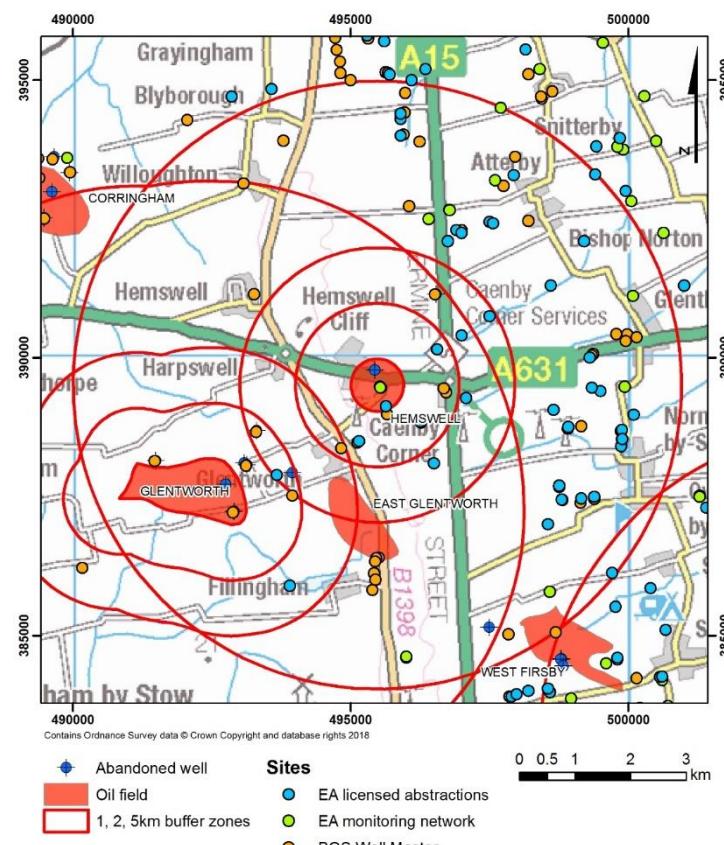


Figure 9. Potential sampling sites around the Hemswell study area

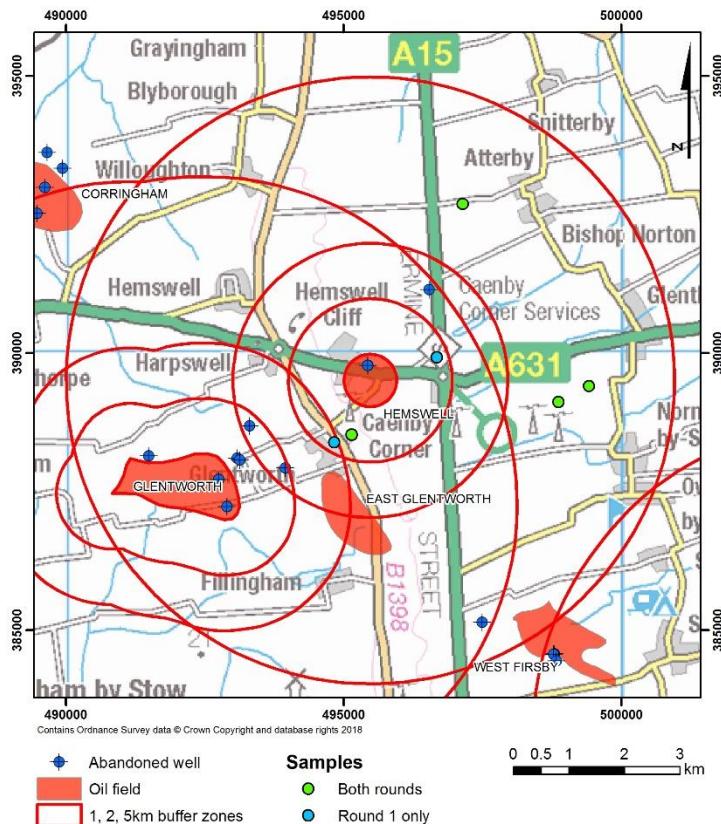


Figure 10. Sites sampled around Hemswell

2.2.4 Lomer

Lomer is a small oil field in Hampshire, underlain by the Seaford Chalk, which is part of the Chalk Group, a Principal aquifer. The field is located within 10 km of a currently producing oil field, but is not itself in a PED Licence area. Groundwater flow is predominately through fractures in the complex structure of the Hampshire Basin (Figure 11). Figure 12 shows the potential sample sites within a 5 km buffer zone.

Seven samples were collected from this area during the September 2016 fieldwork, although 22 sites were visited. A number of boreholes were not suitable for sampling due to water levels being below 50 m below ground level, which is outside the capability of the submersible pumps used by the field teams. Others were deemed unsuitable because of inline pressure vessels and/or water-treatment apparatus. During the second round of fieldwork (January 2017) two new sites were sampled. However one of the original sites could not be sampled. A total of 8 sites were sampled on round 2. All the sample sites are presented in Figure 13. An additional six sites were visited but deemed unsuitable for reasons including lack of landowner permission, landowners not knowing borehole locations, and the presence of storage tanks.

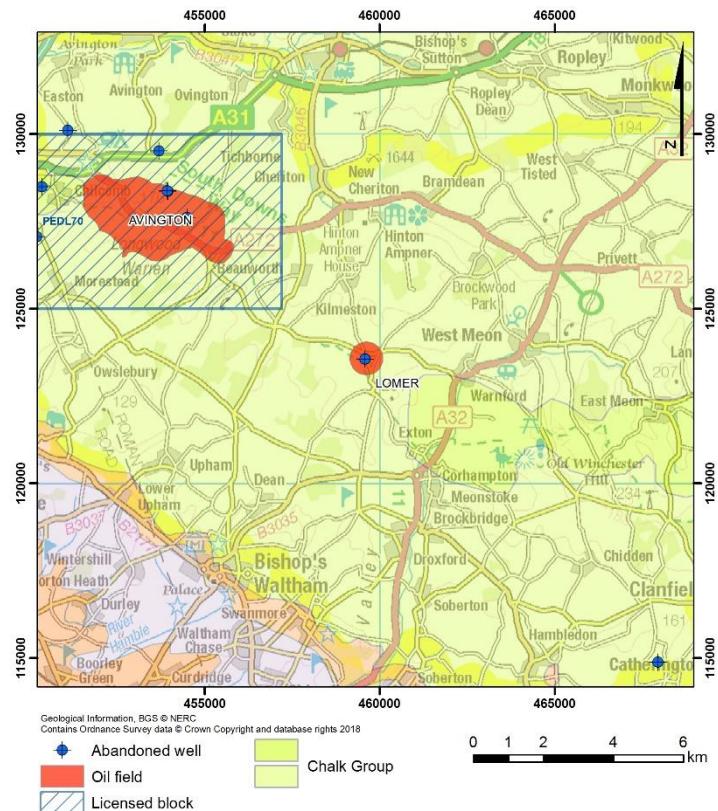


Figure 11. Geology, licensed areas and abandoned wells in the Lomer study area.

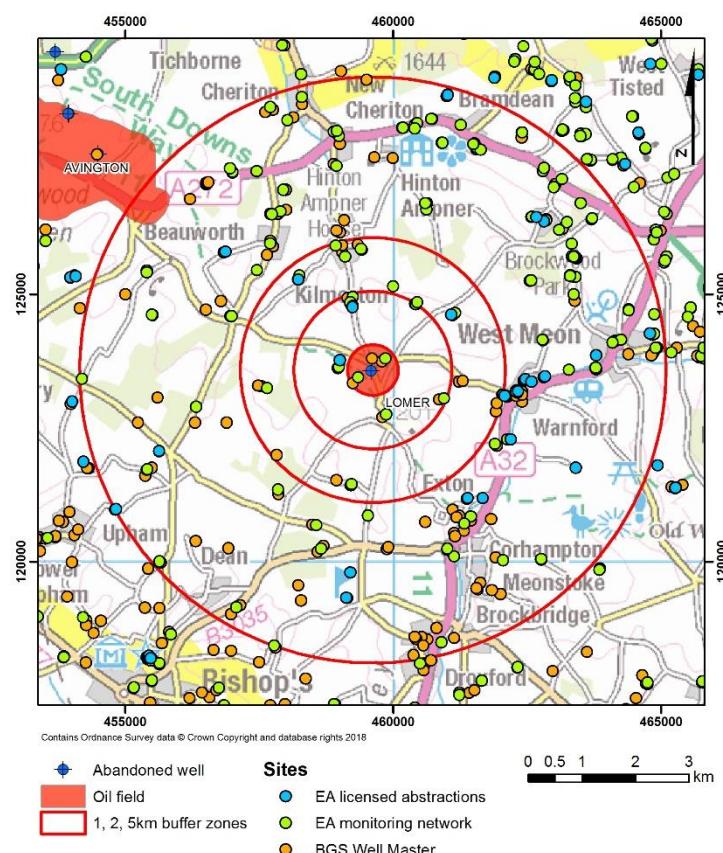


Figure 12. Potential sampling sites around the Lomer study area.

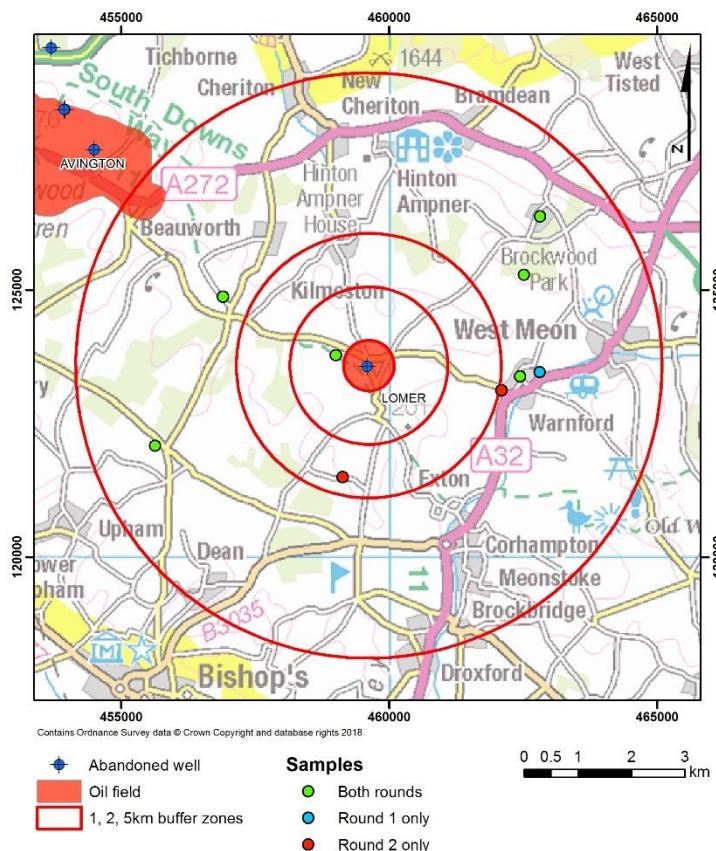


Figure 13. Sites sampled around Lomer

2.3 SAMPLING AND ANALYSIS

A range of samples were taken for inorganic and organic chemical analysis, and the analysis of dissolved gases. The suite analysed was specific to each site, but the full suite is listed in Table 3. The methods used to take the samples are described below.

Efforts were made to sample the groundwater from pumped boreholes where possible. It quickly became apparent that in order to obtain more sample sites, compromises would have to be made. Samples have been taken from springs and in a few cases downstream from storage tanks. These are not ideal samples as dissolved gases and volatile compounds can escape, physico-chemical parameters can change, and solutes can precipitate from solution.

At each site, measurements were made of temperature, specific electrical conductance (SEC), alkalinity (by titration against H_2SO_4), pH, dissolved oxygen (DO), and redox potential (Eh). Where possible, the latter three parameters were measured in a flow cell in order to prevent contact with the atmosphere and retain anaerobic conditions where relevant. Readings were taken until the parameters stabilised and then sampling took place. Where the use of a flow cell was not possible, parameters were measured rapidly in a bucket and sampling condition was recorded.

At each site, groundwater samples were taken for laboratory analysis. Samples for major- and trace-element analysis were collected in pre-rinsed polyethylene bottles and filtered to $<0.2 \mu\text{m}$. Samples required for cation analysis were acidified to 1% (v/v) HNO_3 and 0.5% (v/v) HCl to prevent metal precipitation and minimise sorption to container walls.

Samples for dissolved organic carbon (DOC) analysis were filtered through a $0.45 \mu\text{m}$ silver-impregnated filter and collected in a glass vial pre-cleaned in chromic acid. Samples for various organic compounds (Total petroleum hydrocarbons: TPH CWG, VOC, SVOC, PAH, and others by gas and liquid chromatography mass spectrometry: GC-MS and LC-MS) were collected as unfiltered water in a variety of pre-rinsed glass bottles and vials.

Table 3. Sample analysis suite

Inorganic	Organic
Inductively-coupled plasma mass spectrometry (ICP-MS)	Non-purgeable organic carbon (NPOC)
Ion chromatography (IC)	Total petroleum hydrocarbons (TPH) (CWG)
Wellhead parameters (pH, electrical conductance, dissolved oxygen, redox potential, temperature)	Semi-volatile organic compounds (SVOCs)
	Volatile organic compounds (VOCs)
	Polyaromatic hydrocarbons (PAHs)
	Gas chromatography mass spectrometry (GC-MS)
	Liquid chromatography mass spectrometry (LC-MS)
	Dissolved gases

Samples for dissolved gases could only be collected where pumped water could be sampled before contact with the atmosphere. Where possible, a gas-tight hose was attached directly to the borehole wellhead for an installed pump, or directly to the outlet of a portable pump. If the hose could not be attached to the wellhead, the nearest access point (prior to storage tanks, treatments or pressure vessels) was used. The samples were collected at pump pressure into double-valved steel cylinders of known volume.

Analysis of inorganic samples was carried out at the BGS laboratories in Keyworth, major- and trace-elements by inductively-coupled plasma mass spectrometry (ICP-MS), and anions by ion chromatography (IC). Dissolved organic carbon was also analysed at the BGS as non-purgeable organic carbon (NPOC) by TOC analyser. Dissolved gas samples were analysed at the BGS Wallingford laboratory by gas chromatography using a headspace method.

The remaining organic samples were sent to a variety of external laboratories for analysis. Samples for TPH (CWG) were sent to Alcontrol after the first sampling round, and Jones' Laboratories after the second round. The SVOC samples were analysed at Jones Laboratories for both rounds. The VOC samples, GC-MS and LC-MS samples were analysed at the EA's National Laboratory Service (NLS).

3 Summary results

3.1 ORGANIC CHEMISTRY

The organic-chemistry results from the first round of sampling (September 2016) is summarised in Table 4 to Table 11. These consist of a table identifying the number of samples within each area that have positive detects, and a second table for each area summarising the types of compounds present in the GC-MS and LC-MS screens.

The organic-chemistry results from the second round of sampling (January 2017) is summarised in Table 12 to Table 19. The format of the tables is the same as for the first round.

3.1.1 Round 1 summary

Table 4. Round 1 organic chemistry summary for Nooks Farm

Type	Number of samples	Number of samples with positive detects	notes
TPH CWG	5	0	-
SVOC	4	0	-
PAH	5	0	-
VOC	4	0	-
GC-MS	5	3	
LC-MS	5	3	See Table 5

Table 5. Round 1 GC-MS and LC-MS summary for Nooks Farm

Sample ID	Number GC-MS compounds present	Summary	Number LC-MS compounds present	Summary
AW01-07	0	N/A	0	N/A
AW01-08	7	Ketone, plasticiser, herbicide	2	Herbicide, analgesic
AW01-09	1	Insecticide	0	N/A
AW01-10	5	PAHs, UV filter	8	Pesticide, herbicide, veterinary drug, artificial sweetener
AW01-11	0	N/A	3	Pesticide, herbicide, insecticide

Table 6. Round 1 organic chemistry summary for Ashdown

Type	Number of samples	Number of samples with positive detects	notes
TPH CWG	2	0	-
SVOC	2	0	-
PAH	2	0	-
VOC	2	1	0.55 µg/L Chloroform
GC-MS	2	2	
LC-MS	2	2	See Table 7

Table 7. Round 1 GC-MS and LC-MS summary for Ashdown

Sample ID	Number GC-MS compounds present	Summary	Number LC-MS compounds present	Summary
AW01-28	2	Not present in database	1	Pesticide
AW01-29	4	PAHs	21	Pesticide/ herbicide and metabolite, veterinary drug, insecticide, fungicide, artificial sweetener, flame retardant, surfactant

Table 8. Round 1 organic chemistry summary for Hemswell

Type	Number of samples	Number of samples with positive detects	notes
TPH CWG	6	0	-
SVOC	5	0	-
PAH	6	0	-
VOC	6	1	0.32 µg/L cis-1,2-Dichloroethylene
GC-MS	6	5	
LC-MS	6	6	See Table 9

Table 9. Round 1 GC-MS and LC-MS summary for Hemswell

Sample ID	Number GC-MS compounds present	Summary	Number LC-MS compounds present	Summary
AW01-01	5	Ketone, pesticide related, plasticisers, additives for plastics	19	Pesticides, herbicides, fungicides, flame retardant, veterinary drugs, analgesic, surfactant
AW01-02	5	Ketone, plasticiser, insecticide	2	surfactant, pesticide/fungicide
AW01-03	0	N/A	10	pesticides, herbicides, pharmaceuticals, surfactants
AW01-04	10	Ketone, surfactant, additive for plastics, herbicide, plasticiser, PAHs	22	pesticides, herbicides, fungicides, veterinary drugs, artificial sweetener, analgesic
AW01-05	3	Fungicides, herbicides	15	pesticides, herbicides, veterinary drugs, fungicides, artificial sweeteners, surfactants
AW01-06	5	Ketone, plasticiser,	4	pesticide, herbicide, analgesic, surfactant

Table 10. Round 1 organic chemistry summary for Lomer

Type	Number of samples	Number of samples with positive detects	notes
TPH CWG	5	0	-
SVOC	4	1	7.3 µg/L Benzo(a)anthracene, 8.5 µg/L Chrysene, 23 µg/L Benzo(bk)fluoranthene, 6 µg/L Benzo(a)pyrene, 2 µg/L Indeno(123cd)pyrene, 1.8 µg/L Dibenzo(ah)anthracene, 3.1 µg/L Benzo(ghi)perylene
PAH	5	0	-
VOC	4	1	0.94 µg/L Carbon Disulphide
GC-MS	5	2	See Table 11
LC-MS	5	5	

Table 11. Round 1 GC-MS and LC-MS summary for Lomer

Sample ID	Number GC-MS compounds present	Summary	Number LC-MS compounds present	Summary
AW01-22	7	Pharmaceuticals, compound used in vulcanisation process, insecticide	2	Pesticide/herbicide, veterinary drug
AW01-23	0	N/A	9	Pesticide/-herbicide and metabolite, veterinary drug, insecticide
AW01-24	0	N/A	20	Pesticide/herbicide and metabolite, veterinary drugs
AW01-26	0	N/A	19	Pesticide/herbicide and metabolite, veterinary drugs, insecticide
AW01-27	2	Herbicide and metabolite	16	Pesticide/ herbicide and metabolite, veterinary drugs, insecticide

There have been few detections of organic compounds in the groundwater at any of the sites sampled during the first round of sampling, and where they have been detected they are at concentrations very close to detection limits. Limited conclusions can be made about the impact of hydrocarbons on groundwater quality.

There were no detects in any samples of TPH. Only one sample in round one contained any SVOCs. This was taken from the Lomer area, and contained 7 SVOCs at concentrations up to 23 µg/L (see Table 10). At three sites, VOCs were detected. Chloroform (0.55 µg/L) was detected in one of the Ashdown sites, cis-1,2-dichloroethylene (0.32 µg/L) in one of the Hemswell sites, and carbon disulphide (0.94 µg/L) in one of the Lomer sites.

The GC-MS/LC-MS chromatograms for all the study areas show that the groundwater has been impacted by contaminants including pesticides, herbicides, veterinary and equine drugs, surfactants, and flame retardants, none of which are unusual in groundwater. As part of these analyses, PAHs were detected at one site in each of the Nooks Farm, Ashdown, and Hemswell study areas. However they were not apparent in the specific PAH analyses as they were all <0.01 µg/L, which is the method reporting value.

3.1.2 Round 2 summary

Table 12. Round 2 organic chemistry summary for Nooks Farm

Type	Number of samples	Number of samples with positive detects	notes
TPH CWG	11	0	-
SVOC	11	0	-
PAH	11	0	-
VOC	11	0	-
GC-MS	11	8	
LC-MS	11	9	See Table 13

Table 13. Round 2 GC-MS and LC-MS summary for Nooks Farm

Sample ID	Number GC-MS compounds present	Summary	Number LC-MS compounds present	Summary
AW02-05	9	Dye, pesticide, antifungal preservative, additive for plastics, plasticiser	3	Pesticide, veterinary drugs, analgesic
AW02-06	0	N/A	0	N/A
AW02-07	3	Polymer monomer	2	Pesticide, insecticide
AW02-08	0	N/A	3	Pesticide, herbicide
AW02-09	2	Crosslinking agent	1	Pesticide, insecticide
AW02-10	0	N/A	2	Pesticide, veterinary drugs
AW02-11	1	Not present in database	3	Pesticide, herbicide, veterinary drugs, insecticide
AW02-12	1	Contact allergen	1	Artificial sweeteners
AW02-13	3	Contact allergen, DEET	8	Pesticide/ herbicide and metabolites, veterinary drugs, artificial sweeteners, analgesic
AW02-14	1	Pharmaceutical, fragrance additive	0	N/A
AW02-15	2	Plasticiser, herbicide	4	Pesticide/ herbicide and metabolites

Table 14. Round 2 organic chemistry summary for Ashdown

Type	Number of samples	Number of samples with positive detects	notes
TPH CWG	3	0	-
SVOC	3	0	-
PAH	4	0	-
VOC	3	1	0.41 µg/L Chloroform
GC-MS	4	3	
LC-MS	4	4	See Table 15

Table 15. Round 2 GC-MS and LC-MS summary for Ashdown

Sample ID	Number GC-MS compounds present	Summary	Number LC-MS compounds present	Summary
AW02-36	4	Flavouring, additive for plastics, DEET, fixative, plasticiser	2	Surfactants
AW02-37	0	N/A	21	Herbicide/pesticide and metabolites, pesticides, veterinary drugs, insecticide, antibiotic, analgesic, surfactant, artificial sweetener
AW02-38	6	Acid, herbicide	11	Veterinary drugs, herbicide/pesticide and metabolites, fungicide, surfactant
AW02-39	10	Intermediate of dye and pesticide, additive for plastics, antioxidant additive, used in insecticide and industrial uses, fungicide, fixative, plasticiser, PAHs	3	Pesticide, acaricide, insecticide, surfactant

Table 16. Round 2 organic chemistry summary for Hemswell

Type	Number of samples	Number of samples with positive detects	notes
TPH CWG	4	0	-
SVOC	4	0	-
PAH	4	0	
VOC	4	2	0.12 µg/L MTBE, 0.29 µg/L cis-1,2-Dichloroethylene
GC-MS	4	4	
LC-MS	4	4	See Table 17

Table 17. Round 2 GC-MS and LC-MS summary for Hemswell

Sample ID	Number GC-MS compounds present	Summary	Number LC-MS compounds present	Summary
AW02-01	8	Molluscicide, dye and pesticides, crosslinking agents, plasticiser	17	Pesticide, fungicide, herbicide, veterinary drugs, analgesic, artificial sweetener
AW02-02	1		12	Pesticide, herbicide, veterinary drugs, analgesic, surfactant, artificial sweeteners
AW02-03	8	Ketone, dye and pesticides, plasticiser, insecticide	10	Pesticide, herbicide, veterinary drugs, analgesic, surfactant, artificial sweeteners
AW02-04	6	Dye and pesticides, plasticiser	22	Pesticide/ herbicide and metabolite, fungicide, veterinary dugs, insecticide, surfactant

Table 18. Round 2 organic chemistry summary for Lomer

Type	Number of samples	Number of samples with positive detects	notes
TPH CWG	7	0	-
SVOC	7	0	-
PAH	7	0	
VOC	7	2	0.12 µg/L Bromodichloromethane 0.14 µg/L Carbon tetrachloride 1.04 µg/L Chloroform 0.15 µg/L Chloroform
GC-MS	7	6	
LC-MS	7	6	See Table 19

Table 19. Round 2 GC-MS and LC-MS summary for Lomer

Sample ID	Number GC-MS compounds present	Summary	Number LC-MS compounds present	Summary
AW02-02S	5	Flavouring, fixative, herbicide and metabolite	13	Herbicide/pesticide and metabolite, equine drug, veterinary drug
AW02-03S	3	Flavouring, plasticiser	12	Herbicide/pesticide and metabolite, veterinary drug
AW02-04S	10	Volatile solvent, additives for plastics, used in fragrance and pharmaceuticals, antioxidants, DEET, fixative, plasticiser, used in manufacturer of polyurethane	6	Herbicide/pesticide and metabolite, veterinary drug, insecticide
AW02-05S	1	Not present in database	0	N/A
AW02-06S	0	N/A	8	Herbicide/pesticide and metabolite, veterinary drug, fungicide
AW02-07S	2	Antioxidant, used in manufacture of epoxy resins and polycarbonates	21	Anticonvulsant, herbicide/pesticide and metabolite, veterinary drug, fungicide, analgesic, artificial sweetener
AW02-08S	2	Additives for plastics, plasticiser	22	Herbicide/pesticide and metabolite, fungicide, veterinary drugs, antibiotic, analgesic, insecticide, surfactant, artificial sweetener

Like the first sampling round there have been few detections of organic compounds in the groundwater at any of the sites sampled during the second round of sampling, again, only occurring at low concentrations. Detects do not show any distinct trends, and there are too few sampling rounds to draw any time-series conclusions.

There were no detects in any samples of TPH (CWG) or SVOCs. VOCs were detected at five sites sampled in the second sampling round. Like the previous round chloroform was detected at one Ashdown site, this time at 0.41 µg/L. At a Hemswell site cis-1,2-dichloroethylene was detected again (0.29 µg/L), and additionally in round two another Hemswell site contained 0.12 µg/L MTBE. Two of the Lomer sites had detectable VOCs, one of which contained 0.15 µg/L chloroform, while the other contained 1.04 µg/L chloroform, 0.12 µg/L bromodichloromethane, and 0.14 µg/L carbon tetrachloride.

Similar to round one, the GC-MS/LC-MS chromatograms for all the study areas show that most of the groundwater samples contain contaminants such as pesticides, herbicides, fungicides, veterinary and equine drugs, surfactants, plasticisers and artificial sweeteners. During both sampling rounds

pesticides (herbicides, fungicides, insecticides) dominated the numbers of compounds present. This time, no PAHs were detected in the analyses.

3.2 INORGANIC CHEMISTRY

Summary tables of inorganic data are presented in Table 21 and Table 22. There are insufficient data available to make any time-series conclusions.

A Piper diagram summarises the major-ion chemistry of each of the four study areas (Figure 14). The Lomer samples are Ca-HCO₃ type, and contain little variation. This distribution is generally expected in groundwaters hosted by the Chalk, which is predominantly CaCO₃. The Hemswell samples are also generally Ca-HCO₃ type, but there is more variation between samples in this area, as Ca and HCO₃ do not dominate. The limestones and subordinate sandstones and mudstones that make up the Inferior Oolite Group contain more variation owing to the presence of sandy beds and are in parts ferruginous. The Nooks Farm samples are the most varied, having no dominant type. The linear nature of the Nooks Farm compositions in the diagram suggests that the samples may represent mixing between two end members. There is a large variation in the Ashdown samples too, but as there are so few samples it is difficult to comment further on these waters.

3.3 DISSOLVED GASES

Methane (CH₄) samples were collected from all the sites suitable for the analysis. There are insufficient samples to give meaningful summary statistics, so a table of number of samples collected and ranges is presented (Table 20). Although CH₄ concentration is elevated in three samples (407, 237, 182 µg/L), there is insufficient CH₄ present to allow for stable C/H isotopic analysis. At the time of writing, a minimum concentration of around 1 mg/L CH₄ is required for investigation of δ¹³C in a commercial laboratory. It is interesting to note that there were no elevated concentrations in the samples collected during the second round of sampling.

Table 20. Summary of CH₄ data

	Number of samples Round 1	Range round 1 (µg/L)	Number of samples Round 2	Range round 2 (µg/L)
Nooks Farm	2	0.5-182	6	<0.5-7.6
Ashdown	1	237	2	0.5-0.6
Hemswell	5	0.8-407	3	0.6-3.9
Lomer	3	0.5-70.9	5	<0.5-2.4

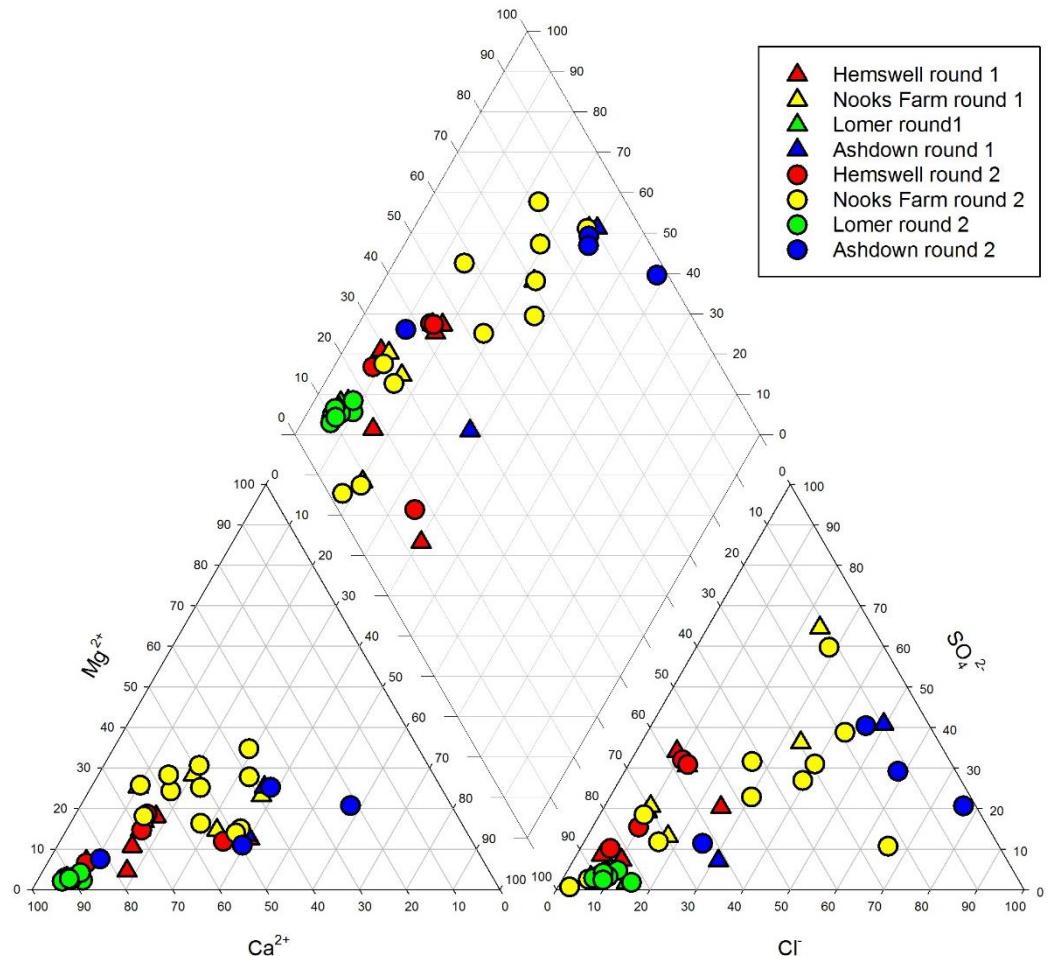


Figure 14. Piper diagram showing major-ion chemistry of the four study areas

Table 21. Round 1 inorganic chemistry selected results

Sample Code	Area	T °C	pH	HCO ₃ mg/L	SEC μS/cm	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cl mg/L	SO ₄ mg/L	NO ₃ mg/L	Br ⁻ mg/L	NO ₂ ⁻ mg/L	F mg/L	NPOC mg/L	Si mg/L	Ba μg/L	Sr μg/L	Mn μg/L	Fe μg/L	Al μg/L	Cu μg/L	Zn μg/L	As μg/L	U μg/L
AW01-0007	Nooks Farm	10.5	6.7	159	426	54.5	8.22	12.1	3.85	23.2	23.7	21.4	<0.05	<0.025	<0.025	0.93	4.92	143	104	0.6	3	<1	5.2	6.6	0.63	0.303
AW01-0008	Nooks Farm	10.2	5.11	7	157	10.0	3.58	5.6	9.03	8.35	30.3	16.2	0.037	<0.005	0.066	4.94	4.97	43.7	38.4	62.3	86	62	1.4	17.9	0.07	0.007
AW01-0009	Nooks Farm	12.4	6.86	309	517	55.8	18.7	22.4	4.91	11.7	8.29	<0.3	<0.1	<0.05	0.241	1.39	8.56	616	295	280	1590	<1	2.5	3.6	0.05	0.049
AW01-0010	Nooks Farm	10.0	5.71	26	191	18.1	3.03	10.6	3.36	17.6	25.4	17.5	0.054	<0.005	0.067	1.83	2.48	48.2	56.0	10.4	2	37	1.3	6.3	0.18	0.064
AW01-0011	Nooks Farm	10.1	6.56	123	316	41.7	9.90	6.3	1.92	10.2	28.5	20.3	<0.05	<0.025	0.054	<0.5	5.46	130	92.0	4.3	1	2	<0.4	2.2	0.20	0.116
AW01-0028	Ashdown	13.7	6.06	64	179	7.3	2.97	7.7	0.88	18.8	5.81	<0.2	0.056	<0.025	0.108	2.88	4.44	27.7	36.7	880	17100	<1	1.3	53.5	0.37	<0.005
AW01-0029	Ashdown	12.9	5.49	12	290	21.2	3.67	17.9	3.83	36.0	40.1	23.0	0.099	<0.005	0.012	1.07	2.31	40.0	67.3	36.2	41	35	2.8	19.1	0.14	0.018
AW01-0001	Hemswell	12.4	7.05	392	1021	145	24.7	43.5	2.94	35.3	185	4.03	0.105	<0.05	0.349	5.20	3.66	37.2	1695	29.7	40	<1	0.8	6.8	0.14	1.57
AW01-0002	Hemswell	11.9	7.04	411	771	123	10.9	29.0	3.30	30.2	28.8	<0.3	<0.1	<0.05	0.255	1.50	8.01	20.2	450	25.4	1430	10	0.5	3.6	1.58	0.005
AW01-0003	Hemswell	12.5	7.1	359	953	143	18.3	35.9	2.26	47.2	152	0.467	0.1	<0.05	<0.05	4.62	4.61	31.3	933	9.9	247	<1	0.9	1.9	0.10	1.29
AW01-0004	Hemswell	11	6.75	334	858	150	7.61	15.8	0.95	27.3	71.4	68.4	<0.1	<0.05	<0.05	2.04	3.31	24.8	215	1.3	5	<1	0.7	2.7	0.13	0.426
AW01-0005	Hemswell	11.1	6.97	345	1054	168	6.02	41.1	6.44	92.2	101	44.0	<0.1	<0.05	<0.05	1.07	4.62	31.9	238	1.5	5	<1	2.4	6.1	0.10	0.948
AW01-0006	Hemswell	10.3	7.12	465	806	80.2	12.8	76.9	2.72	17.4	36.2	0.663	<0.1	<0.05	<0.05	1.68	7.98	15.7	574	18.0	760	35	<0.4	2.7	0.19	0.005
AW01-0021	Lomer	12.4	7.12	277	554	99.3	1.71	8.6	0.51	18.3	11.8	22.7	<0.05	<0.025	<0.025	1.13	5.17	9.8	209	0.5	4	1	49.1	15.6	0.22	0.195
AW01-0022	Lomer	15.9	7.14	260	676	111	1.72	9.5	1.27	25.6	3.95	90.1	<0.1	<0.05	<0.05	0.81	5.01	11.5	265	0.5	2	1	7.2	34.6	0.25	0.368
AW01-0023	Lomer	12.5	7.05	372	765	137	1.85	8.5	2.37	23.3	16.6	57.8	<0.1	<0.05	<0.05	1.44	6.34	18.1	210	0.7	8	2	5.1	33.8	0.18	0.161
AW01-0024	Lomer	12.0	7.01	311	605	106	2.03	7.5	0.90	17.1	11.3	32.2	<0.05	<0.025	<0.025	1.56	4.97	13.3	174	0.4	2	<1	2.7	8.0	0.16	0.159
AW01-0025	Lomer	n/a	7.64	279	n/a	98.6	1.64	7.2	0.90	16.6	10.9	26.3	0.055	0.009	0.052	0.79	4.51	16.2	244	0.2	1	<1	1.9	3.6	0.18	0.194
AW01-0026	Lomer	13.2	7.04	329	620	110	1.94	8.0	0.81	17.3	8.07	25.2	<0.1	<0.05	<0.05	0.56	4.71	14.2	189	1.8	13	3	4.4	21.9	0.13	0.185
AW01-0027	Lomer	10.6	7.01	308	584	105	1.88	6.9	0.75	15.2	7.50	24.0	<0.05	<0.025	<0.025	1.69	5.10	16.8	214	<0.2	<1	<1	1.0	1.9	0.16	0.200

Table 22. Round 2 inorganic chemistry selected results

Sample	Area	T °C	pH	HCO ₃ mg/L	SEC μS/c	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cl mg/L	SO ₄ mg/L	NO ₃ mg/L	Br mg/L	NO ₂ mg/L	F mg/L	NPOC mg/L	Si mg/L	Ba μg/L	Sr μg/L	Mn μg/L	Fe μg/L	Al μg/L	Cu μg/L	Zn μg/L	As μg/L	U μg/L	
AW02-01	Hemswell	10.6	7.05	363	1033	150	25.6	38.3	2.76	40.9	160	14.1	0.120	0.101	0.392	1.79	4.11	35.1	1617	9.8	26	<1	1.4	5.4	0.15	1.576	
AW02-02	Hemswell	10.4	7.07	352	988	154	19.8	39.7	2.43	46.4	152	1.23	0.113	<0.025	0.230	1.58	4.82	32.2	940	9.4	253	<1	1.2	3.4	0.10	1.275	
AW02-03	Hemswell	10.39	7.12	429	837	98.5	13.3	72.4	3.01	19.6	41.1	13.5	0.053	<0.025	0.156	1.05	7.44	17.4	541	18.7	652	15	1.0	2.8	0.20	0.113	
AW02-04	Hemswell	10.7	7.09	339	880	156	7.27	17.0	0.84	26.3	55.0	92.2	0.082	<0.025	0.029	1.49	3.36	23.1	216	0.6	7	<1	0.8	2.0	0.12	0.415	
AW02-05	Nooks Farm	9.9	5.01	5	126	10.1	1.91	5.1	6.55	7.05	20.0	12.7	0.034	<0.005	0.038	1.78	4.34	46.0	29.4	88.1	17	76	2.5	20.2	0.15	0.005	
AW02-06	Nooks Farm	3.8	7.05	299	527	56.7	21.5	24.0	5.30	10.7	6.44	<0.3	<0.1	<0.05	0.279	1.55	9.28	634	305	309	1980	1	9.2	8.1	0.05	0.020	
AW02-07	Nooks Farm	5.1	7.29	393	629	80.0	20.3	22.6	8.45	6.16	1.99	0.16	<0.05	<0.025	0.171	0.57	11.6	890	886	23.3	388	<1	<0.4	4.1	0.04	0.003	
AW02-08	Nooks Farm	6.7	6.05	65	382	39.1	11.8	9.2	4.60	23.2	37.9	51.1	0.054	<0.025	0.028	1.23	4.51	148	104	5.3	6	3	4.1	11.9	0.42	0.056	
AW02-09	Nooks Farm	7.2	5.8	37	315	23.2	13.5	19.5	2.99	59.6	13.1	<0.1	0.066	<0.025	0.122	1.76	9.68	279	118	711	1050	4	1.7	8.1	0.04	0.004	
AW02-10	Nooks Farm	8.5	5.25	15	290	25.1	7.45	11.0	3.56	19.1	23.7	60.1	<0.1	<0.05	0.064	1.26	5.99	59.7	119	409	85	202	1.6	23.9	0.22	0.052	
AW02-11	Nooks Farm	4.7	6.11	49	230	23.1	4.10	12.2	1.77	18.4	18.7	9.79	<0.05	<0.025	0.184	1.58	3.78	123	90.7	654	85	188	7.3	115	0.37	0.026	
AW02-12	Nooks Farm	10.2	6.81	166	448	60.6	9.93	12.9	4.31	21.4	21.3	19.9	<0.05	<0.025	0.062	0.61	5.52	155	117	1.0	6	<1	9.9	3.9	0.74	0.385	
AW02-13	Nooks Farm	9.6	5.89	29	209	18.9	3.23	13.9	3.64	19.8	18.3	15.0	<0.05	<0.025	0.054	1.98	2.45	44.0	56.6	20.7	23	37	2.0	8.2	0.21	0.070	
AW02-14	Nooks Farm	6.4	6.64	127	333	44.3	10.8	6.9	2.12	9.83	25.6	19.2	<0.05	<0.025	0.055	0.94	5.91	130	92.0	2.2	3	2	<0.4	3.9	0.23	0.108	
AW02-15	Nooks Farm	5.3	5.97	45	347	24.9	10.6	21.7	2.92	35.6	37.5	19.6	0.052	<0.025	<0.025	0.48	4.45	57.7	103	323	6	1	1.1	5.5	0.04	0.136	
AW02-01	Lomer		7.24	264	550	104	1.61	11.7	2.30	19.7	11.6	21.3	<0.05	<0.025	0.054	n/a	10.7	18.8	132	1.4	2	<1	17.4	824	0.18	0.368	
AW02-02	Lomer		10.6	7.05	293	544	114	2.08	8.0	0.82	14.3	6.25	22.8	<0.05	<0.025	0.057	1.04	5.53	17.6	226	<0.2	1	<1	11.4	30.2	0.17	0.213
AW02-03	Lomer		10.2	5.98	314	622	124	2.32	8.2	0.75	15.3	9.27	30.2	<0.05	<0.025	0.037	0.62	5.32	15.5	202	<0.2	1	<1	8.7	8.2	0.20	0.191
AW02-04	Lomer		10.9	7.12	276	559	108	1.81	9.6	0.49	17.6	8.00	20.0	<0.05	<0.025	0.046	1.07	5.34	9.3	214	0.3	<1	<1	35.2	21.6	0.19	0.196
AW02-05	Lomer		10.1	6.83	255	730	130	3.71	13.6	0.93	27.3	4.22	104	0.064	<0.025	0.118	0.90	6.35	19.1	641	0.3	2	<1	8.2	5.1	0.41	0.923
AW02-06	Lomer		10.4	6.9	361	778	117	2.31	8.6	1.00	15.4	8.68	26.8	<0.05	<0.025	0.048	0.96	5.39	13.6	184	<0.2	3	<1	4.4	13.7	0.14	0.180
AW02-07	Lomer		11.7	6.93	373	609	154	2.05	9.2	1.91	19.8	13.7	54.6	0.056	<0.025	0.034	1.22	7.07	17.4	225	0.3	1	<1	6.6	7.4	0.17	0.173
AW02-08	Lomer		10.2	6.92	318	634	116	2.06	9.2	0.84	18.5	6.52	25.2	0.055	<0.025	0.036	0.66	5.23	15.8	191	1.0	17	<1	5.3	18.3	0.14	0.196
AW02-36	Ashdown		10.2	4.46	11	221	13.7	5.76	14.5	3.54	29.9	20.2	16.5	0.102	<0.01	0.056	1.46	3.08	47.1	49.3	41.2	2	77	12.4	54.4	0.13	0.018
AW02-37	Ashdown		11.8	5.44	17	289	25.3	3.38	20.8	3.89	32.7	38.9	21.1	0.074	<0.01	0.038	0.91	2.18	33.5	71.5	5.0	6	19	11.8	16.5	0.22	0.019
AW02-38	Ashdown		5.1	6.51	115	373	58.9	3.29	8.4	0.85	27.3	16.4	19.8	0.043	0.221	0.044	1.92	1.45	18.0	112	80.7	72	6	4.5	5.5	0.18	0.194
AW02-39	Ashdown		10.1	4.34	2	195	6.6	3.83	19.7	0.91	34.6	12.6	13.3	0.077	<0.01	0.083	1.39	3.13	46.8	39.9	604	9	369	14.8	85.7	0.32	0.052

NPOC: non-purgeable organic carbon

4 Further reconnaissance

In May 2017, a further reconnaissance was undertaken in order to establish whether other HC well/wellfields could prove to be more appropriate for the Abandoned Wells study. This involved a desk study, followed by visits to potential groundwater sites to assess the logistics of sampling (proximity to HC well, ease of access, suitability of site for representative sampling).

In the first instance, five possible new sites were selected. A desk study was performed to assess whether the sites were suitable for investigation. The sites chosen are presented in Table 23, which shows how many sites were identified from each database within 5 km of each HC field. It should be noted that there is some overlap of BGS WellMaster sites with EA databases ('NALD', Monitoring Network), so this table does not represent a total of unique sites. The WellMaster database includes any borehole reported to BGS where water has been struck. It can therefore include exploratory boreholes drilled during construction projects, sites not deemed suitable for water abstraction, and sites that have been disused. Therefore, the number of sites that is suitable for sampling is often far fewer than the total number of records. While there are fewer sites in the EA databases, these are generally more reliable for identifying suitable sampling sites. However, sometimes an abstraction licence can exist, but the borehole is no longer used, the owners can be unaware of the presence of a borehole, or indeed unwilling to allow sampling. More details for each site are provided below.

Table 23. Desk study summary of potential sites within 5 km of field

Site	Field type	EA NALD Groundwater sources	EA Monitoring Network	BGS WellMaster
Broughton	oil	24	8	156
Calow	gas	5	0	84
Eskdale	gas	10	3	24
Everton	gas	24	30	71
Ironville	gas	2	1	85

For each area, the initial desk study was undertaken in order to select the best potential sites available. Prior to the field reconnaissance, potential sites were checked on maps and aerial photographs to see if they likely still existed. A shortlist of potential sites was produced and during May 2017 the sites on the shortlist were visited to establish suitability for sampling. The background investigation and subsequent reconnaissance are discussed below for each of the fields named in Table 23.

4.1 BROUGHTON

Broughton is an oil field near Scunthorpe in Lincolnshire. Figure 15 presents the geology, licensed areas and abandoned wells around the Broughton oil field. The field is underlain by the Inferior Oolite Group and in a current PED licensed area. There is another oilfield within 5 km. The area is covered in numerous licensed blocks.

Figure 16 shows the locations of the potential sites, with the 1, 2, and 5 km buffers. There are fewer sites in the south-west of the area, in particular the EA licensed abstractions are found in clusters. However, there are possible sample sites throughout the area.

Figure 17 shows the locations of sites visited during the reconnaissance. The sites with most promise were all located in the area of greatest density, but only one site was considered to be suitable.

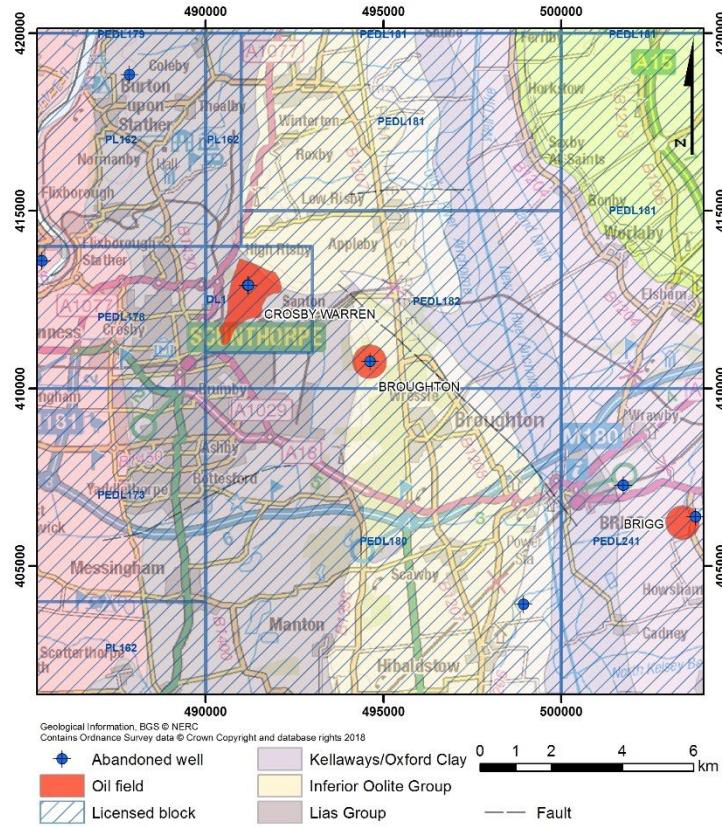


Figure 15. Geology, licensed areas and abandoned wells around the Broughton oil field

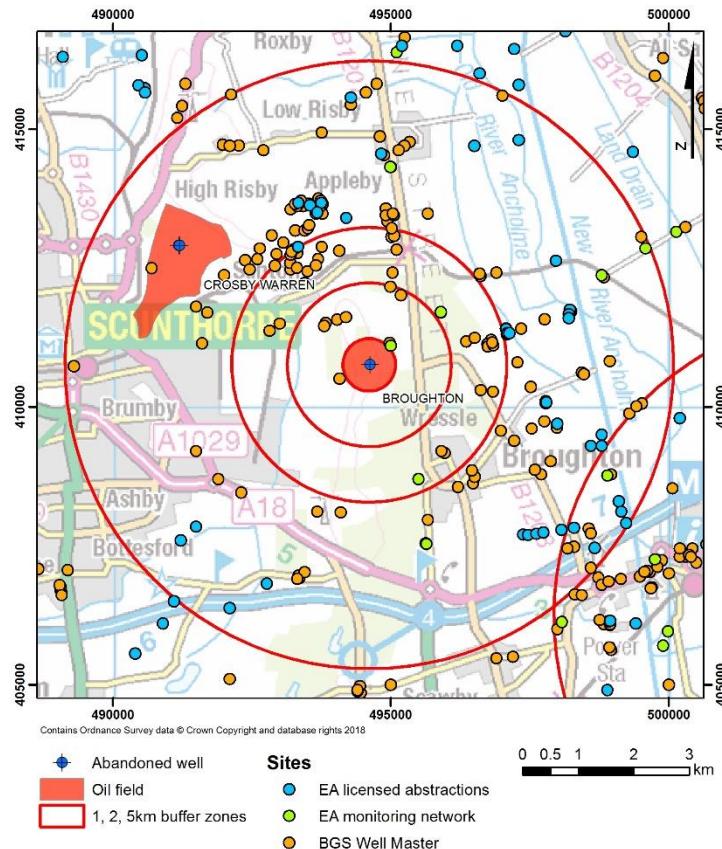


Figure 16. Potential sampling sites around the Broughton oil field

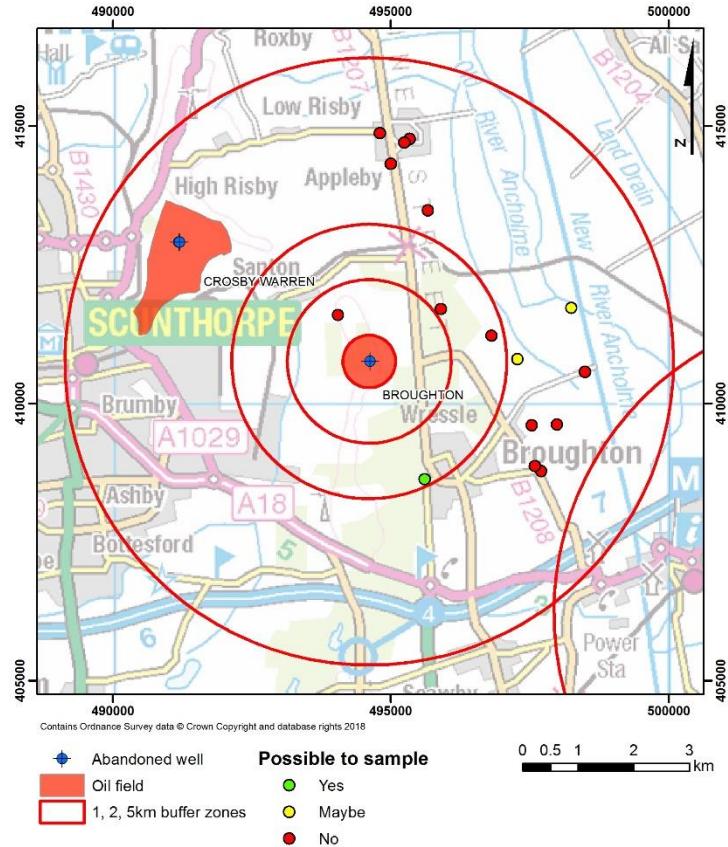


Figure 17. Sites considered during a reconnaissance of the area around the Broughton oil field

4.2 CALOW

Calow is a gas field near Chesterfield in Derbyshire. Figure 18 presents the geology, licensed areas and abandoned wells around the Calow gas field. The field is underlain by Lower and Middle Coal Measures and is situated within a current PED licensed area.

Figure 19 shows the locations of the potential sites, with the 1, 2, and 5 km buffers. There is a relatively even distribution around the gas field. However, the sites with most potential (EA databases) are mostly located in the south west of the region.

Only four identified sites were found to be suitable around Calow, and these were all clustered to the east of the area (Figure 20). The sites denoted ‘maybe’ were boreholes associated with mine workings owned by a third party, for which permission had been gained in theory, but the sites had not been assessed for sampling practicality.

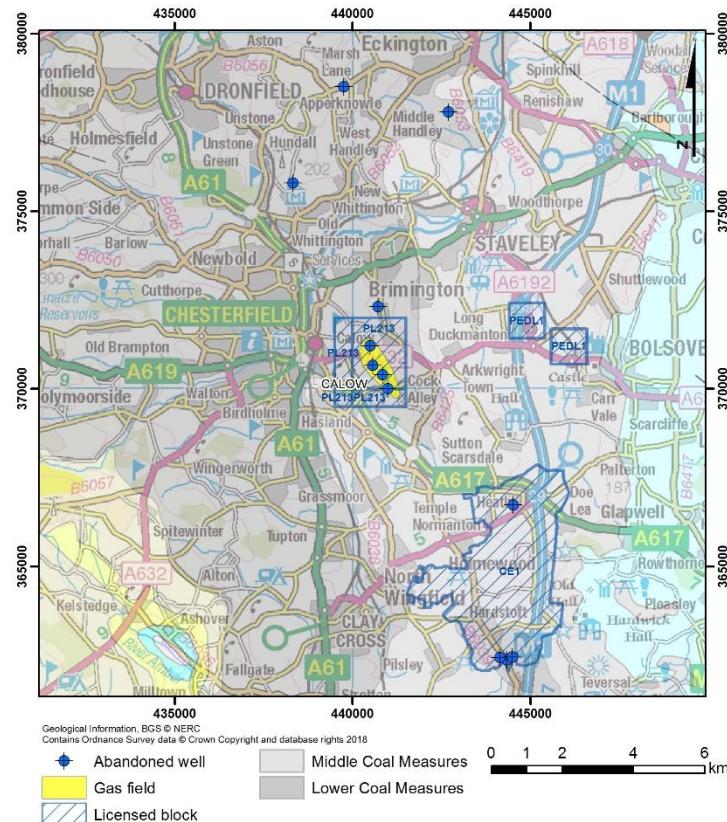


Figure 18. Geology, licensed areas and abandoned wells around the Calow gas field

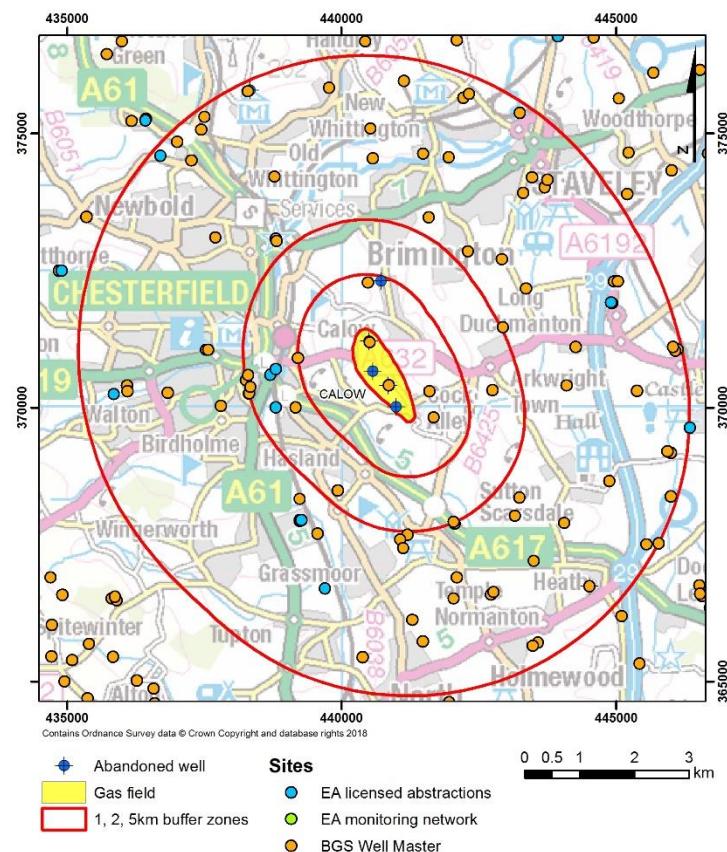


Figure 19. Potential sampling sites around the Calow gas field

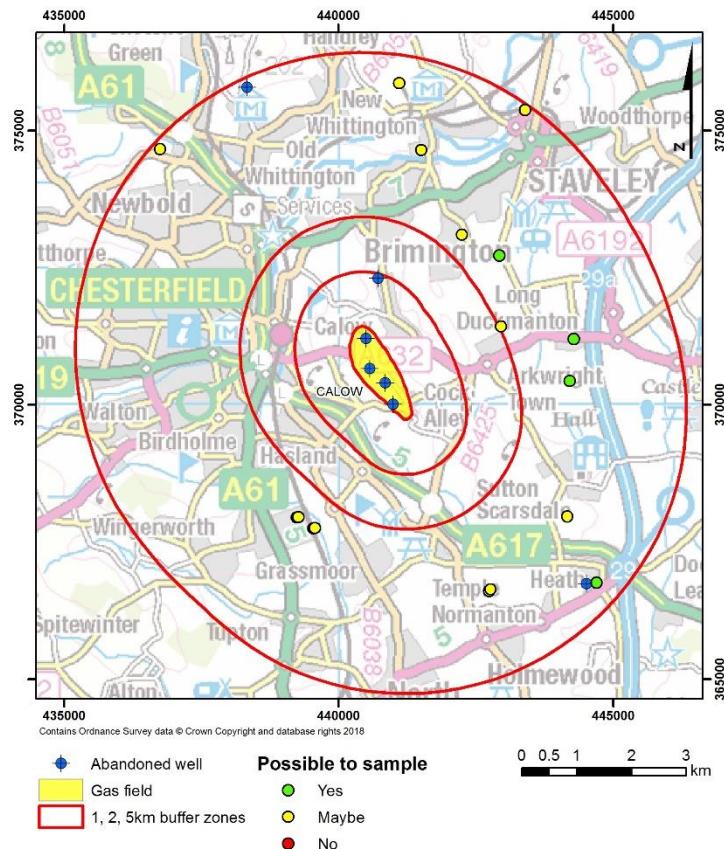


Figure 20. Sites considered during a reconnaissance of the area around the Calow gas field

4.3 ESKDALE

Eskdale is a gas field near Whitby in North Yorkshire. Figure 21 presents the geology, licensed areas and abandoned wells around the Eskdale gas field. The field is underlain by the Ravenscar and Lias Groups. There are no licensed blocks within 5 km of the field.

Figure 22 shows the locations of the potential sites, with the 1, 2, and 5 km buffers. There is a lack of sites in the west and the south-east of the region. While eleven sites were considered suitable, these were all located in the south and south-east of the region (Figure 23).

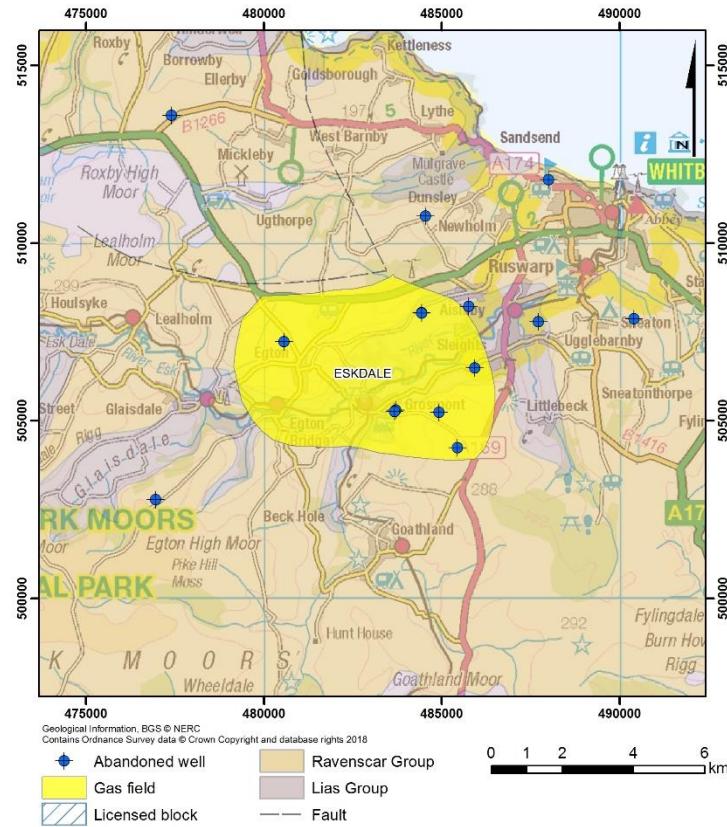


Figure 21. Geology, licensed areas and abandoned wells around the Eskdale gas field

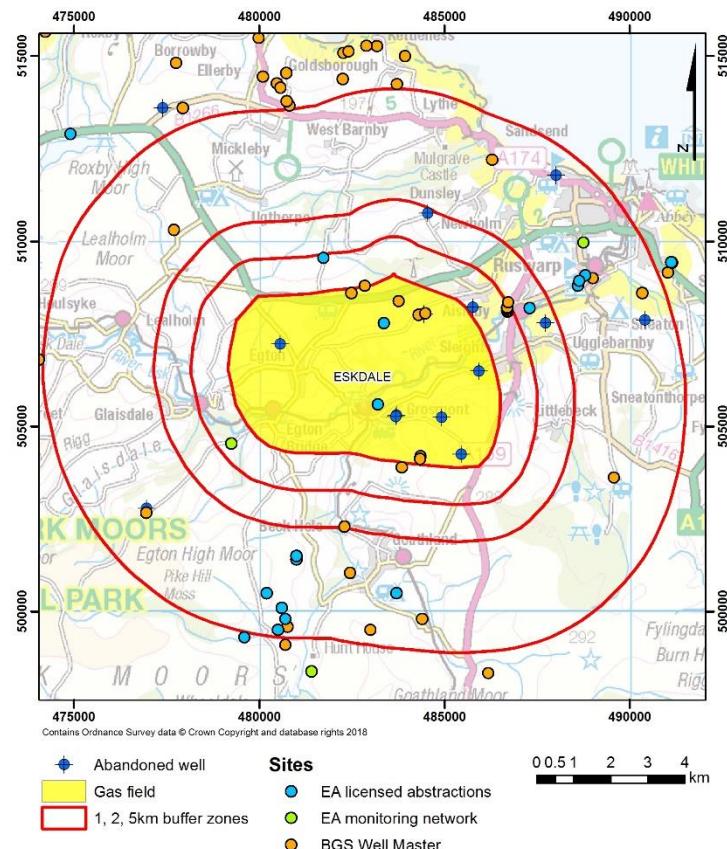


Figure 22. Potential sampling sites around the Eskdale gas field.

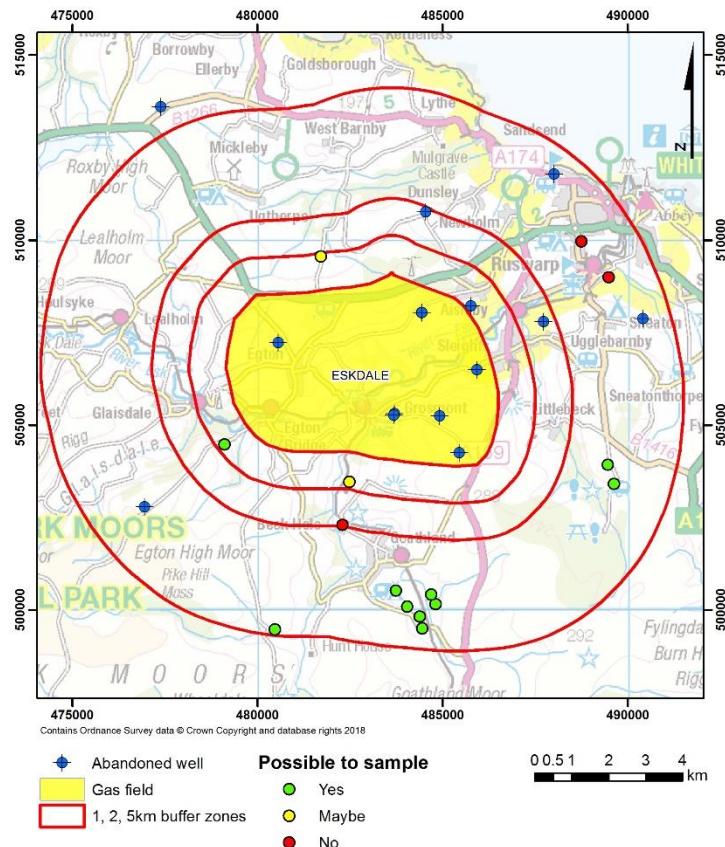


Figure 23. Sites considered during a reconnaissance of the area around the Eskdale gas field

4.4 EVERTON

Everton is a gas field near Bawtry in South Yorkshire. Figure 24 presents the geology, licensed areas and abandoned wells around the Everton gas field. The field is underlain by Triassic sandstones and mudstones, and the whole area is situated within current PED licensed areas.

Figure 25 shows the locations of the potential sites, with the 1, 2, and 5 km buffers. There is a relatively even distribution around the gas field. Ten sites were considered suitable for future sampling, but they were all clustered around the north-west of the region (Figure 26). The sites denoted 'maybe' were boreholes associated with mine workings owned by a third party for which permission had been gained in theory, but the sites had not been assessed for their sampling practicality.

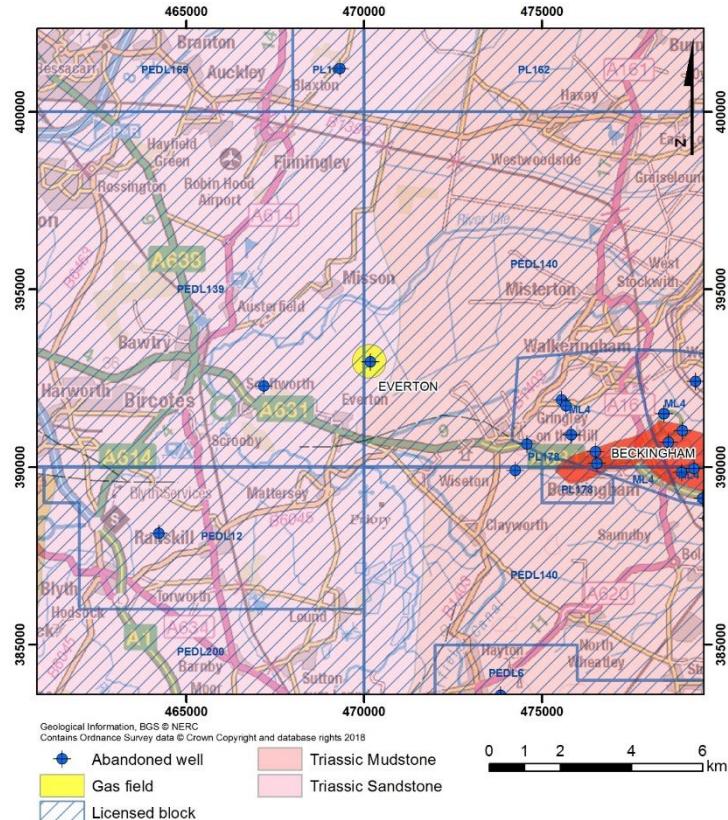


Figure 24. Geology, licensed areas and abandoned wells around the Everton gas field

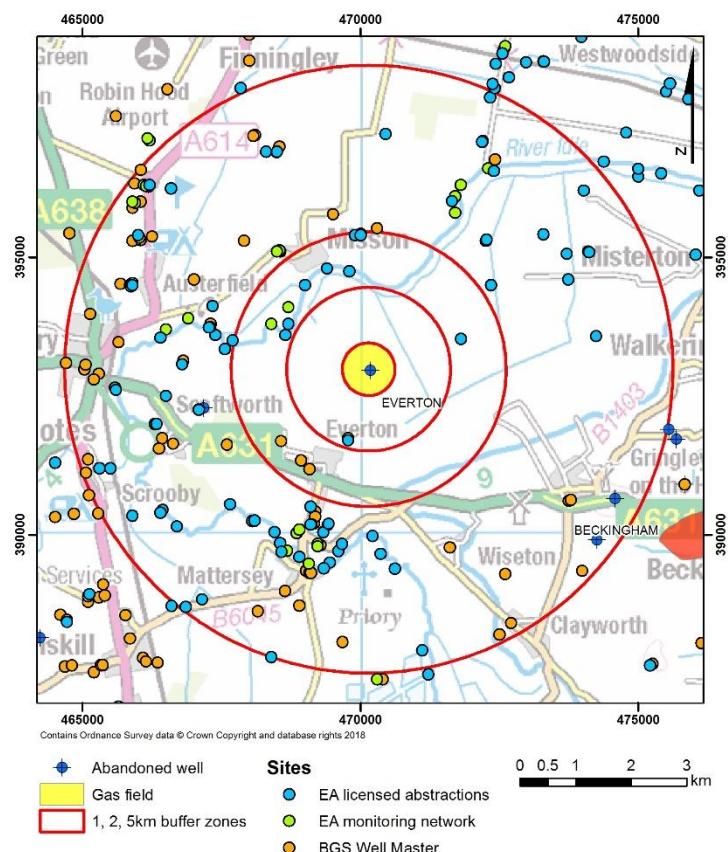


Figure 25. Potential sampling sites around the Everton gas field

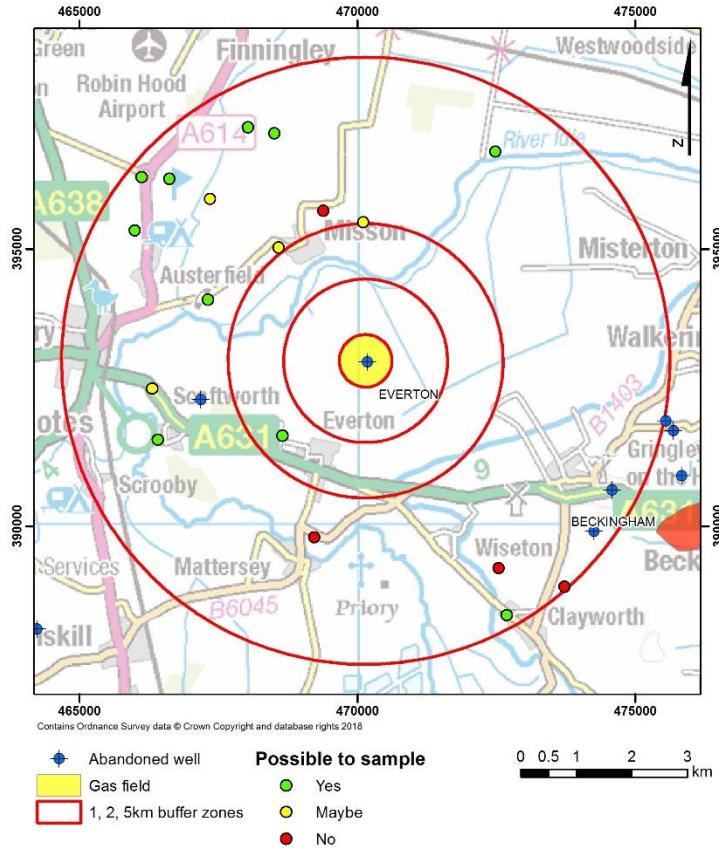


Figure 26. Sites considered during a reconnaissance of the area around the Everton gas field

4.5 IRONVILLE

Ironville is a gas field near Ripley in Derbyshire. Figure 27 presents the geology, licensed areas and abandoned wells around the Ironville gas field. There are no licensed blocks within 5 km of the gas field.

Figure 28 shows the locations of the potential sites, with the 1, 2, and 5 km buffers. There is a relatively even distribution around the gas field. However, the sites with most potential (EA databases) are generally clustered around the north of the area. Only one site was suitable for future sampling (Figure 29). The sites denoted ‘maybe’ were boreholes associated with mine workings boreholes associated with mine workings owned by a third party, for which permission had been gained in theory, but the sites had not been assessed in person for sampling practicality.

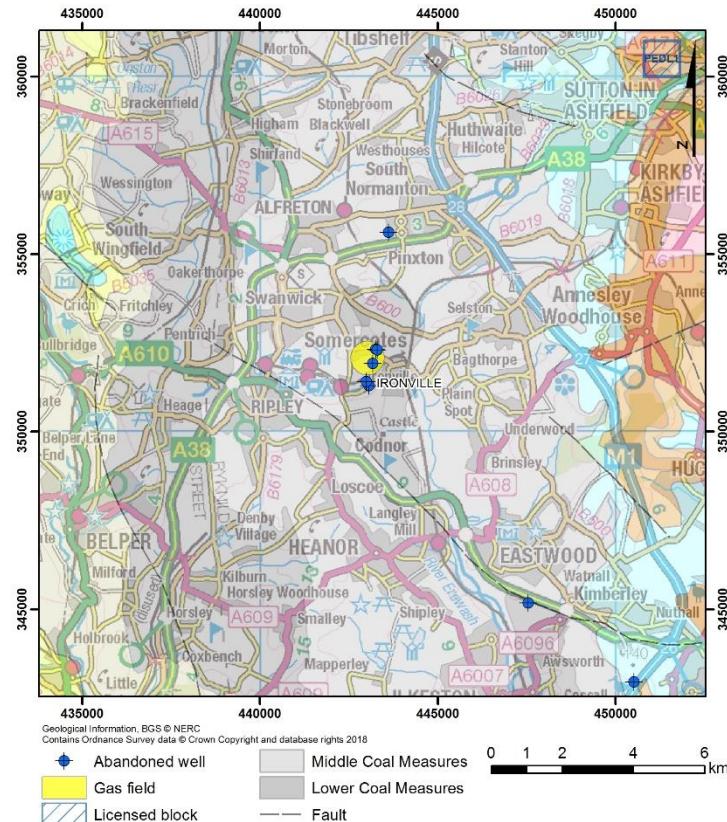


Figure 27. Geology, licensed areas and abandoned wells around the Ironville gas field

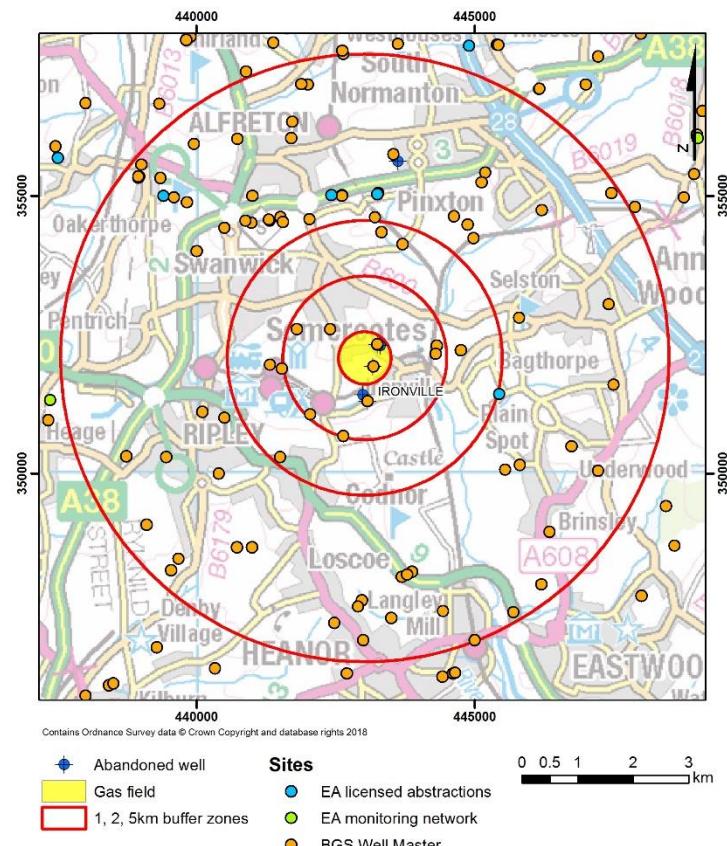


Figure 28. Potential sampling sites around the Ironville gas field

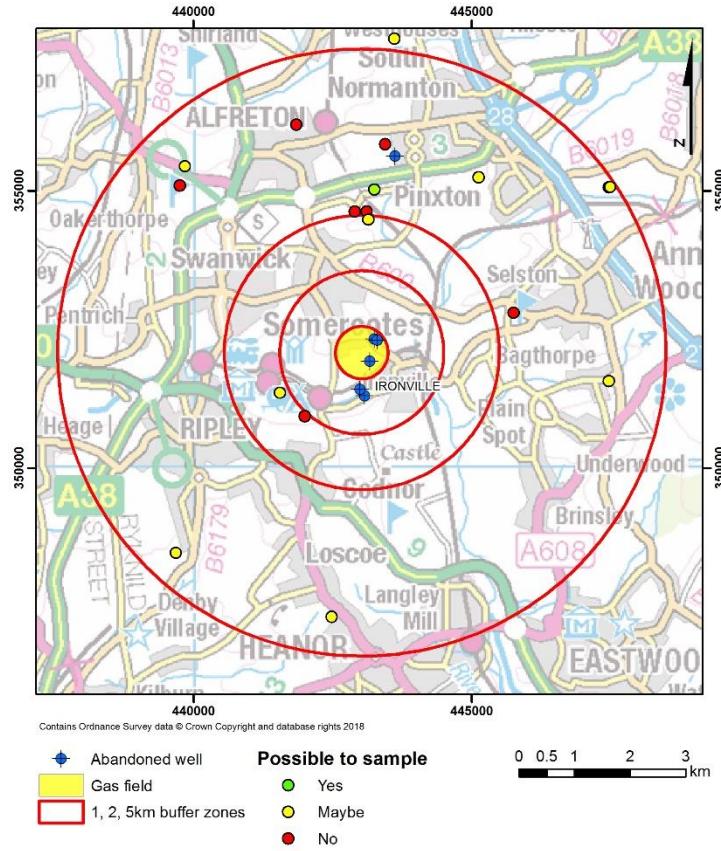


Figure 29. Sites considered during a reconnaissance of the area around the Ironville gas field

4.6 OUTCOME OF RECONNAISSANCE

Table 24 presents a summary of the results of this fieldwork. Of the five areas, only Eskdale and Everton had sufficient suitable sites. However, when the distribution of these sites is taken into consideration, it can be seen that they were not evenly distributed, and were therefore not ideally located.

Further groundwater sampling was therefore deemed not useful and it was concluded instead that a soil gas study may be more appropriate. Soil gas surveys can be carried out wherever representative sites can be found, so the main constraint was landowner permission. The survey can take the form of a grid and so does not have the same constraints associated with lack of suitable groundwater boreholes.

Table 24. Summary of reconnaissance visits

Site	Field type	Sites visited	Suitable sites
Broughton	oil	18	1
Calow	gas	15	4
Eskdale	gas	18	11
Everton	gas	18	10
Ironville	gas	16	1

5 Soil Gas Survey

5.1 INTRODUCTION

After the difficulties in locating suitable groundwater sampling points and discussions between the BGS and the EA, it was agreed that a soil gas survey would be carried out as an alternative approach. Two gas wells considered in the initial stages of the project were identified as being suitable for a soil gas survey based on location and geology. These were Bolney and Ashdown, each in Sussex. A combination of wide-area survey and point measurements of soil gas concentration and CO₂ and CH₄ flux were applied to the study areas.

5.2 MONITORING SITE SELECTION AND SUPPORTING INFORMATION

The soil gas survey focussed on two abandoned hydrocarbon (gas) wells in East and West Sussex. Ashdown 1 is located at Crowborough Warren in West Sussex on the Ashdown Formation, an interbedded sandstone and siltstone of the Wealden Group.

The Bolney 1 well is located to the north-east of Bolney village, primarily on Upper Tunbridge Wells Sand, an interbedded sandstone and siltstone of the Tunbridge Wells Sand Formation. The northern boundary of the survey site includes a small strip of the field located on the Wadhurst Clay Formation, a mudstone of the Wealden Group.

Reconnaissance for soil gas surveys around the Ashdown 1 and Bolney 1 wells was carried out in September 2017, with a second reconnaissance to assess ground conditions undertaken in November 2017. Access directly to the abandoned well was feasible at both sites, and access permissions (site operations permitting) were granted by landowners/estate managers as needed, including for the use of a quad bike provided this could be scheduled around livestock and other site activities.

5.3 MONITORING DATA AND PROCESSING ACTIVITIES

The soil gas surveys were completed in January 2018. Mobile mode was used for rapid wide-area screening of near-surface CO₂ flux. Given the relatively small areas concerned, this was easily achieved using a hand-held mobile open path CO₂ laser system, which avoided the need to take an all-terrain vehicle with mounted laser probes into restricted spaces with potentially soft terrain.

Point measurements of soil gases CH₄, CO₂, O₂, H₂S and H₂ were made by driving a hollow steel push probe 0.5–1 m into the ground. The extracted soil gas was measured immediately using field instruments, or samples were collected into evacuated glass extantainer vials for subsequent laboratory analysis, primarily for stable isotopes of carbon.

In addition, gas flux (CO₂ and CH₄) point measurements were made at the soil surface using a non-invasive chamber-based field instrument.

5.4 RESULTS AND DISCUSSION

In general, soil gas surveys would not normally be attempted in winter in the UK. Soil gas surveys are ideally undertaken in dry conditions when the movement of gas is unimpeded. Waterlogging or frozen ground inhibits or completely eliminates the free movement of gas between the soil and the atmosphere, and can trap gas to form lenses or pools in the subsurface that would otherwise be more mobile and freely dispersed.

As expected, ground conditions at the time of survey were non-optimal at either the Ashdown 1 or Bolney 1 site. The sites were variously wet under foot and occasionally waterlogged between the surface and the full sampling depth of the soil gas push probe (<1 m). Nonetheless, mobile laser data, CO₂ and CH₄ flux, soil gas data and samples for stable carbon isotopes were collected where possible from both the Ashdown 1 and Bolney 1 sites.

5.4.1 Ashdown 1

Although permission to access the field containing what was believed to be the remaining surface expression of the abandoned well at Ashdown was not granted in advance, it was possible to access the lane immediately adjacent to the west of the well (Figure 30, B) that ran south from the road. The field to the west of the lane (Figure 30, C) was also accessible.



Figure 30. Ashdown 1 soil gas survey area showing the location of the Ashdown 1 well (A), adjacent lane (B) and neighbouring equestrian jumps (C) course to the west

5.4.1.1 ASHDOWN 1 – MOBILE CO₂ LASER

Mobile CO₂ laser data for Ashdown 1 are shown in Figure 31. Near-surface anomalies detected by laser often manifest as rapid changes in absolute CO₂ concentration over a short distance, which can be detected using a moving average approach. The five-point moving average (Figure 31, upper right panel) indicates a small number of changes in CO₂ concentration close to the well. These are supported by regions of elevated absolute CO₂ concentrations (Figure 31, upper left panel) along the eastern boundary of the field and the lane, close to the reported location of the well. However, it is unclear whether this is a true anomaly or an artefact of the survey, given that the adverse ground conditions may have had an impact on achieving a steady survey pace.

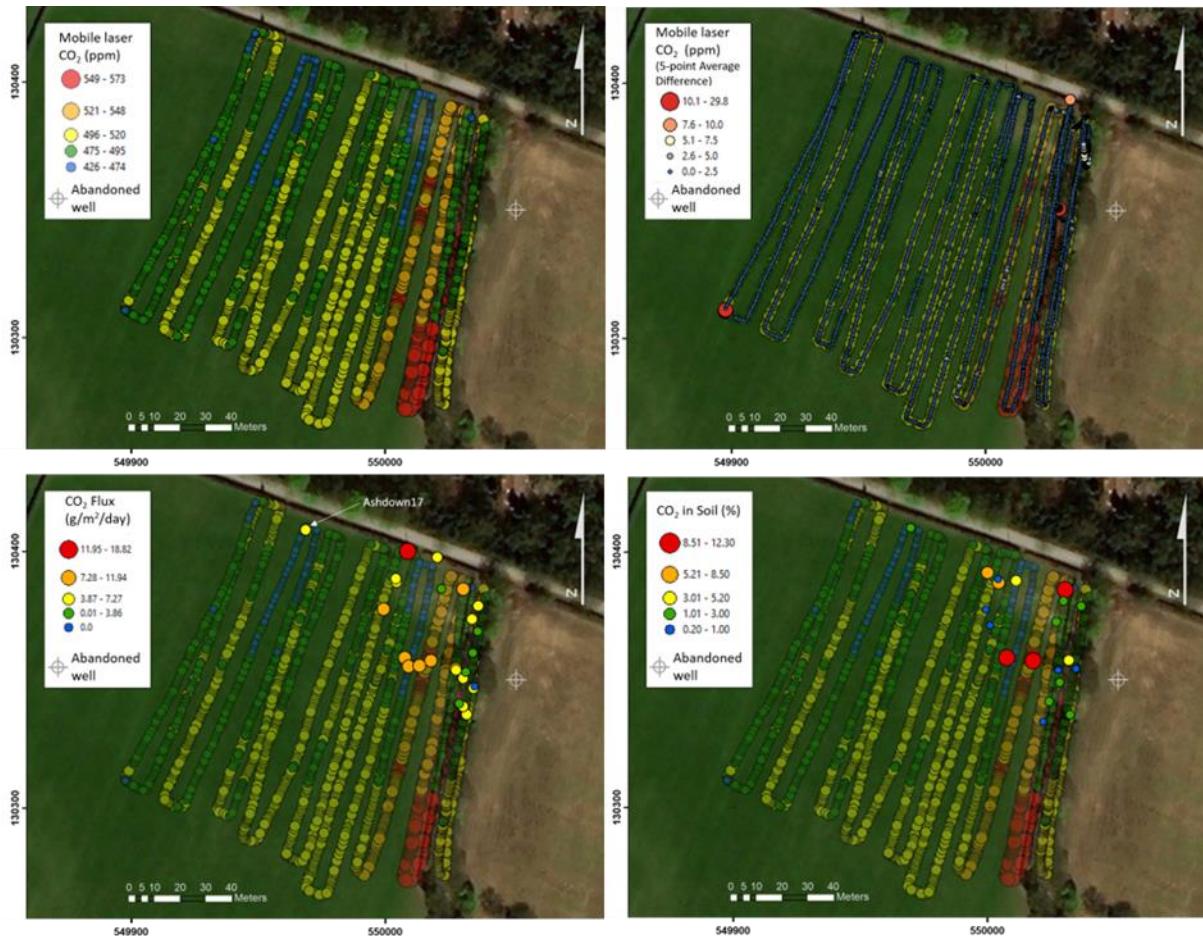


Figure 31. Ashdown 1 open path CO₂ laser, CO₂ flux and CO₂ in soil gas. Laser CO₂ concentrations (upper left panel), overlaid with moving five-point average (upper right panel), CO₂ flux (lower left panel) and CO₂ concentration (lower right panel). Note that the accuracy of the location of the abandoned well, based on well records, is ±10 metres. Map data sources: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

5.4.1.2 ASHDOWN 1 – CO₂ AND CH₄ FLUX

A limitation of the mobile laser survey is that sensitivity is relatively poor because of the dilution of soil CO₂ in air, so it is typically combined with a more sensitive point measurement approach. A total of 25 flux measurements were collected from the adjacent lane and field to the west of the Ashdown 1 well (Figure 31, lower left panel). This includes five measurements collected during a reconnaissance visit in November 2017, since CO₂ fluxes were reasonably consistent with measurements taken during the survey in January 2018. A ‘background’ measurement was also collected at sufficient distance from the well to be considered unaffected. The background CO₂ flux was 7.27 g m⁻²/day. For the remaining measurement points, CO₂ flux ranged between 0.62 and 12.91 g m⁻²/day with the highest CO₂ flux recorded along the field boundary with Warren Road. Flux measurements taken closest to the well, i.e. along the north-south lane on the eastern extent of the survey area, were close to background. Moderate flux was detected along a transect due west of the well, from the lane into the neighbouring field.

There was no detectable CH₄ flux at any of the Ashdown 1 measurement points at the time of survey.

5.4.1.3 ASHDOWN 1 – SOIL GAS

Single point measurements provide relatively high sensitivity, since the gas is extracted from the soil, or soil surface, where concentrations are highest. A sufficient number of analyses over a site provide a good indication of the range of conditions. The soil gas study included field measurements of CH₄, CO₂ which can be produced from methane oxidation or be present in reservoir gas, and O₂ which is useful in determining the source of CH₄ and CO₂. The trace gases H₂S and H₂ were also included in this survey.

Soil gas measurements were made at 22 locations across a grid pattern covering the lane and field to the west of the Ashdown 1 well. In addition, high sensitivity methane measurements were taken at all gas

sampling points plus two further points, where gas flow was insufficient for concomitant measurement of other soil gases.

Methane concentrations ranged from 0 to 2.8 ppm, i.e. consistent with atmospheric methane, although peaks of 3.3 and 3.7 ppm were observed at sample points in the lane close to the well. Hydrogen sulphide was not detected at any of the Ashdown 1 measurement points. Diatomic hydrogen was detected at ppm levels at all but one site; the highest H₂ concentration (47 ppm) was found at the northern end of the lane.

The concentrations of CO₂ are shown with the mobile laser CO₂ measurements in the lower right panel in Figure 31. This includes five measurements taken during the reconnaissance visit in November 2017. These include the three highest CO₂ concentrations (10.7, 10.8 and 12.3%), the highest being found in the north-eastern corner of the field. In January 2018, the highest CO₂ concentrations (7.1 and 8.5%) were again found alongside the northern field boundary. Moderate CO₂ flux was detected in the same area (Figure 31, lower left panel). Given the extremely wet surface conditions, the high CO₂ concentrations could be the result of gaseous CO₂ becoming trapped under a layer of water below the soil surface.

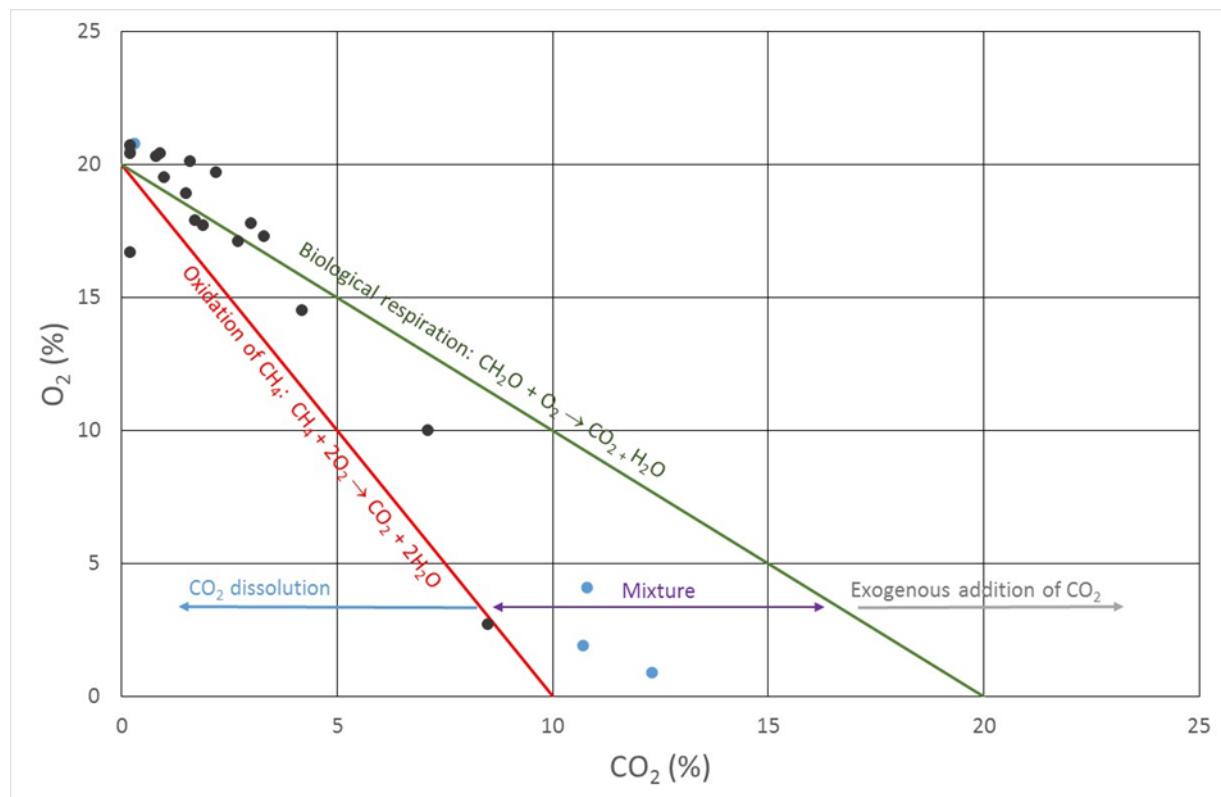


Figure 32. Ashdown 1 CO₂ and O₂ ratios in soil gas collected in January 2018 (black points) and November 2017 (blue points)

Gas compositions (CO₂ to O₂ ratios) can, by comparison with soil gas trends for the common background processes of biological respiration and methane oxidation, provide insight into the sources of soil gases. Gas compositions plotting to the left of the CH₄ oxidation (red) line in Figure 32 suggest dissolution of CO₂ and reaction with carbonate in the soil. Those plotting to the right of the biological respiration (green) line indicate CO₂ added from an exogenous source e.g. CO₂ leaking into the vadose zone from depth (Romanak, Bennett et al. 2012). Ashdown 1 soil gas compositions at first appeared to lie along the CH₄ oxidation line, but with more data the relationship became more ambiguous and, if anything, appears more consistent with biological respiration combined with dissolution. Without further measurements in more favourable, i.e. drier, conditions it is not possible to distinguish between these processes.

5.4.1.4 ASHDOWN 1 – STABLE CARBON ISOTOPES IN CO₂

Carbon isotope analysis ($\delta^{13}\text{C}$) of CO₂ samples collected at nine soil gas measurement points along the lane and field to the west of the abandoned well ranged between $\delta^{13}\text{C}$ VPDB -28.29 and -23.13 ‰, and are consistent with a biogenic source of CO₂ (Ekblad and Hogberg 2000, Beaubien, Jones et al. 2013). Hydrocarbons related to the Ashdown 1 well are expected to be biogenic in origin, so the value of further

stable isotope analysis of CO₂ in source attribution at Ashdown 1 should be considered carefully in any future surveys.

5.4.2 Bolney 1

At Bolney 1 there is no obvious surface expression of the well, although there was a moderate-sized surface depression (aerial view inset in Figure 33) where the landowner reported the location of the Bolney 1 abandoned well to be. The survey focussed on high-resolution coverage in an approximate north-south and east-west grid transecting the well, with a broader laser survey (Figure 34) extending towards the southern and eastern extents of the survey area.

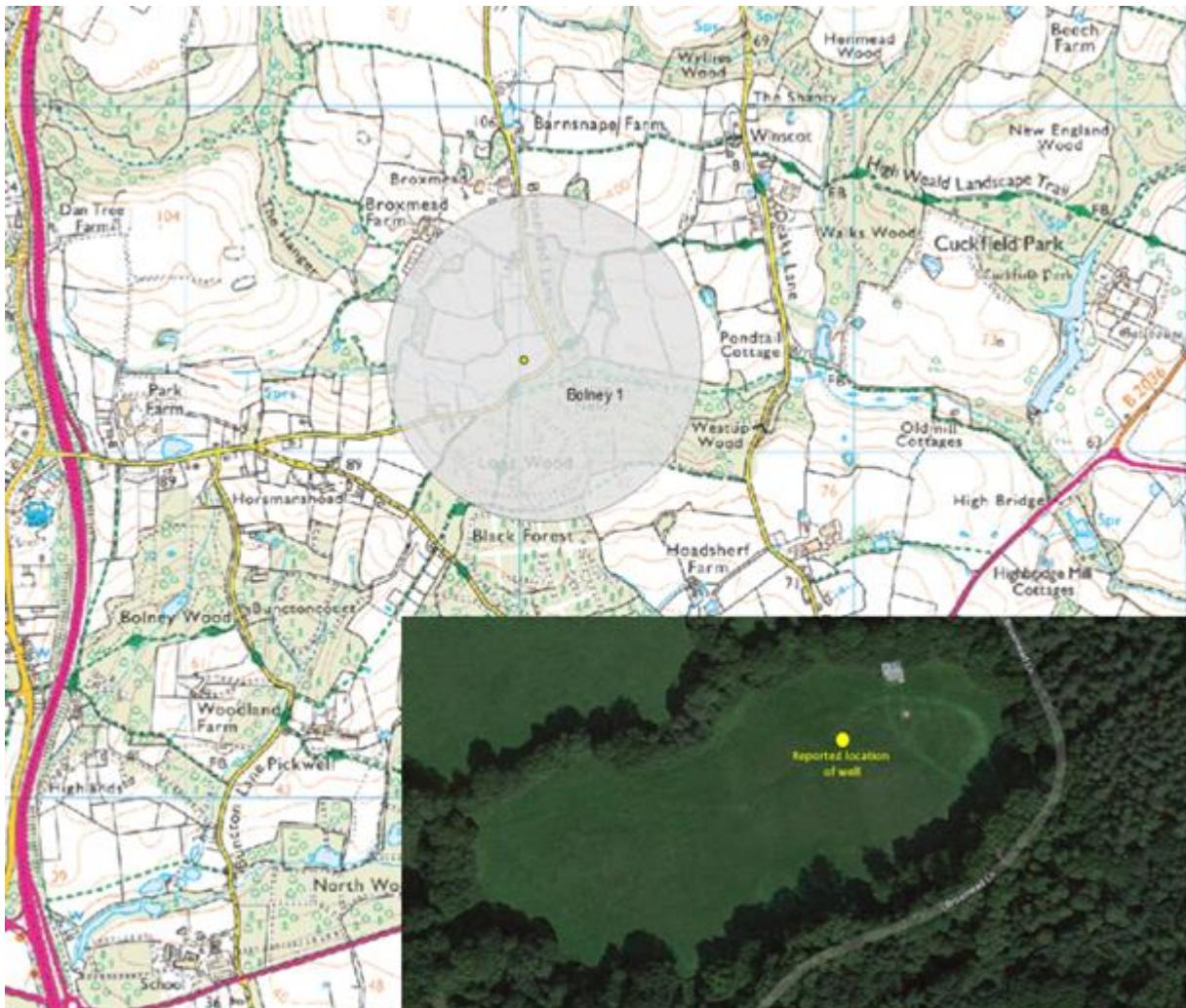


Figure 33. Bolney 1 soil gas survey area and reported location of the Bolney 1 well. Inset satellite imagery ©2018 Google; Inset map data ©2018 Google



Figure 34. Figure 4. Open path CO₂ laser surveying at Bolney 1

5.4.2.1 BOLNEY 1 – MOBILE CO₂ LASER

Mobile CO₂ laser data for the Bolney 1 survey area are shown in Figure 35. Absolute CO₂ concentrations indicate areas of elevated CO₂ towards the south-western boundary of the site (upper left panel), and the five-point moving average (upper right panel) indicates a few rapid changes in CO₂, but none shows any clear correlation with the reported location of the well. This lack of correlation is unsurprising since both the ground and weather conditions were especially wet at the time of the Bolney 1 survey, which will have impacted on the mobility of CO₂ at the surface or near surface.

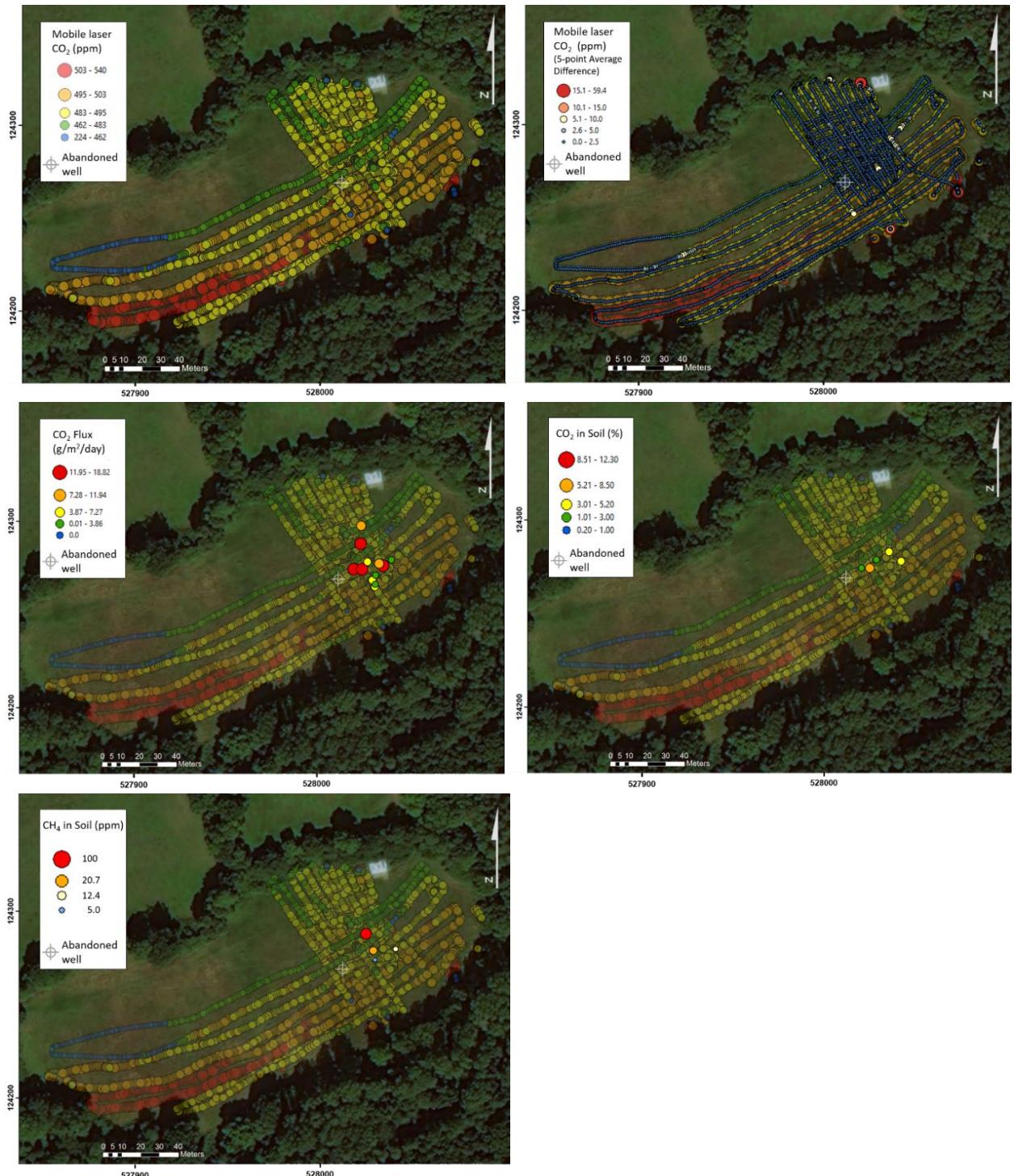


Figure 35. Bolney 1 open path CO₂ laser, CO₂ flux, and CO₂ and CH₄ in soil gas. Laser CO₂ concentrations (upper left panel), overlaid with moving five-point average (upper right panel), CO₂ flux (centre left panel), CO₂ concentration (centre right panel) and CH₄ concentration (lower right panel). Note that the accuracy of the location of the abandoned well, based on well records, is ± 10 metres. Base map data sources: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

5.4.2.2 BOLNEY 1 – CO₂ AND CH₄ FLUX

A total of 17 flux measurements were obtained across the reported location of the well during the January 2018 survey. Carbon dioxide flux ranged between 0.06 and 18.83 g/m²/day, with the highest CO₂ flux recorded close to the location of the well (Figure 35, centre left panel). There was no detectable CH₄ flux at any of the Bolney 1 measurement points at the time of survey.

5.4.2.3 BOLNEY 1 – SOIL GAS

Obtaining soil gas samples at Bolney 1 was especially difficult under the extremely wet conditions. Gas flows were frequently low and short-lived before water was drawn through the push probe. As a result it was only possible to collect eight measurements for CH₄, and five measurements for CO₂, O₂ and other soil gases.

Hydrogen sulphide was not detected at any of the Bolney 1 soil gas measurement points. Diatomic hydrogen was detected at ppm levels at all but one location; the highest hydrogen concentration (30 ppm) was measured during the reconnaissance in November and appears co-located with one of the highest flux measurements collected during the January survey close to the reported location of the well, but where other measured soil gas concentrations (e.g. CO₂) were low.

Methane concentrations at Bolney 1 ranged from 1.6 to 100 ppm, with four of the eight measurements significantly elevated compared to expected atmospheric concentrations of c.1.8 ppm (Figure 35, lower left panel). Poor gas flow meant it was not possible to analyse for other soil gases at the highest (100 ppm) methane concentration, but it was coincident with one of the highest CO₂ flux measurements obtained (17.94 g/m²/day), close to the well.

Concentrations of CO₂ in soil gas are shown with the mobile laser CO₂ concentrations in Figure 35, centre right panel. The apparently random distribution of sample points is a reflection of poor gas flow preventing a soil gas measurement to be collected; only three of the five soil gas measurements reported were made during the January 2018 survey. The two additional measurements are taken from the reconnaissance visit in November 2017. Carbon dioxide concentrations range between 1.6 and 7.4%, with the highest concentration recorded in November 2017, close to the reported location of the well.

For completeness, gas compositions (CO₂ to O₂ ratios) for the Bolney 1 survey area are plotted in Figure 36. Given the lack of samples, it is not possible to reach any conclusions with respect to the source of CO₂ in soil gas.

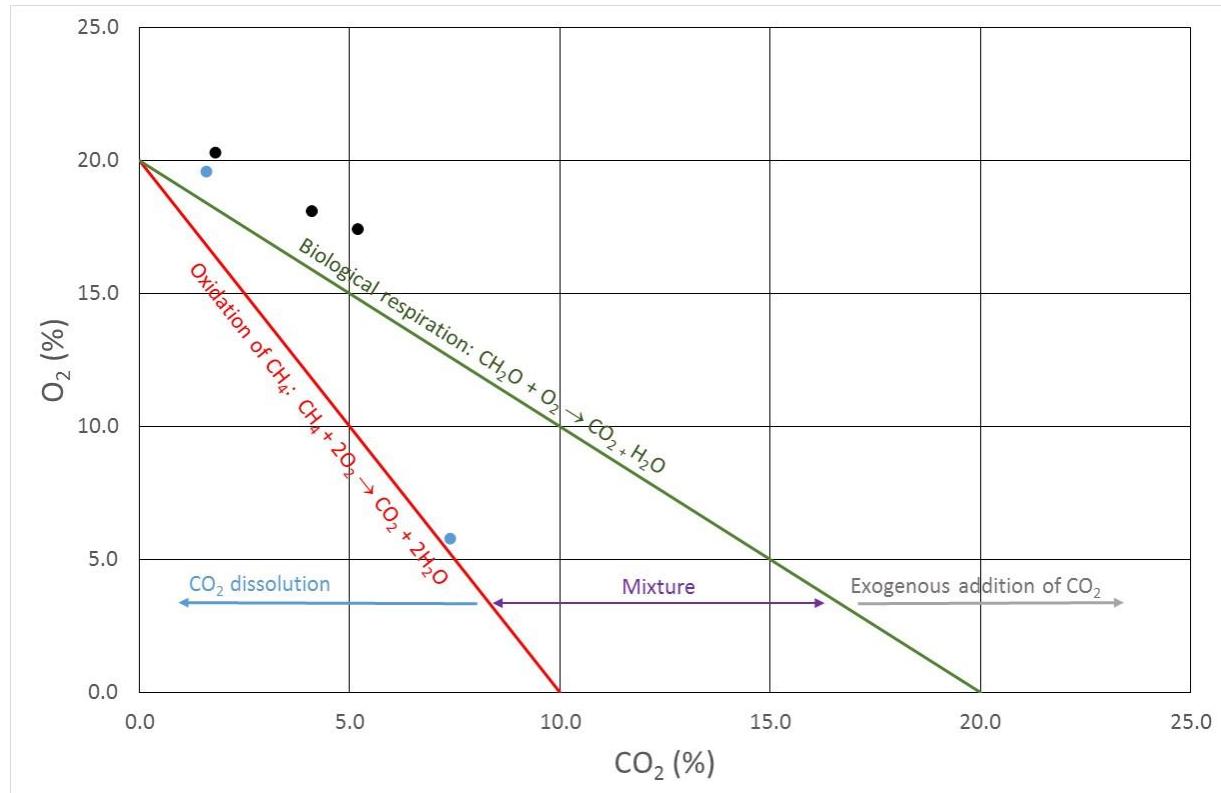


Figure 36. Bolney 1 CO₂ and O₂ ratios in soil gas collected in January 2018 (black points) and November 2017 (blue points)

5.4.2.4 BOLNEY 1 – STABLE CARBON ISOTOPES IN CO₂

Carbon isotope analysis ($\delta^{13}\text{C}$) of CO₂ samples collected at the four measurement points with sufficient gas flow are tightly grouped, with $\delta^{13}\text{C}$ VPDB ranging from -27.78 to -27.43 ‰. These are in common with the Ashdown 1 site and consistent with a biogenic source of CO₂.

5.5 SOIL GAS SUMMARY

The limited amount of soil gas data available appear to indicate elevated CH₄ and/or CO₂, and intriguing, but ambiguous, gas composition relationships around both abandoned wells. However, the ground and weather conditions at the time of survey (heavy rain, standing water, extensive waterlogging) prevented sufficient quantities of meaningful gas or flux data to be collected at either site and, as a result, the survey findings to date have to be considered inconclusive.

Establishing the extent to which any tentative findings from this survey could be attributed to the two wells, or are an artefact of the conditions at the time of survey, warrants further investigation in drier conditions e.g. in spring or, ideally, in autumn. Repeat or continuous measurements at a small number of sites will provide information on temporal variations (e.g. diurnal or seasonal changes), and obtaining better-quality data overall would allow the processes responsible for producing CH₄ and CO₂ around these wells to be distinguished with more certainty. Given the good relationship now established with the landowners, securing access to both sites for any future work should be relatively easy.

6 Conclusions

This report presents the decision making process behind the final selection of the four Abandoned Well study areas. An initial phase of fieldwork revealed significant difficulties in finding sufficient suitable sampling sites. The resulting data failed to indicate an unequivocal impact on the groundwater from HC fields in the four study areas.

Additional sample sites were sought to increase the sampling network in all locations, and springs were included from the Nooks Farm area. Despite a concerted effort, sufficient sample sites could not be found for conducting a robust groundwater investigation. The new data provided no further evidence of impact on groundwater.

A reconnaissance was then undertaken to investigate new potential areas for study. Despite significant effort this demonstrated that other areas were as equally unsuitable.

A soil gas survey was completed in January 2018 after discussions between the BGS and the EA at two sites identified as being suitable: Bolney and Ashdown in Sussex. Due to poor ground conditions, the results were ambiguous, but did show elevated concentrations of both CO₂ and CH₄. Further work in dry ground conditions would be required to say with certainty that these elevated concentrations are directly linked to the presence of the gas wells.

References

- Beaubien, S. E., D. G. Jones, F. Gal, A. K. A. P. Barkwith, G. Braibant, J. C. Baubron, G. Ciotoli, S. Graziani, T. R. Lister, S. Lombardi, K. Michel, F. Quattrocchi and M. H. Strutt (2013). "Monitoring of near-surface gas geochemistry at the Weyburn, Canada, CO₂-EOR site, 2001–2011." International Journal of Greenhouse Gas Control 16, Supplement 1(0): S236-S262.
- Ekblad, A. and P. Hogberg (2000). "Analysis of delta C-13 of CO₂ distinguishes between microbial respiration of added C-4-sucrose and other soil respiration in a C-3-ecosystem." Plant and Soil 219(1-2): 197-209.
- Romanak, K. D., P. C. Bennett, C. Yang and S. D. Hovorka (2012). Process-based approach to CO₂ leakage detection by vadose zone gas monitoring at geologic CO₂ storage sites. Geophysical Research Letters 39(15): L15405.

Appendix 1 Hydrocarbon field factsheets



**British
Geological Survey**

NATIONAL ENVIRONMENT RESEARCH COUNCIL

Abandoned Wells Project 2016

Name and type of field: ASHDOWN gas field

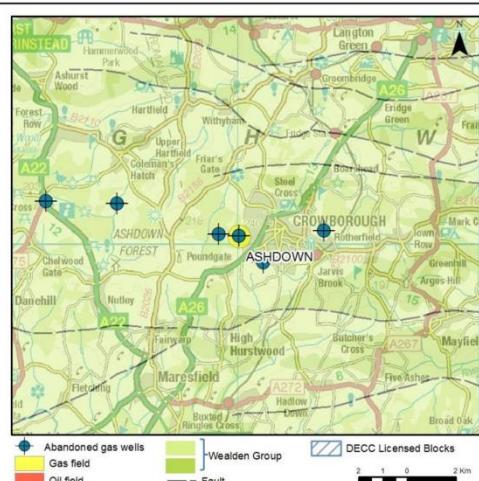
Grid reference of primary well: 550060, 130341

Number of hydrocarbon wells in field: One, Ashdown 1 detailed below

Licence number: No PEDL locally

BGS reference: TQ53SW/BJ/3

Location: Crowborough, East Sussex



Hydrocarbon well information:

*All depths in mbgl

Depth: 1383 m

Hydrocarbon (oil and gas) shows: Purbeck between 241-253 m 0.7 m³/day; 262-288 m 1.3 m³/day; 327-336 m 17.3 m³/day; 896-904 m 90.9 m³/day.

Water strikes: No data for sands in Ashdown Formation, no water 241-253 m, 262-288 m; 629-635 m 9.5 m³/day drilling fluid and gaseous water; 703-708 m 13.6 m³/day drilling fluid and gaseous water; 896-904 m 5.5 m³/day water.

Comments: Drilled by BP. Water analysis available. Area known to be a zone of shallow thermogenic gas. 5 additional 'Ashdown' wells in the area.

Bedrock aquifer: Ashdown Formation, Secondary A

Superficial aquifer: No designation

GW levels (main aq): -

GW flow direction: Complex, faulted and discontinuous multi-layered aquifer. Clay layers.

Other aquifer props: Top Ashdown, Pebble Bed, is best part of the aquifer. T range: <50m²/d - >150m²/d.

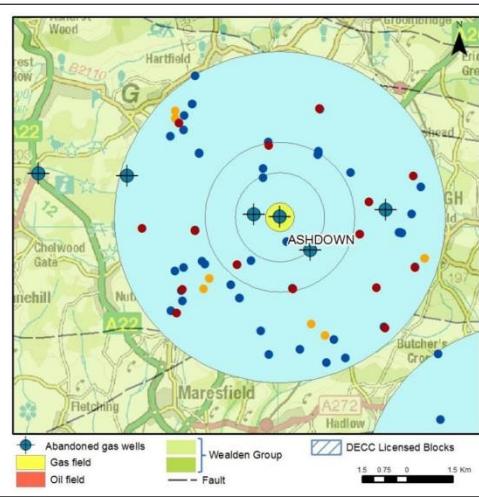
Groundwater

Potential groundwater sampling points:

	Wellmaster	EA Licence	EA database
Within field	1	0	0
1km	4	0	0
2km	11	0	3
5km	54	9	16

Key

●	EA monitoring network
○	EA Licensed boreholes
●	Wellmaster Boreholes
●	Buffer Zone





Name of field: ASHDOWN

Cross section:

SOUTH

Eastbourne

Gault Clay
Lower Greensand
Weald Clay
Tunbridge Wells Formation

Wadhurst Clay Formation
Ashdown Formation
Purbeck Group

River Medway
NORTH

Vertical exaggeration x10
0 5 10 km
Horizontal scale

Stratigraphy and aquifers (in blue):

Geology		Top (mbgl)	Base (mbgl)	Thickness (m)
Age	Formation			
Lower Cretaceous	Ashdown Formation	Surface	172	172
Upper Jurassic	Purbeck, Portland, Kimmeridge, Corallian, Oxford Clay, Kellaways	172	1147	975
Middle Jurassic	Cornbrash, Forest Marble, Gt Oolite series, Fullers Earth, Inferior Oolite	1147	1376	230
Lower Jurassic	Upper Lias	1376	1383	7

Hydrocarbon well log:

- LEGEND -

SHALE, CLAY, MARL OR MUDSTONE	FIRECLAY
SANDY SHALE ETC.	IRONSTONE
INTERBEDDED SHALE ETC & SANDST.	CHERT & FLINT
CONGLOMERATE	ANHYDRITE, GYPSUM OR SALT
BRECCIA	LIMESTONE
PEBBLY SANDSTONE	DOLOMITIC LIMEST. OR DOLOMITE ROCK
SANDSTONE	IGNEOUS ROCK
COAL	

GEOLOGICAL FORMATION	DEPTH FEET	LOG	DETAILS OR FORMATION	OIL, GAS, WATER, COAL SEADS	REMARKS	CASING	DATE	REMARKS
WEALDEN			No samples				3-6-54	Commenced Drilling
ASHDOWN SAND	15-24m	50	Light brown sandy clay					Cellar 14' 10% hole 3 barrels
	30-48m	100	Brown and grey silt and silt with lignite streaks					
	45-72m	150	Grey and brown sandy clay					
	60-96m	200	Grey brown silt					
	76-20m	250	Grey sandy clay					
	91-46m	300	Brown and white silt & silt					
	106-68m	350	Grey fine med gr silt with sphaeroides					
	121-92m	400	Med gr grey silt w lignite streaks					
	137-1bm	450	Fine grained grey brown silt					
	152-40m	500	Grey and brown clay with silt bands					
	167-64m	550	Fine gr hard grey lignit. - II					
			Grey shale with Ostracodes with thin silt bands					
			Thin band of grey silt					
			Thin bands of white crstl. silt					
PURBECK	(192-21m)							

Name and type of field: BOLNEY gas field

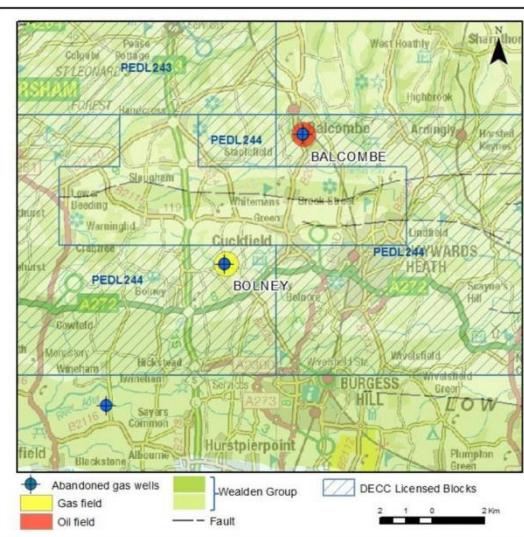
Grid reference of primary well: 528011, 124269

Number of wells in field: One, BOLNEY 1

Licence number: PEDL244

BGS reference: TQ22SE17/BJ

Location: Haywards Heath, West Sussex



Hydrocarbon well information:

*All depths in mbgl

Depth: 2,440 m

Hydrocarbon (oil and gas) shows: Hastings Beds, gas @ ~132m, Purbeck, oil @ ~293m & ~400m (significant), Kimmeridge, Corallian and Great/Inferior Oolite.

Water strikes: Not reported

Comments: Drilled by ESSO for gas exploration – testing of the prospective Mesozoic and Palaeozoic. Poor porosity. Gas analysis available, good logs and report. Area known to be a zone of shallow thermogenic gas.

Bedrock aquifer: Tunbridge Wells Sand, Secondary A

Superficial aquifer: No designation

GW levels (main aq): TWS 17-105 mAOD

GW flow direction: Complex due to faulting, compartmentalised.

Other aquifer props: TWS usually unconfined, forms springs.

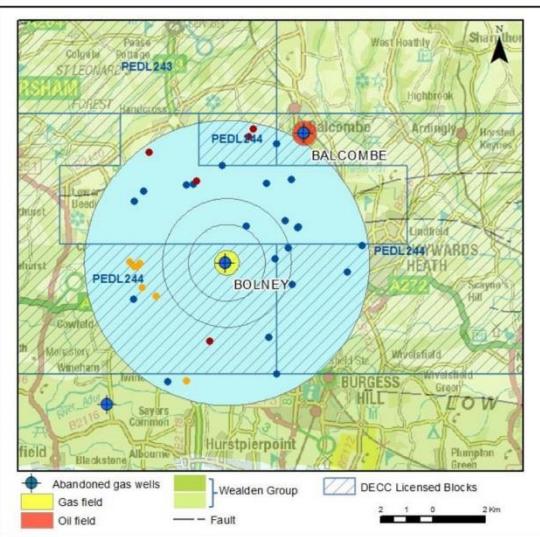
Groundwater

Potential groundwater sampling points:

	Wellmaster	EA Licence	EA database
Within field	1	0	0
1km	1	0	0
2km	4	0	0
5km	25	7	5

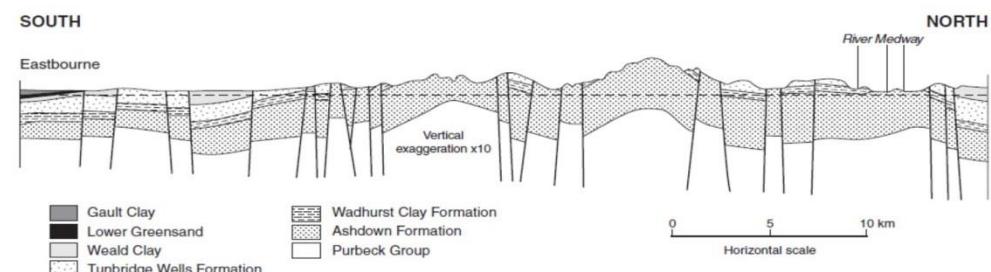
Key

●	EA monitoring network
○	EA Licensed boreholes
●	Wellmaster Boreholes
●	Buffer Zone



Name of field: BOLNEY

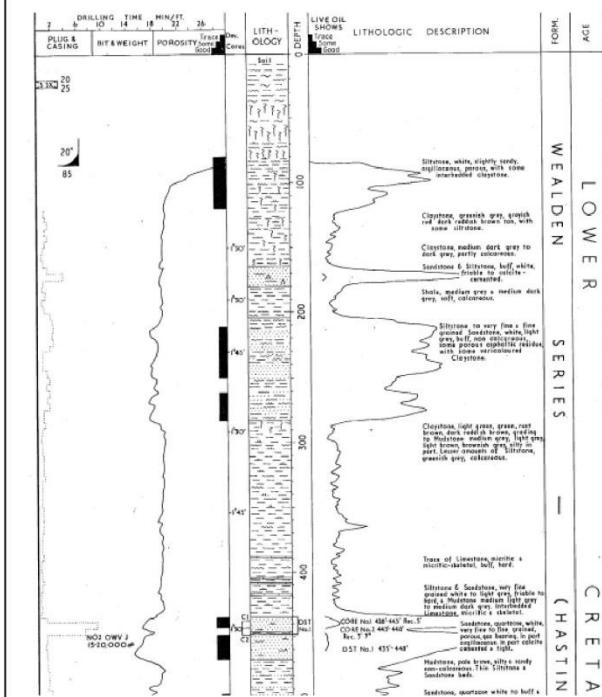
Cross section:



Stratigraphy and aquifers (in blue):

Geology		Top (mbgl)	Base (mbgl)	Thickness (m)
Age	Formation			
Cretaceous	Hastings Beds	Surface	213	213
Upper Jurassic	Purbeck, Portland, Kimmeridge, Corallian, Oxford and Kellaways	213	1170	957
Middle Jurassic	Great Oolite, Fullers Earth, Inferior Oolite	1170	1420	250
Lower Jurassic	Upper, Middle and Lowe Lias	1420	1900	480
Carboniferous	Carboniferous Limestone	1900	1960	60
Devonian	Upper and Middle, sandstone, siltstone and mudstone	1960	2440	480

Hydrocarbon well log:



Name and type of field: CALOW gas field

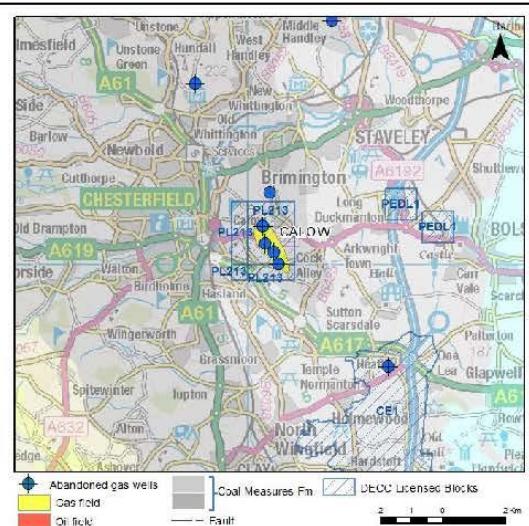
Grid reference of primary well: 440850, 370400

Number of wells in field: Four, CALOW 1 described below

Licence number: PL213

BGS reference: SK47SW/BJ/43

Location: Calow, near Chesterfield, Derbyshire



Hydrocarbon well information:

*All depths in mbgl

Depth: 1130

Hydrocarbon (oil and gas) shows: oil seepage 322 – 628 m. Gas 148-154 m 78.6 m³/day; 220-230 m 572.8 m³/day; 220-241 m 2455 m³/day; 293-298 m 818 m³/day; 312-319 m 264 m³/day; 312-341 m 168 m³/day. No gas from 421-910m

Water strikes: not recorded

Comments: BP, exploration for oil. Three more non-Calow HC wells within the buffered area.

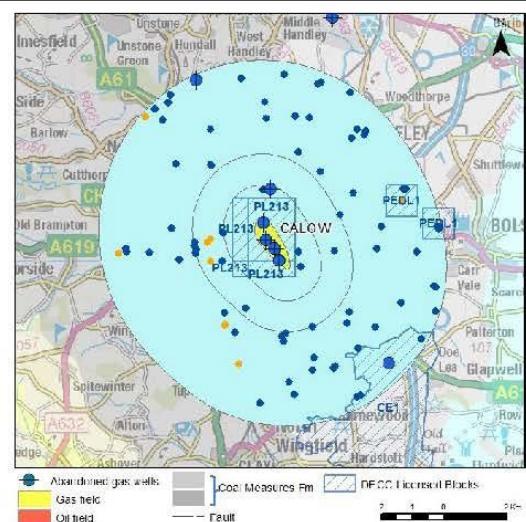
Bedrock aquifer: Lower Coal measures, Secondary A

Superficial aquifer: No designation

GW levels (main aq):

GW flow direction:

Other aquifer props: predominantly fracture flow in Coal Measures sandstones. Higher yields near old mines.



Groundwater

Potential groundwater sampling points:

	Wellmaster	EA Licence	EA database
Within field	2	0	0
1km	5	0	0
2km	14	3	0
5km	84	9	0

Key

	EA monitoring network
	EA Licensed boreholes
	Wellmaster Boreholes
	Buffer Zone



Name of field: CALOW

Cross section:

Not available.

Stratigraphy and aquifers (in blue):

Geology		Top (mbgl)	Base (mbgl)	Thickness (m)
Age	Formation			
Carboniferous	Lower Coal Measures	surface	251	251
Carboniferous	Millstone Grit	251	829	578
Carboniferous	'Limestone shales'	829	841	12
Carboniferous	Carboniferous Limestone	841	1130	291

Note: Depths and formation names are taken from the original driller's log as the interpretation is difficult to read.

Hydrocarbon well log:

Name and type of field: CLEVELAND HILLS gas field

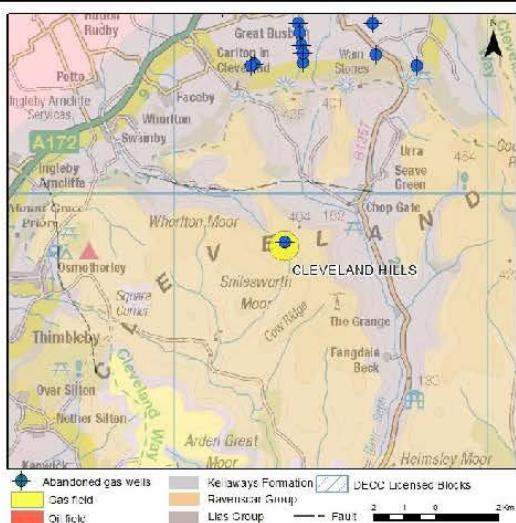
Grid reference of primary well: 453540 498440

Number of wells in field: One, Cleveland Hills 1

Licence number: A64 no PEDL number

BGS reference: SE59NW/BJ/1

Location: Cleveland Hills, Middlesbrough, North Yorkshire



Hydrocarbon well information:

*All depths in mbgl

Depth: 1915 m

Hydrocarbon (oil and gas) shows: Gas seen at 1300, 1330, 1520 m bgl. At 1517 m bgl yielded 682 m³/day of gas

Water strikes: Salt water seen in several tests between 974 m bgl and 1875 m bgl.

Comments: No additional HC wells in the 5km buffered zone.

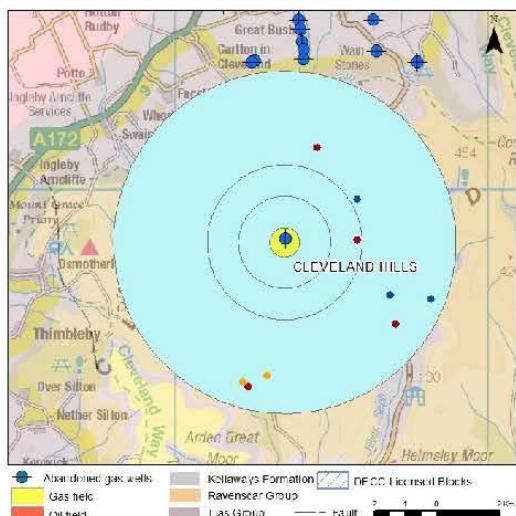
Bedrock aquifer: Ravenscar Group (Cloughton Fm), Secondary A

Superficial aquifer: none

GW levels (main aq):

GW flow direction:

Other aquifer props: Deltaic and estuarine deposits, variable facies. Water quality issues.



Groundwater

Potential groundwater sampling points:

	Wellmaster	EA Licence	EA database
Within field	0	0	0
1km	0	0	0
2km	0	0	1
5km	3	2	5

Key

	EA monitoring network
	EA Licensed boreholes
	Wellmaster Boreholes
	Buffer Zone



Name of field: CLEVELAND HILLS

Cross section:

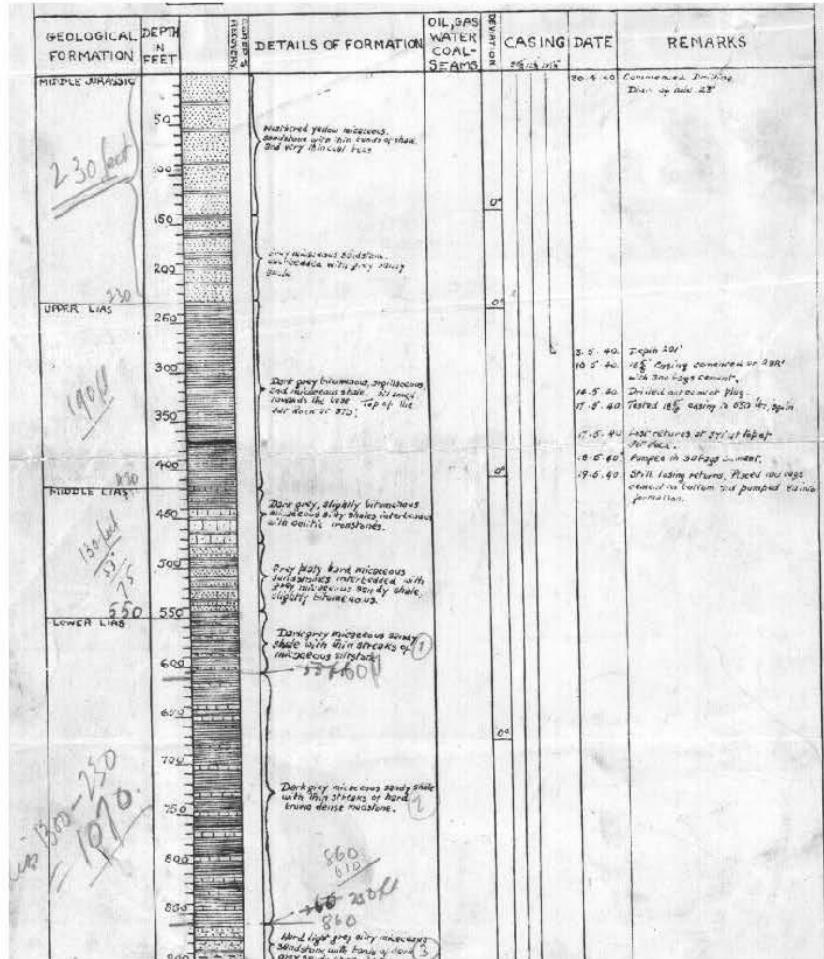
Not available.

Stratigraphy and aquifers (in blue):

Geology		Top (mbgl)	Base (mbgl)	Thickness (m)
Age	Formation			
Mid Jurassic	Ravenscar Group	surface	43	43
Jurassic	Upper Lias, Middle Lias, Lower Lias (Rhaetic (shale)/new name Penarth Group)	43	407	364
Triassic	Keuper Marls, Bunter Sandstone	407	890	483
Permo-Trias	Permo-Trias	890	973	83
Permian	Permian	973	1170	197
Carboniferous	Carboniferous	1170	1180	10

Note: Most beds unnamed.

Hydrocarbon well log:



Name and type of field: CLOUGHTON gas field

Grid reference of primary well: 499381, 496797

Number of wells in field: One, Cloughton 1

Licence number: No PEDL number

BGS reference: SE99NE/BJ/5

Location: Cloughton, N. Yorkshire



Hydrocarbon well information:

*All depths in mbgl

Depth: 3078 m

Hydrocarbon (oil and gas) shows: Gas show. Little gas recovered from Carboniferous sandstone or Magnesian Limestone

Water strikes: Not recorded

Comments: Plugged and abandoned after drilling.
Other HC wells near buffered zone.

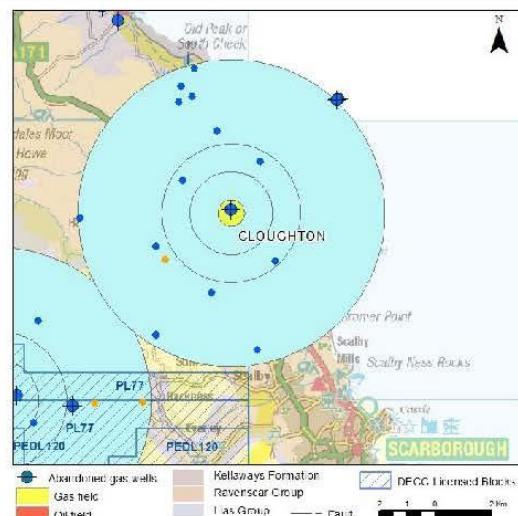
Bedrock aquifer: Ravenscar Group, Secondary A

Superficial aquifer: None

GW levels (main aq):

GW flow direction:

Other aquifer props: Deltaic and estuarine deposits, variable facies. Water quality issues.



Groundwater

Potential groundwater sampling points:

	Wellmaster	EA Licence	EA database
Within field	0	0	0
1km	0	0	0
2km	3	0	0
5km	14	1	0

Key

	EA monitoring network
	EA Licensed boreholes
	Wellmaster Boreholes
	Buffer Zone



Name of field: CLOUGHTON

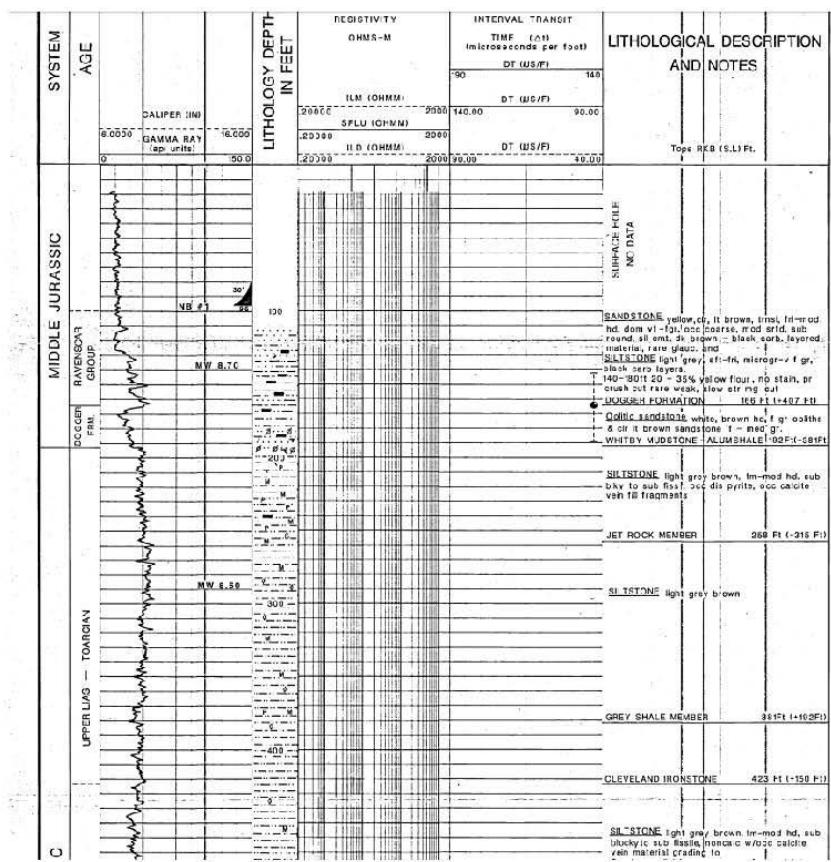
Cross section:

Not available.

Stratigraphy and aquifers (in blue):

Geology		Top (mbgl)	Base (mbgl)	Thickness (m)
Age	Formation			
Mid Jurassic	First 30m not logged, Ravenscar Group, Dogger Formation	?	59	
Jurassic	Upper Lias, Lias Group	59	471	412
Triassic	Penarth Group, Mercia Mudstone Group, Sherwood Sandstone Group	471	1100	633
Permian	Eskdale Group, Staintondale Group, Teeside Group, Aislaby Group, Don Group	1100	1820	717
Lower Permian	Rotliegendes/ Westphalian A	1820	~1840	~20
Upper Carb				
Carboniferous	Lower Westphalian A; Namurian A, B and C	~1840	3080	~1240

Hydrocarbon well log:



Name and type of field: ESKDALE gas field

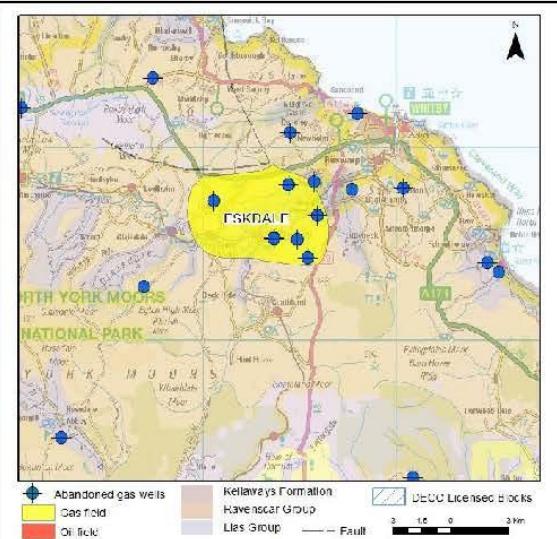
Grid reference of primary well: 484480, 508060

Number of wells in field: Eight, Eskdale 2 described below

Licence number: No PEDL locally.

BGS reference: NZ80NW/BJ/27

Location: Grosmont near Whitby, North Yorkshire



Hydrocarbon well information:

*All depths in m bgl

Depth: 1540 m

Hydrocarbon (oil and gas) shows: Gas found at and below 1300 m

Water strikes: Not recorded

Comments: Drilling problems encountered at Eskdale

1. Eskdale 2 – ‘put officially on production 23/09/60’ drilled 1939. Eight Eskdale wells in well field, a further 5 Eskdale wells in buffered zone.

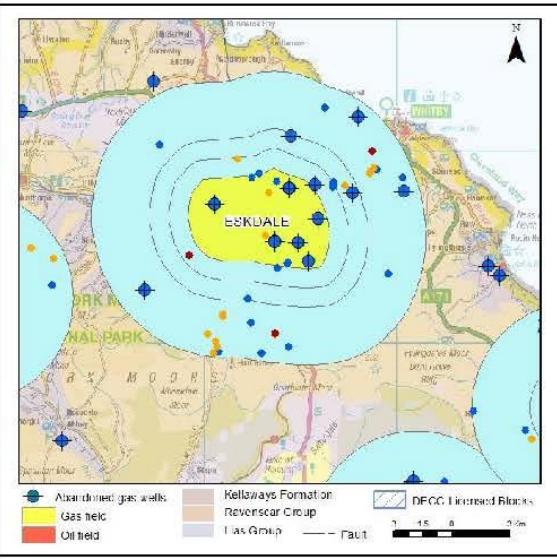
Bedrock aquifer: Ravenscar Group, Secondary A

Superficial aquifer: Till, Secondary A

GW levels (main aq):

GW flow direction:

Other aquifer props: Deltaic and estuarine deposits, variable facies. Water quality issues.



Groundwater

Potential groundwater sampling points:

	Wellmaster	EA Licence	EA database
Within field	6	2	0
1km	12	3	1
2km	14	4	1
5km	24	14	3

Key

●	EA monitoring network
○	EA Licensed boreholes
●	Wellmaster Boreholes
●	Buffer Zone



Name of field: ESKDALE

Cross section:

Not available.

Stratigraphy and aquifers (in blue):

Age	Formation	Geology		
		Top (mbgl)	Base (mbgl)	Thickness (m)
Jurassic	Ravenscar Group	?	?	
Jurassic	Upper, Middle, Lower Lias		378	
Triassic	Penarth Group (Rheatic), Keuper and Bunter.	378	1000	622
Permian	Saliferous Marl (Roxby Fm?), Upper Permian Salt, Upper Magnesian Lst, Middle Permian	1000	1540	550

Ravenscar Group not differentiated on log.

Hydrocarbon well log:

GEOLOGICAL FORMATION	DEPTH FEET	DRILLING RATE ft/min	DETAILS OF FORMATION	OIL, GAS, WATER, COAL SEAMS	DEVIATION	CASING	DATE	REMARKS
LIAS	UPPER		Cellar				17 - 1 - 37	Commenced drilling cellar 13' 6"
	MIDDLE		50	Hard dark grey micaceous shale and mudstone. Traces of pyrite, sandy limestones and fossil fragments. Sandy streaks and banding.				
			100					
			150					
			200	Shell (grey, brown?) fragments in yellow sandy limestone.	Brackish water 20°			188' Lost 78 cu ft of mud.
			250	Sandy mudstone, laminated with light grey sandstone		0°		200' Lost 415 cu ft of mud.
			300					256-264' Lost 480 cu ft of mud.
			350	Less sandy hard grey mudstone				274' Lost 36 cu ft of mud.
			400	420-422' Hard grey micaceous slightly sandy mudstone, with softer shaly mudstone below				297-308' Lost 36 cu ft of mud.
			450					
			500	475-50 Hard sandy shaly mudstone with brown limestone fragments, followed by hard grey slightly carbonaceous slightly sandy mudstone. Fossilsiferous in core 495-515'		0°		Depth 367' Shut down 5 days repairing 32 M Gears.
			550					
			600	Hard brown limestone fragments at 580-600' in shaly mudstone containing sandy limestone 605-625'				562' Lost 30 cu ft of mud.
			650					

Name and type of field: EVERTON gas field

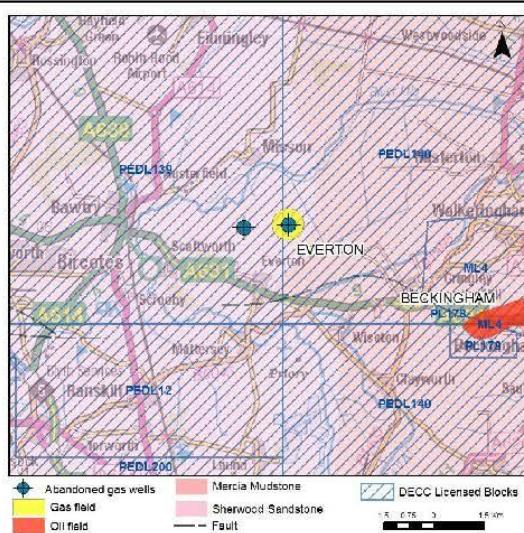
Grid reference of primary well: 470175, 392960

Number of wells in field: One, Everton 1 described below

Licence number: PEDL139

BGS reference: SK79SW/BJ/22

Location: Everton, North Nottinghamshire



Hydrocarbon well information:

Depth: 1660 m

Hydrocarbon (oil and gas) shows: No details

Water strikes: No details

Comments: Enterprise Oil drilled Everton 1 well – deep oil target reached. Everton 2 was drilled as a coal bed methane borehole by Greenpark Energy in 2010. Exploration of the Everton Coalfield – abandoned without reaching target formation.

Bedrock aquifer: Sherwood Sandstone, Principal aquifer.

Superficial aquifer: Peat, Secondary A, unproductive.

GW levels (main aq): -

GW flow direction: Eastwards

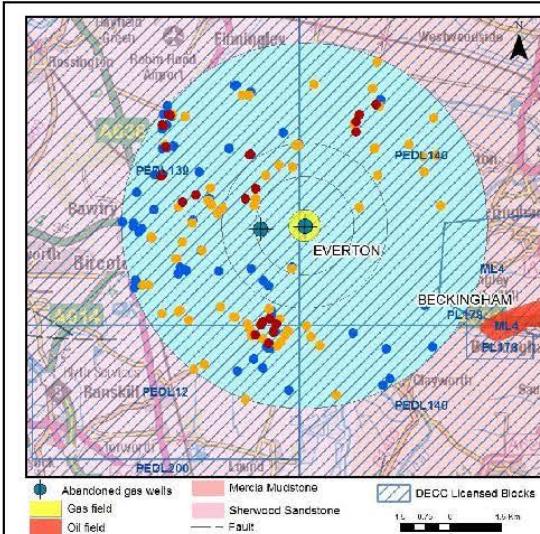
Other aquifer props: Unconfined. Dual porosity, fractures significantly contribute to GW flow. $T = 76\text{--}92 \text{ m}^3/\text{d}$.

Groundwater

Potential groundwater sampling points:

	Wellmaster	EA Licence	EA database
Within field	0	0	0
1km	1	1	0
2km	5	10	2
5km	75	80	24

Key

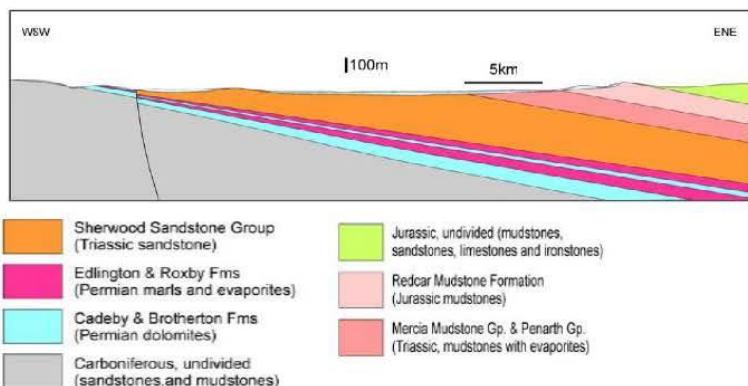


	EA monitoring network
	EA Licensed boreholes
	Wellmaster Boreholes
	Buffer Zone



Name of field: EVERTON

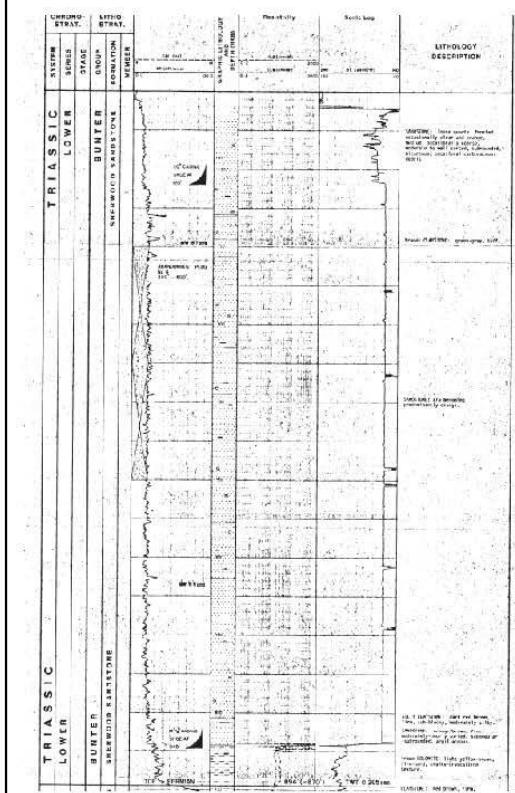
Cross section:



Stratigraphy and aquifers (in blue):

Geology		Top (mbgl)	Base (mbgl)	Thickness (mbgl)
Age	Formation			
Triassic	Sherwood Sandstone	surface	272	272
Permian	Zechstein – Upper Marls, Upper Magnesian Lst, Middle Marls, Lower Magnesian Lst	272	419	147
Carboniferous	Middle Coal Measures, Lower Coal measures, Millstone Grit	419	2079	1660

Hydrocarbon well log:



Name and type of field: GODLEY BRIDGE gas field

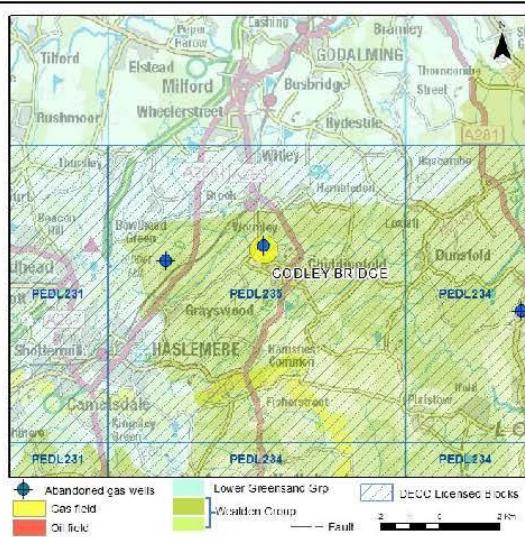
Grid reference of primary well: 495232, 136640

Number of wells in field: One, Godley Bridge 1 described below

Licence number: PEDL 235

BGS reference: SU93NE/B1/21

Location: Chiddingfold, Sussex



Hydrocarbon well information:

*All depths in mbsf

Depth: 2584 m

Hydrocarbon (oil and gas) shows: Gas analysis for CH₄, C₂H₆, C₃H₈, C₄H₁₀ in log. Just CH₄ until 823 m. Highest concentrations of all gasses 1873 m. See log and 'production during drilling' file.

Water strikes: Not recorded.

Comments: Discovery, not field. Two other Godley Bridge HC wells within the buffered zone.

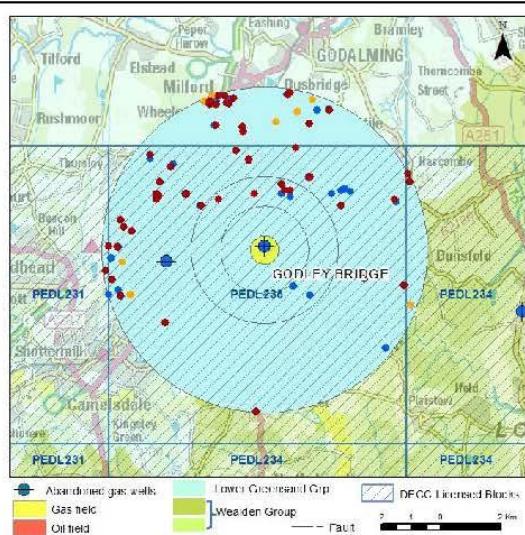
Bedrock aquifer: Weald Clay Formation, Secondary A

Superficial aquifer: Alluvium

GW levels (main aq):

GW flow direction:

Other aquifer props: Patchy aquifer, faulting.



Groundwater

Potential groundwater sampling points:

	Wellmaster	EA Licence	EA database
Within field	0	0	0
1km	0	0	0
2km	8	0	6
5km	71	24	57

Key

	EA monitoring network
	EA Licensed boreholes
	Wellmaster Boreholes
	Buffer Zone



Name of field: GODLEY BRIDGE

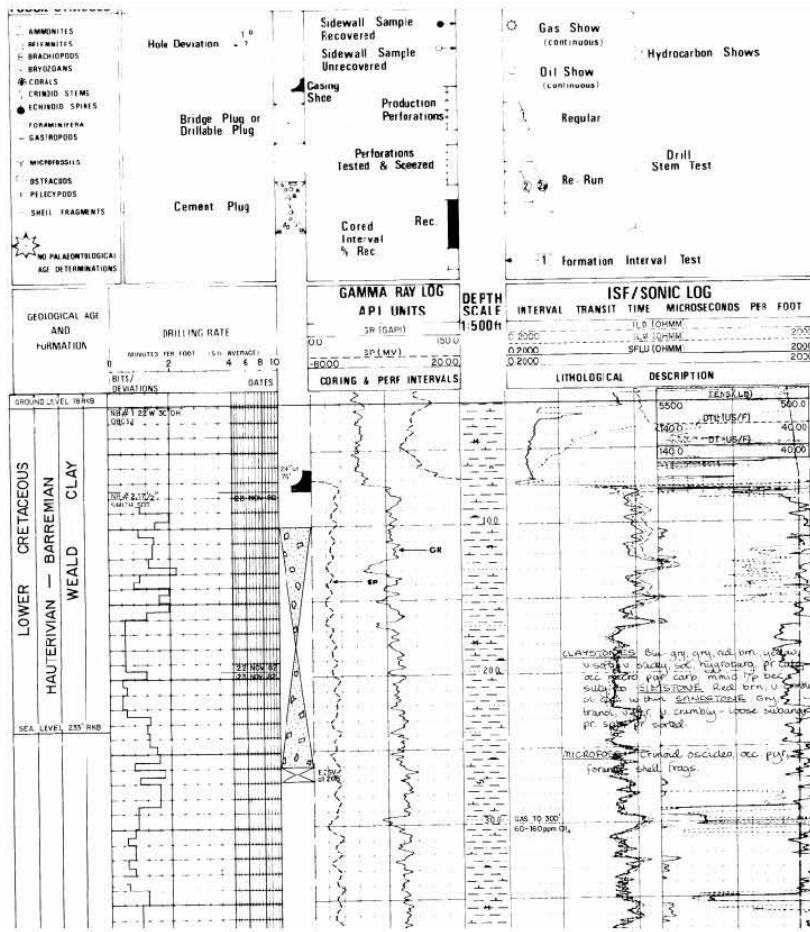
Cross section:

Not available.

Stratigraphy and aquifers (in blue):

Geology		Top (mbgl)	Base (mbgl)	Thickness (m)
Age	Formation			
Cretaceous	Weald Clay	surface	345	345
Cretaceous	Hastings Beds, Purbeck Beds (Durlston Fm)	345	734	389
Jurassic	Purbeck beds (Lulworth Fm, Purbeck Anhydrite), Portland Beds, Kimmeridge Clay, Corallian Beds, Oxford Clay, Kellaway Beds,	734	1780	1046
Middle Jurassic	Great Oolite Series, Inferior Oolite series	1780	2000	220
Lower Jurassic	Upper, Middle and Lower Lias,	2000	2580	580

Hydrocarbon well log:



Name and type of field: HEATHFIELD gas field

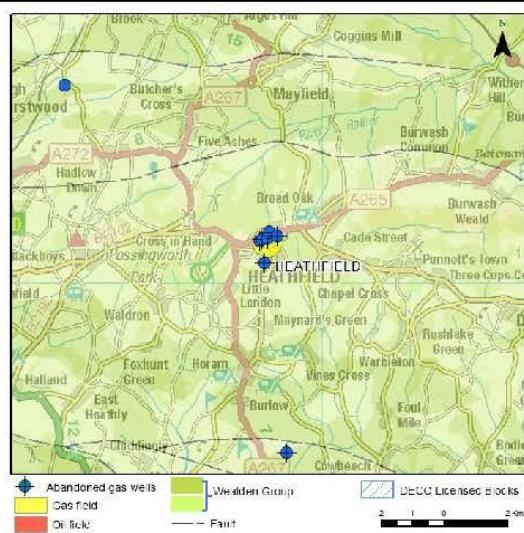
Grid reference of primary well: 558110, 121380

Number of wells in field: Five. See below

Licence number: No PEDL or other licence details

BGS reference: TQ52SE/BJ/7, 9 to 13.

Location: Heathfield, East Sussex



Hydrocarbon well information:

*All depths in mbgl

Depth: TQ52SE/BJ/9 115 m. Drilled or completed depths not recorded for 5 of the wells. Article suggests 3 wells were 76 m, 91 m, 107 m deep.

Hydrocarbon (oil and gas) shows: Well 4 produced 68200 m³/day enough to provide natural gas to a small number of houses. Well at the Railway station (TQ52SE/BJ/9) provided gas to at least 1957.

Water strikes: Railway well records no water.

Comments: Prospective water wells that produced gas. A further HC well, Heathfield 6 within the buffered zone.

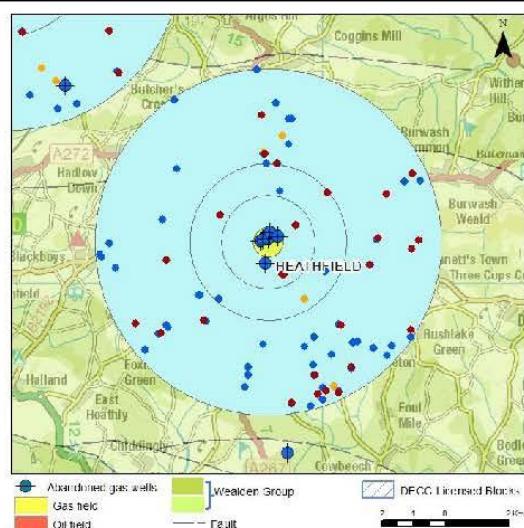
Bedrock aquifer: Ashdown Formation, Secondary A.

Superficial aquifer: None recorded

GW levels (main aq):

GW flow direction:

Other aquifer props: Complex hydrogeology, patchy, multi-layered aquifer, faulting in region.



Groundwater

Potential groundwater sampling points:

	Wellmaster	EA Licence	EA database
Within field	4	0	0
1km	6	0	3
2km	11	1	5
5km	69	5	27

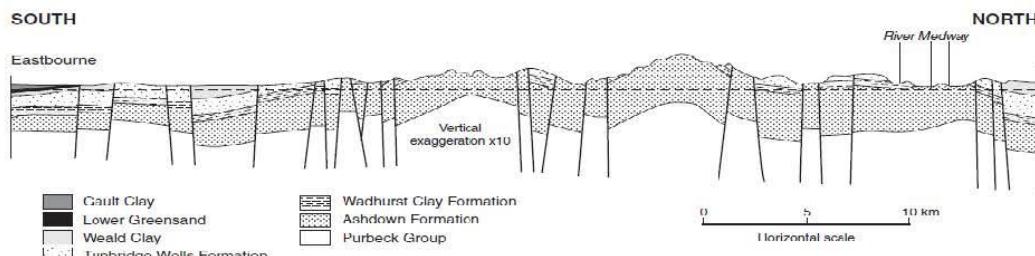
Key

●	EA monitoring network
●	EA Licensed boreholes
●	Wellmaster Boreholes
●	Buffer Zone



Name of field: HEATHFIELD

Cross section:



Stratigraphy and aquifers (in blue):

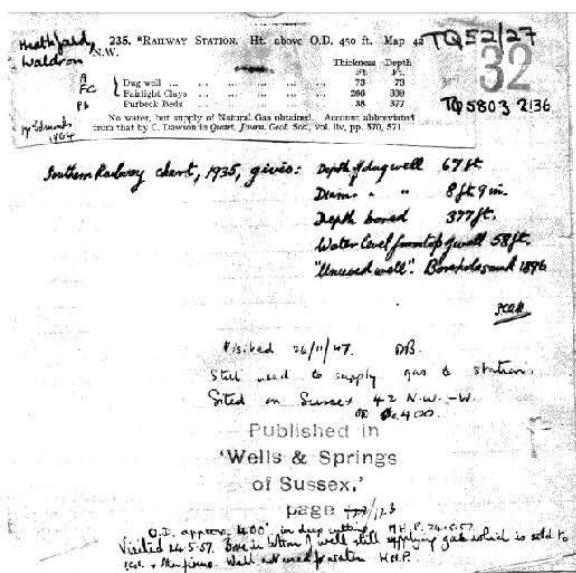
Geology		Top (mbgl)	Base (mbgl)	Thickness (m)
Age	Formation			
Cretaceous	Ashdown sands		103	103?
Jurassic	Purbeck	103	115	12

No borehole log exists for five of the boreholes. Boreholes were not cored and samples were poor. They are quoted as Ashdown Sands at least 81m, Purbeck about 30 m.

The above log is for (TQ52SE/BJ/9) of which the first 22 m is an existing dug well.

Hydrocarbon well log:

No borehole log exists for five of the six boreholes, just a description which records boreholes were not cored and samples were poor. The log for the well at the Railways station (TQ52SE/BJ/9) is below.



Name and type of field: IRONVILLE gas field

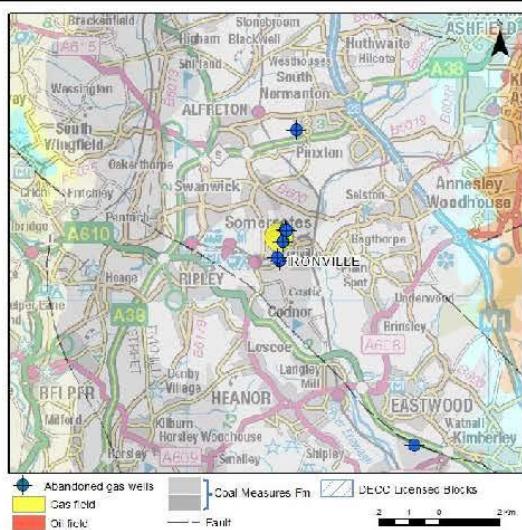
Grid reference of primary well: 443300, 352300

Number of wells in field: Three, Ironville 3 described below

Licence number: No licence number

BGS reference: SK45SW/BJ/14

Location: Ironville, Derbyshire



Hydrocarbon well information:

*All depths in mbsf

Depth: 836 m

Hydrocarbon (oil and gas) shows: Oil show 180 to 190m, 240m, 370m, 408m, 615m, 660m, 710m and 830m. Oil and gas shows 515 to 530m, 585m, 680m. Tested ~235m 0.3 m³/day water and trace gas. 36 to 60 m³/day gas between 510-535 m.

Water strikes: Possible strike 45-50 m. Between 700-735 m ~9 m³/day of water.

Comments: Gas for electricity, discovery not field. Three further Ironville HC wells within the buffer zones.

Bedrock aquifer: Lower Coal Measures, Secondary A

Superficial aquifer: None

GW levels (main aq):

GW flow direction:

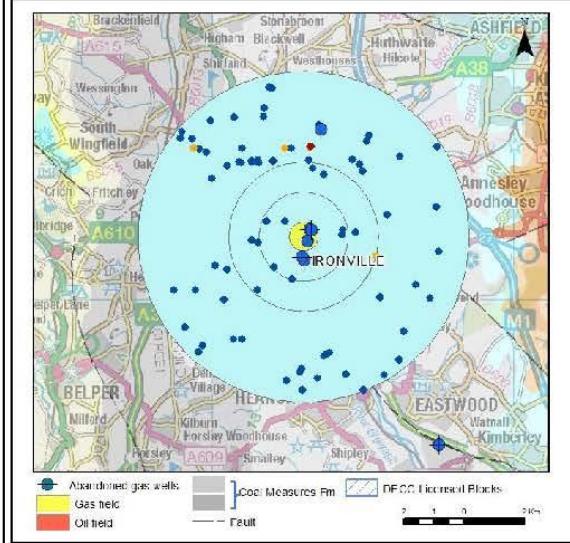
Other aquifer props: predominantly fracture flow in Coal Measures sandstones. Higher yields near old mines.

Groundwater

Potential groundwater sampling points:

	Wellmaster	EA Licence	EA database
Within field	3	0	0
1km	10	0	0
2km	16	0	0
5km	85	4	1

Key



●	EA monitoring network
●	EA Licensed boreholes
●	Wellmaster Boreholes
●	Buffer Zone



Name of field: IRONVILLE

Cross section:

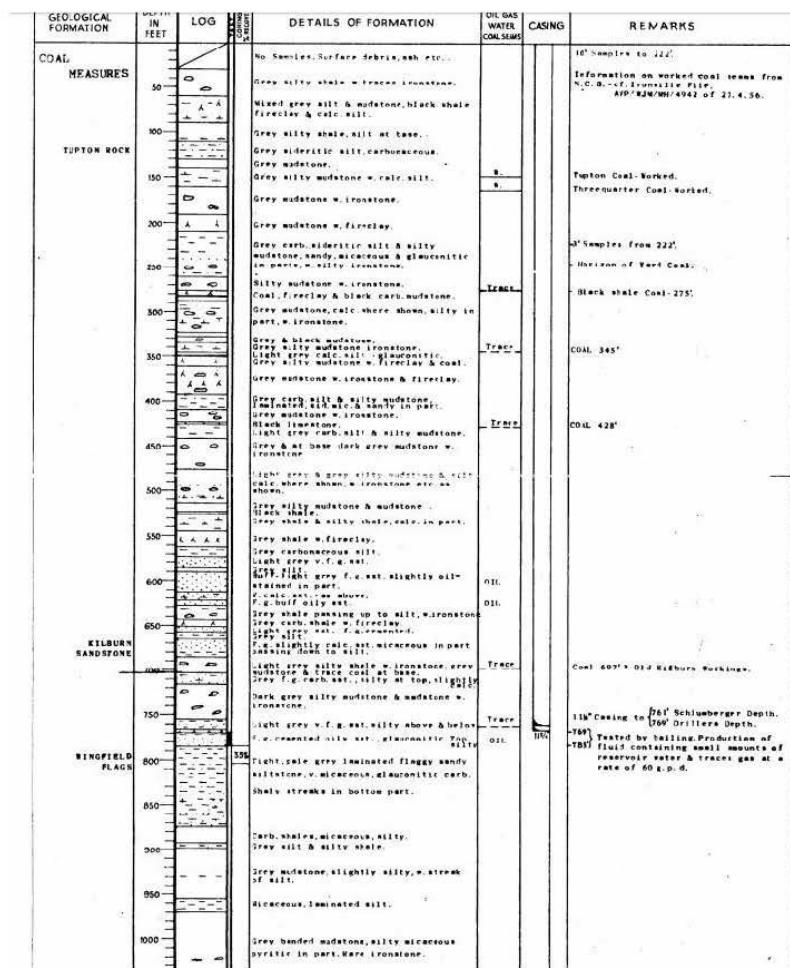
Not available.

Stratigraphy and aquifers (in blue):

Geology		Top (mbgl)	Base (mbgl)	Thickness (m)
Age	Formation			
Carboniferous	Coal Measures	surface	399	399
Carboniferous	Millstone Grit	399	681	282
Carboniferous	Carboniferous Limestone Series	681	836	155

Detailed geological description within the log file.

Hydrocarbon well log:



Name and type of field: NOOKS FARM gas field

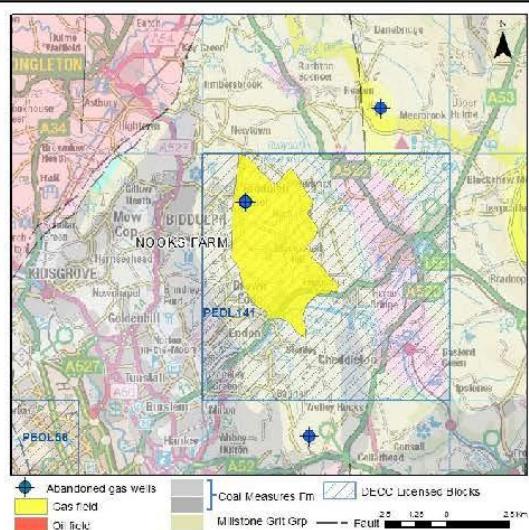
Grid reference of primary well: 391747, 0358032

Number of wells in field: Three, Nooks Farm 1a described below

Licence number: PEDL 141

BGS reference: SJ95NW/BJ/12

Location: Biddulph Moor, Staffordshire



Hydrocarbon well information:

*All depths in mbsf

Depth: 625 m

Hydrocarbon (oil and gas) shows: Good gas production.

Water strikes: None recorded

Comments: Nook Farm 1 – ‘unsatisfactory’. Nook Farm 1a drilled as replacement. Well 1z is listed as ‘current’. Werrington 1 and Gun Hill 1 HC wells within the buffer zone.

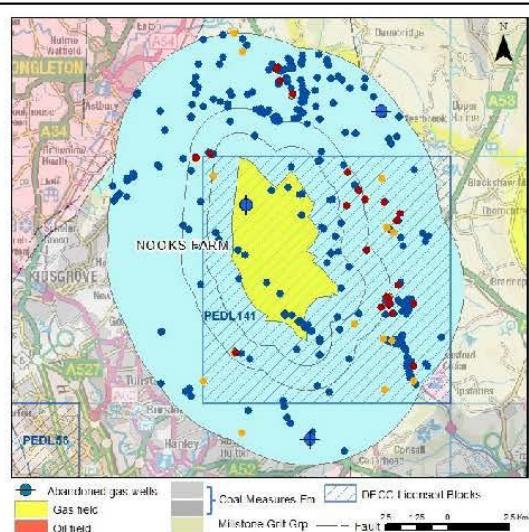
Bedrock aquifer: Millstone Grit Group, Secondary A

Superficial aquifer: Till, Secondary Undiff

GW levels (main aq):

GW flow direction:

Other aquifer props: Predominantly fracture flow. Variable yields.



Groundwater

Potential groundwater sampling points:

	Wellmaster	EA Licence	EA database
Within field	15	0	0
1km	40	3	0
2km	81	7	10
5km	289	28	34

Key

●	EA monitoring network
●	EA Licensed boreholes
●	Wellmaster Boreholes
●	Buffer Zone



Name of field: NOOKS FARM

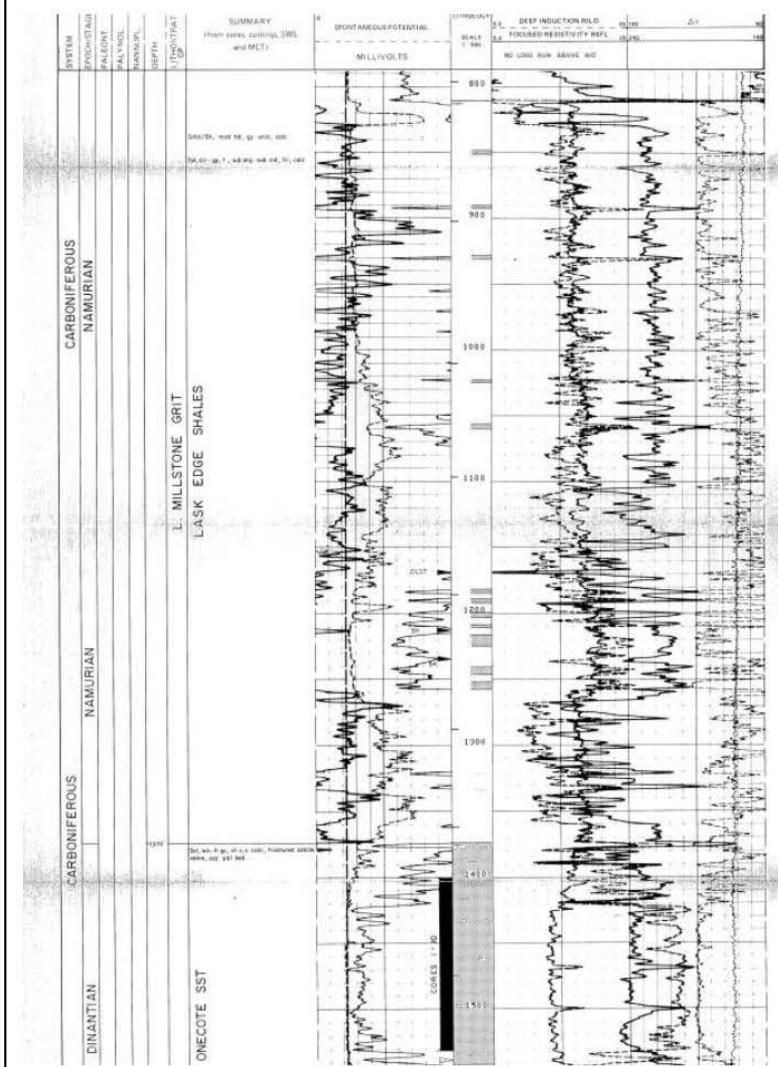
Cross section:

Not available.

Stratigraphy and aquifers (in blue):

Geology		Top (mbgl)	Base (mbgl)	Thickness (m)
Age	Formation			
Carboniferous	Millstone Grit	surface	419	419
Carboniferous	Carboniferous Limestone	419	625	206

Hydrocarbon well log:



Name and type of field: RALPH CROSS gas field

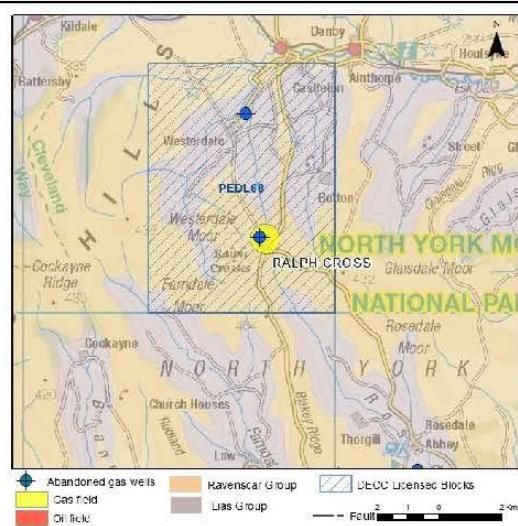
Grid reference of primary well: 467583, 502423?

Number of wells in field: One, Ralph Cross 1

Licence number: PEDL68

BGS reference: NZ60SE/BJ/1

Location: Westerdale Moor, North Yorkshire



Hydrocarbon well information:

*All depths in mbgl

Depth: 1631 m (Difficult to link to other records)

Hydrocarbon (oil and gas) shows: Methane noted in log in 'considerable' amounts.

Water strikes:

Comments: Westerdale 1 HC well within the 5 km buffered zone.

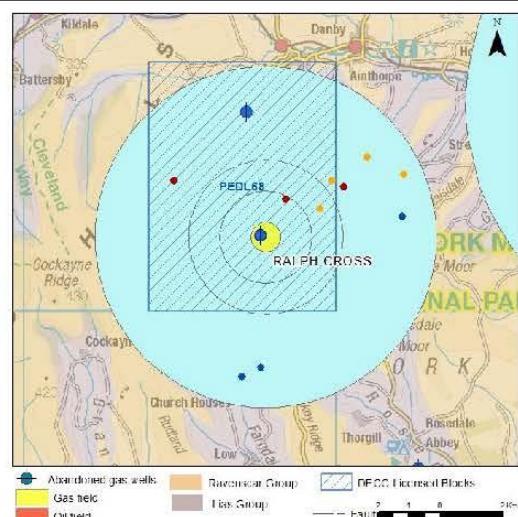
Bedrock aquifer: Jurassic Ravenscar Group, Secondary A

Superficial aquifer: None

GW levels (main aq):

GW flow direction:

Other aquifer props:



Groundwater

Potential groundwater sampling points:

	Wellmaster	EA Licence	EA database
Within field	0	0	0
1km	0	0	1
2km	0	2	1
5km	3	4	3

Key

	EA monitoring network
	EA Licensed boreholes
	Wellmaster Boreholes
	Buffer Zone



Name of field: RALPH CROSS

Cross section:

Not available.

Stratigraphy and aquifers (in blue):

Geology		Top (m)	Base (m)	Thickness (m)
Age	Formation			
	Log starts at 914 m	914		
	Upper Mag Limestone	1039	1071	
	Evaporite	1071	1079	
	Middle Magnesian Limestone	1079	1631	

Hydrocarbon well log:

NZ 60SE /1

RALPH CROSS NO. 1 G II (b) 1

SAMPLE DESCRIPTION

Interval	Description
3000-3010	Sandstone, brick red, medium grained, sub-angular, mainly quartzose with infrequent black speckling, slightly dolomitic, dense, grading in part to a sandstone, brick red, fine grained, marly, sporadically micaceous, dense.
3010-3015	Sandstone, as above, variably fine and medium grained, and interbedded shale, brick red, slightly dolomitic.
3015-3030	Shale, brick red, slightly dolomitic, in part micromicaceous, gypsum veinlets and interbedded sandstone, brick red, becoming finer grained and more argillaceous, dense.
3030-3035	As above, becoming increasingly shaly.
3035-3055	Shale, brick red, slightly dolomitic to moderately dolomitic, moderately high, variable silt to fine sand content, firm, variably micromicaceous, grading to fine interbeds of sandstone, brick red, fine grained, dense.
3055-3060	Predominantly shale, brick red, dolomitic, firm, variable silt to fine grained sand content, in part micromicaceous with minor amounts of sandstone, brick red, fine grained, brick red shale matrix, dense.
3060-3065	Shale, brick red, dolomitic, variably micaceous, and interbedded sandstone, brick red, fine grained, argillaceous, dolomitic, firm, dense.
3065-3085	As above, shale increasingly micaceous and with infrequent gypsum blebs.
3085-3095	Landed 9-5/8" casing at 3083' K.B. Shale, red, dolomitic, considerable sand content, firm, variably micaceous. (Also abundant cement.) Samples of very poor quality.
3095-3120	Cement only.

Name and type of field: TWYFORD gas field

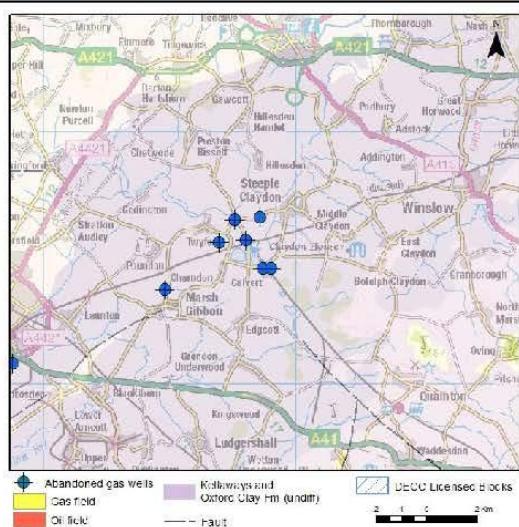
Grid reference of primary well: 467600, 226500

Number of wells in field: Four, Twyford 2 described below.

Licence number: No PEDL

BGS reference: SP62NE/BJ/3

Location: Twyford, Buckinghamshire



Hydrocarbon well information:

*All depths in mbgl

Depth: 154 m

Hydrocarbon (oil and gas) shows: No gas until 126 m then gas and water to 144 m.

Water strikes:

Comments: No field, Sub-commercial, shallow Jurassic. Four Twyford HC wells within 1 km. An additional 2 (Calver East 1 and Calver West 1) within 1 km buffer zone and Marsh Gibbon 1 within the 5 km buffer zone.

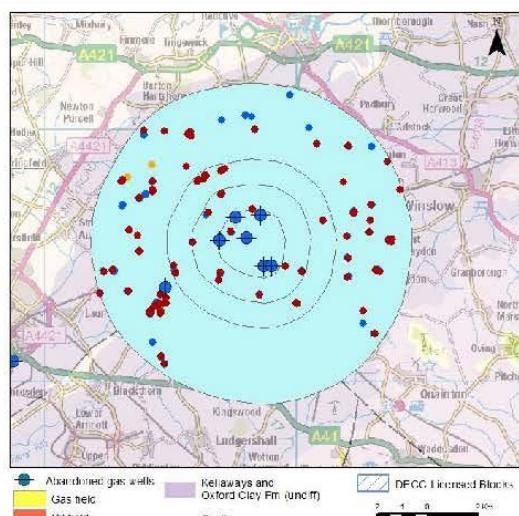
Bedrock aquifer: Oxford Clay, unproductive

Superficial aquifer: none

GW levels (main aq):

GW flow direction:

Other aquifer props:



Groundwater

Potential groundwater sampling points:

	Wellmaster	EA Licence	EA database
Within field	8	0	7
1km	14	0	17
2km	20	0	31
5km	82	2	90

Key

●	EA monitoring network
○	EA Licensed boreholes
■	Wellmaster Boreholes
●	Buffer Zone



Name of field: TWYFORD

Cross section:

Not available.

Stratigraphy and aquifers (in blue):

Geology		Top (mbgl)	Base (mbgl)	Thickness (m)
Age	Formation			
Jurassic	Lower Oxford Clay	surface	8	8
Jurassic	Kellaways, Cornbrash Fm, Great and Inferior Oolite, Upper, Middle and Lower Lias	8	138	130
Triassic	Rheatic (Penarth Grp) or Tywford Beds	138	140	2
Lower Paleozoic	Cambrian or Tremadoc	140	154	14

There is a difference of opinion between the BP and M.G. Sumbler's logs. See below.

Hydrocarbon well log:

Twyford No 2 (BP, 1981)		SP62NE/3		
		NGR 6760 2650		
		Log Types available Gamma Ray; Resistivity; Chippings, cores		
RG Box No 3248				
Ground level	277.4	84.6		
Datum Level	278.9	85.0		
casing to	503	153.3		
terminal depth	505	153.9		
	ft	m		
Oxford Clay Formation and	0	0.0	26	7.6
Kellaways Sand Member	25	7.6	35	10.7
Kellaways Clay Member	36	10.7	42	12.8
Combeas Formation	42	12.8	47	14.3
Forest Marble Formation	47	14.3	58	16.8
White Limestone Fm	55	16.8	103	31.4
with Blaen Member at	56	16.8	86	20.1
Arley Member at	66	20.1	83	25.3
Shipton Member at	83	25.3	103	31.4
Rutland Formation	103	31.4	119	36.3
Taynton Limestone	119	36.3	140	42.7
Sherp's Hill Formation	140	42.7	144	13.9
Horsehay Sand Formation	144	23.9	148	45.1
Whitby Mudstone Formation	148	45.1	179	54.6
Marlstone Rock Formation	179	54.6	184	56.1
Dyrrham Formation	184	56.1	211	64.3
Charmouth Mud Formation	211	64.3	452	137.8
with 100 Marker at	260	79.2	294	86.5
85 Marker at	308	93.9	320	97.5
?70 Marker at	390	118.9	399	121.6
?Penarth Group (Twyford Beds)	452	137.8	458.5	139.8
Tremadoc (dip 80°)	455.5	139.8	505	153.9
				14.2
			m OD	
			+77.4 OD	
			+74.3 OD	
			+72.2 OD	
			+70.7 OD	
			+68.2 OD	
			+63.6 OD	
			+64.9 OD	
			+59.7 OD	
			+53.6 OD	
			+48.7 OD	
			+42.3 OD	
			+41.1 OD	
			+39.9 OD	
			+30.4 OD	
			+28.9 OD	
			+20.7 OD	
			+5.8 OD	
			+4.5 OD	
			+2.5 OD	
			-36.6 OD	
			-54.8 OD	
			-58.9 OD	

Interpreted from Gamma Ray Log NB: Upper part is radically different from BP completion log and IGS chipping record, the classification of which appears to be substantially wrong.
NB: There remains some doubt about the classification of the lower part of the Great Oolite Group. Compare the cored bh. Calvert 1/76 SP62SE/20. The ?Penarth Group is Twyford Beds facies; green-grey argillaceous calcareous sandstones which were proved by coring and produce a fairly marked leftward peak in the gamma log. There is little evidence to support the assumed Rhaetian age, and in my view these strata could well be Sinemurian-Pliensbachian

M G Sumbler

12 October 2000

Name and type of field: BAXTERS COPSE oil field

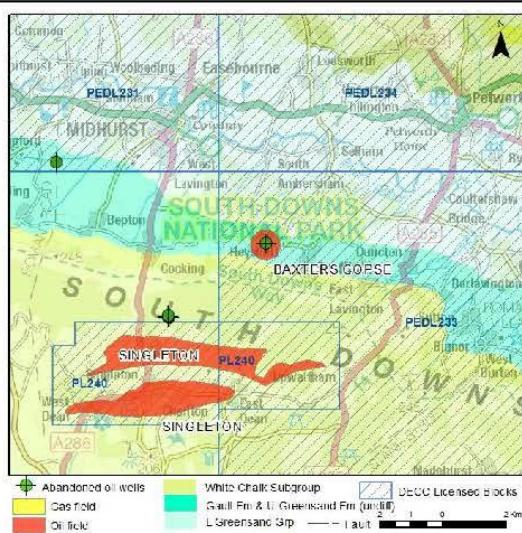
Grid reference of primary well: 491496, 117733

Number of wells in field: One, Baxters Copse 1

Licence number: PEDL 233

BGS reference: SU91NW/BJ/10

Location: Graffham, West Sussex



Hydrocarbon well information:

*All depths in mbsf

Depth: 2365 m

Hydrocarbon (oil and gas) shows: Some CH₄, C₂H₆, C₃H₈, C₄H₁₀ seen during drilling, details on log.

Borehole produced 150 BFPD (25% was 37° API oil, light crude oil).

Water strikes: Not noted.

Comments: Discovery not field. Oil and gas in field. Five additional Singleton HC wells within the buffered area.

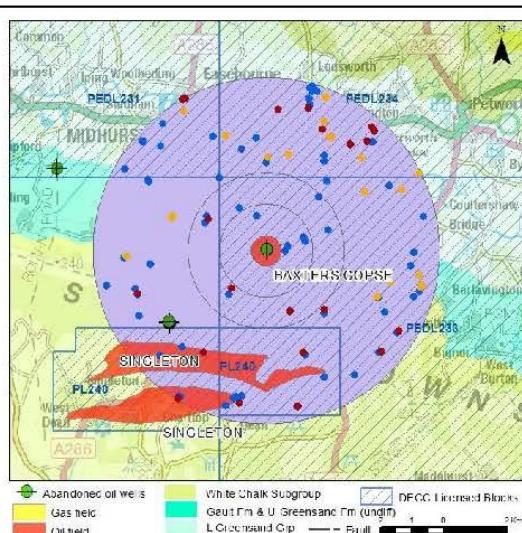
Bedrock aquifer: Gault Formation, unproductive

Superficial aquifer: None

GW levels (main aq):

GW flow direction:

Other aquifer props: No Upper Greensand present at this site, only Gault Fm.



Groundwater

Potential groundwater sampling points:

	Wellmaster	EA Licence	EA database
Within field	0	0	0
1km	6	0	0
2km	12	0	4
5km	78	22	27

Key

●	EA monitoring network
●	EA Licensed boreholes
●	Wellmaster Boreholes
●	Buffer Zone



Name of field: BAXTERS COPSE

Cross section:

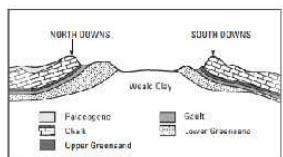
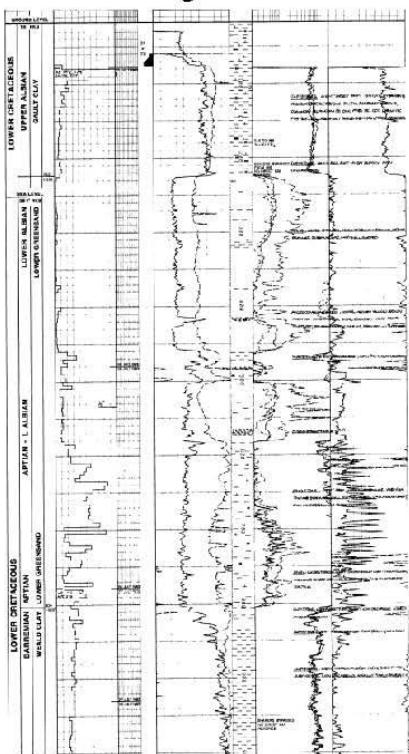


Figure 5.2.10 Schematic representation of the Lower Greensand Group of the Weald dipping away from outcrop.

Stratigraphy and aquifers (in blue):

Geology		Top (mbgl)	Base (mbgl)	Thickness (m)
Age	Formation			
Cretaceous	Gault Formation	surface	69	69
Cretaceous	Lower Greensand	69	245	176
Cretaceous	Weald Clay, Hastings Beds, Durston Fm	245	783	538
Upper Jurassic	Purbeck Beds, Portland Beds, Kimmeridge Clay, Corallian Beds, Oxford Clay, Kellaway Beds	783	1510	727
Middle Jurassic	Great and Inferior Oolite Series	1510	1720	210
Lower Jurassic	Upper, Middle and Lower Lias	1720	2120	400
Triassic	Penarth Grp, Mercia Mudstone Grp, Sherwood Sandstone Group	2120	2270	150
?	?	2270	2370	100

Hydrocarbon well log:



Name and type of field: BECKERING oil Field

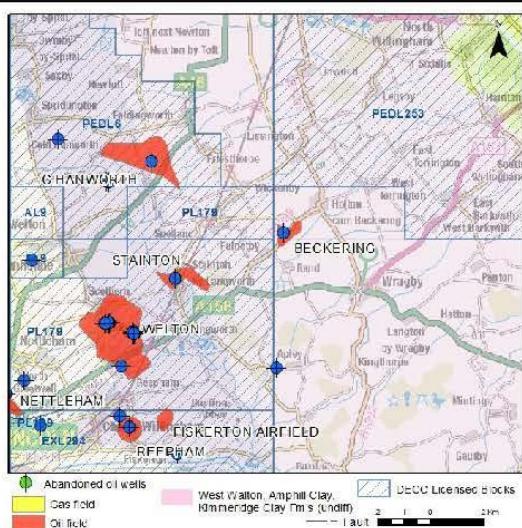
Grid reference of primary well: 510396, 380252

Number of wells in field: One, Beckering 1

Licence number: No PEDL

BGS reference: TF18SW/BJ/13

Location: Berkerking, Lincolnshire



Hydrocarbon well information:

*All depths in mbgl

Depth: 1699 m

Hydrocarbon (oil and gas) shows: No details

Water strikes: No details

Comments: Beckering 1 buffered zone overlaps with other oil fields. Within the buffered zone are the following HC wells Apley 1 and 5 Stainton wells.

Bedrock aquifer: Ampthill Clay, unproductive

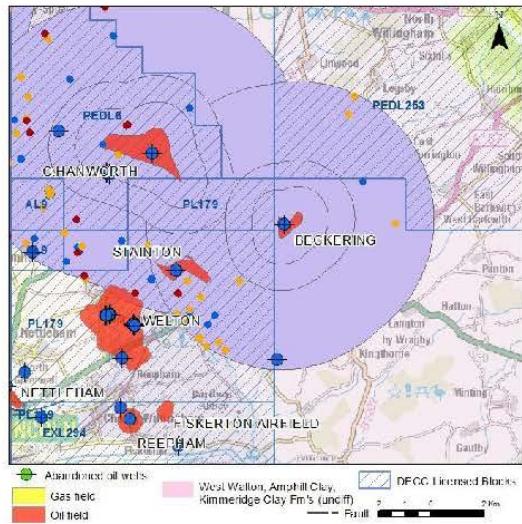
Superficial aquifer: Glaciofluvial deposits – sands and gravels. Secondary A

GW levels (main aquifer):

GW flow direction:

Other aquifer props:

[View Details](#)



Groundwater

Potential groundwater sampling points:

	<i>Wellmaster</i>	<i>EA Licence</i>	<i>EA database</i>
Within field	0	0	0
1km	0	0	0
2km	0	0	0
5km	5	15	2

Key

	EA monitoring network
	EA Licensed boreholes
	Wellmaster Boreholes
	Buffer Zone



Name of field: BECKERING

Cross section:

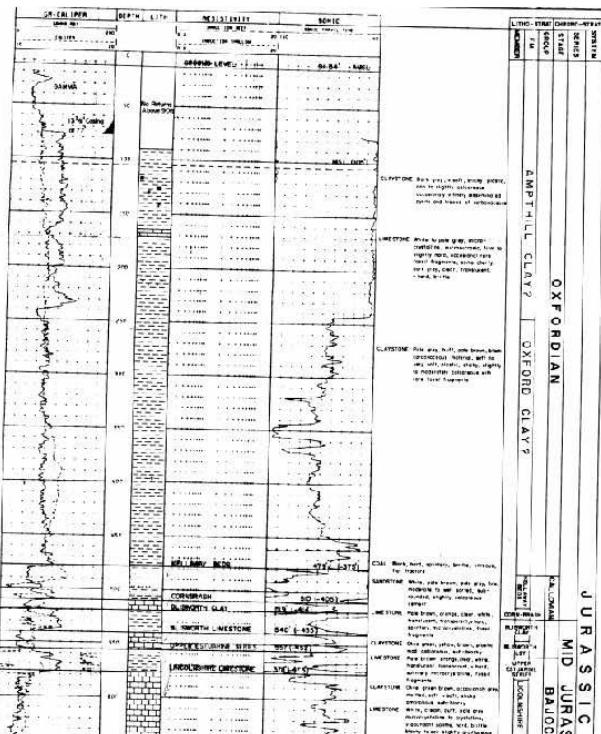
Not available.

Stratigraphy and aquifers (in blue):

Age	Formation	Geology		
		Top (mbgl)	Base (mbgl)	Thickness (m)
Recent	Glaciofluvial sands and gravels	surface	?	?
Jurassic	Amphill Clay/ Oxford Clay	?	146	?
Jurassic	Kellaway Beds, Cornbrash, Blisworth Clay, Blisworth Lst Upper Estuarine series, Lincolnshire Lst, Upper, Middle and Lower Lias	146	452	306
Triassic	Penarth, Mercia Mudstone, Sherwood Sst	452	975	523
Permian	Zechstein, Basal Sands	975	~1180	205
Carboniferous	Westphalian A, B and C, Namurian-Dinantian	~1180	1700	520

Top of borehole not logged.

Hydrocarbon well log:



Name and type of field: BELVOIR oil field

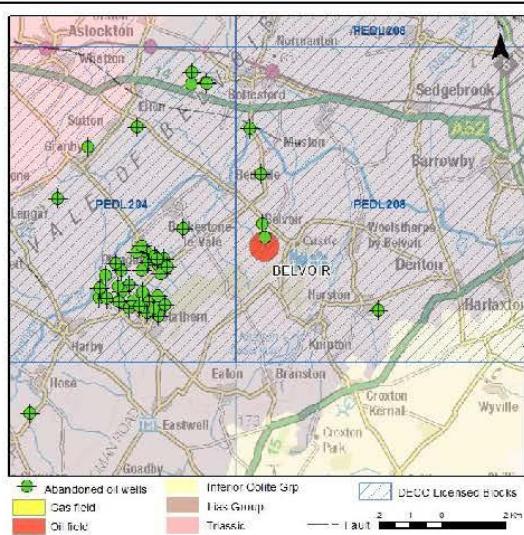
Grid reference of primary well: 480924, 333979

Number of wells in field: One, Belvoir 1

Licence number: PEDL 208

BGS reference: SK83SW/BJ/107

Location: Belvoir, Leicestershire



Hydrocarbon well information:

*All depths in mbgl

Depth: 960 m

Hydrocarbon (oil and gas) shows: Presence of oil seen in the core description from about 560 m to 590m, 700 m, 860 m to 920 m

Water strikes:

Comments: Discovery, not field. Noted as a potential oil producer. Details of oil, gas and water flow/ trace has been obscured on this log. One additional HC well 0 to 1 km, 1 HC well within 1-2km, 38 HC wells within 2 to 5 km of well field. Total 40 additional HC wells in the buffered zone.

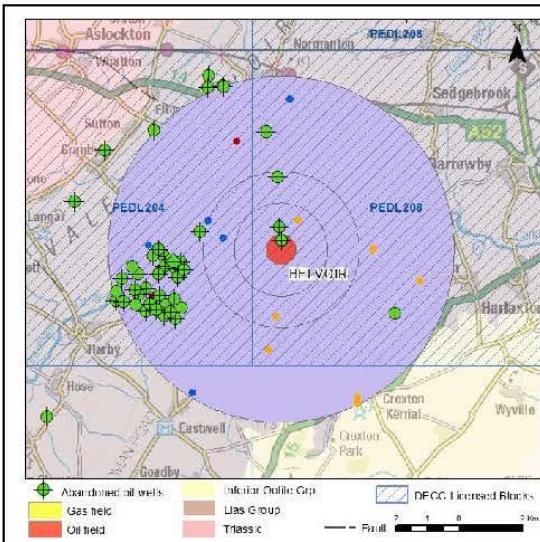
Bedrock aquifer: Lias Group/ (Charmouth Mudstone Fm), Secondary Undiff.

Superficial aquifer: Secondary Undiff

GW levels (main aq):

GW flow direction:

Other aquifer props: Seen in borehole log as mudstone with limestone bands.



Groundwater

Potential groundwater sampling points:

	Wellmaster	EA Licence	EA database
Within field	0	0	0
1km	0	1	0
2km	2	2	0
5km	37	8	2

Key

●	EA monitoring network
●	EA Licensed boreholes
●	Wellmaster Boreholes
●	Buffer Zone



Name of field: BELVOIR

Cross section:

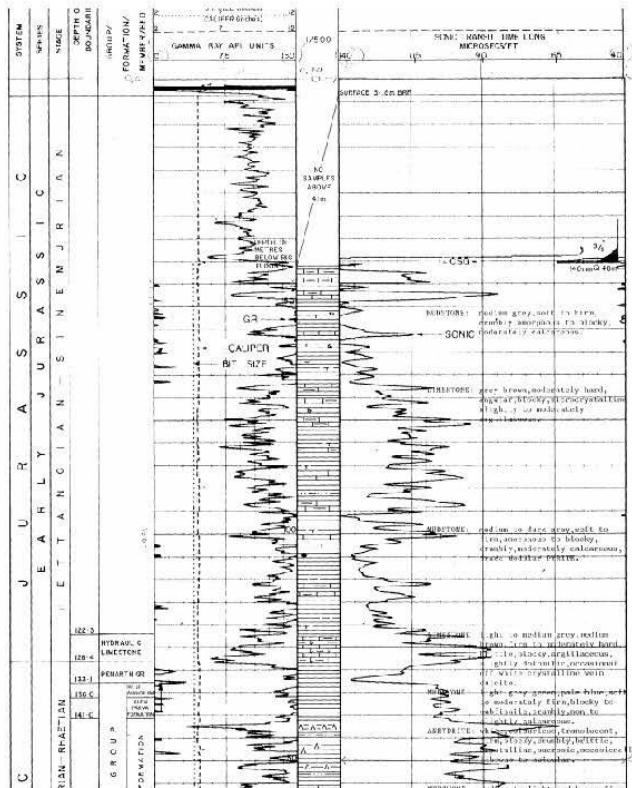
Not available.

Stratigraphy and aquifers (in blue):

Geology		Top (mbgl)	Base (mbgl)	Thickness (m)
Age	Formation			
Jurassic	Hettangian - Sinemurian		128.4	
Triassic	Penarth Group, Mercia Mudstone Group, Sherwood Sandstone Group	128	466	338
Permian	Zechstein Marl, Basal Permian Breccia	466	484	18
Carboniferous	Westphalian A and B, Marsdenian-Yeadonian, Kinderscoutian, Dinantian	484	960	476

More detail in log. No samples above 41 m

Hydrocarbon well log:



Name and type of field: BRIGG oil field

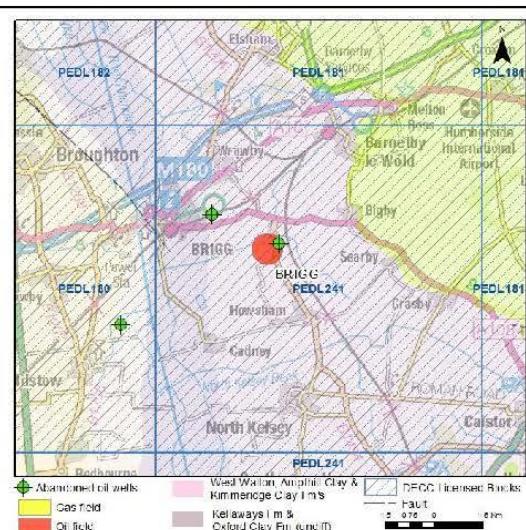
Grid reference of primary well:

Number of wells in field: Two, Brigg 1 described below.

Licence number: PEDL 241

BGS reference: TA00NW/BJ/122

Location: Brigg, Lincolnshire



Hydrocarbon well information:

*All depths in mbgl

Depth: 1937m

Hydrocarbon (oil and gas) shows: Oil shows from 1650 m to 1750 m and 1880 m to bottom of hole.

Water strikes: Not recorded.

Comments: Oil well, not field - not developed.

Three additional Glanford HC wells in 1-2km buffer zone and 1 Hibaldstow HC well within 2-5km buffer.

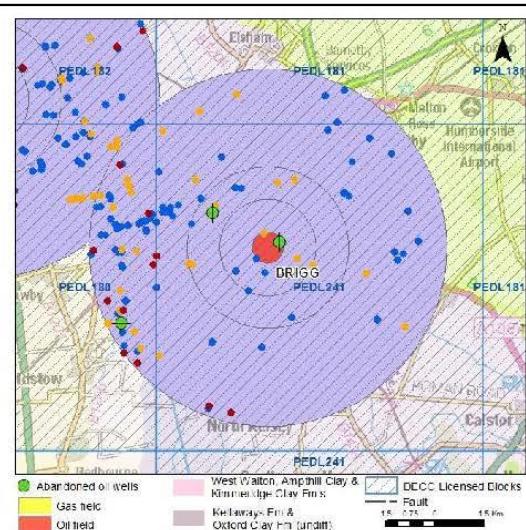
Bedrock aquifer: Amphil Clay (Ancholme Clay), unproductive.

Superficial aquifer: Brighton Sand Fm, Secondary Undiff.

GW levels (main aq):

GW flow direction:

Other aquifer props:



Groundwater

Potential groundwater sampling points:

	Wellmaster	EA Licence	EA database
Within field	1	1	0
1km	4	2	0
2km	8	9	0
5km	99	32	14

Key

●	EA monitoring network
○	EA Licensed boreholes
●	Wellmaster Boreholes
○	Buffer Zone



Name of field: BRIGG

Cross section:

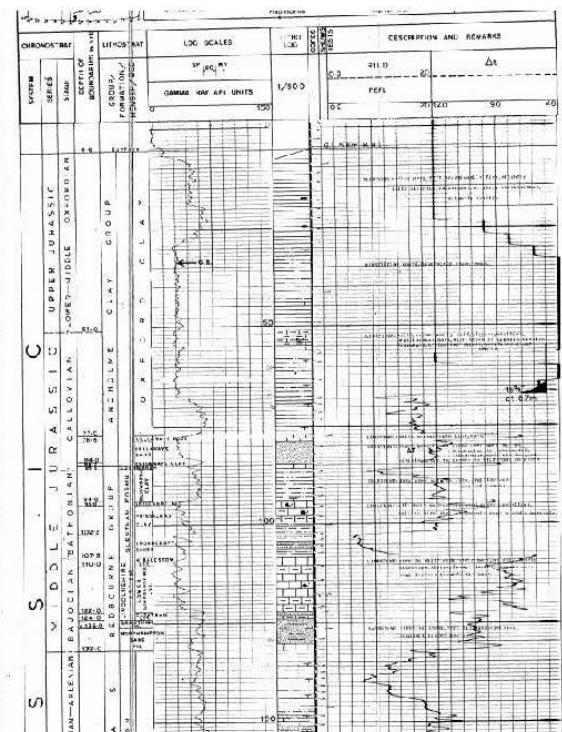
Not Available.

Stratigraphy and aquifers (in blue):

Geology		Top (mbgl)	Base (mbgl)	Thickness (m)
Age	Formation			
Upper Jurassic	Ancholme Clay group	surface	84	84
Middle Jurassic	Redbourne Group	84	132	48
Lower Jurassic	Lias	132	318	186
Triassic	Rhaetic, Mercia Mudstone, Sherwood Sandstone	318	944	626
Permian	Zechstein	944	1270	326
Carboniferous	Westphalian A, B & C, Namurian, Diantian	1270	1940	670

More detail on log.

Hydrocarbon well log:



Name and type of field: BROUGHTON oil field

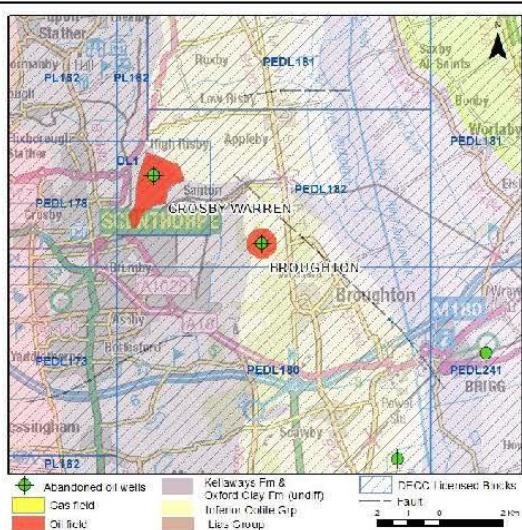
Grid reference of primary well: 494624, 410766

Number of wells in field: One, Broughton B1

Licence number: PEDL 182

BGS reference: SE91SW/BJ/456

Location: Broughton, Lincolnshire



Hydrocarbon well information:

*All depths in mbgl

Depth: 1920 m

Hydrocarbon (oil and gas) shows: Westphalian A and Upper Namurian moderate to good hydrocarbon shows but only Peniston Flags produced oil (40 bopd), others formations water and traces of oil and gas

Water strikes:

Comments: More detailed information in the log. Oil well only, not field – not developed. Additional oil field (Crosby Warren) and 3 HC wells within the 2 – 5 km buffer zone.

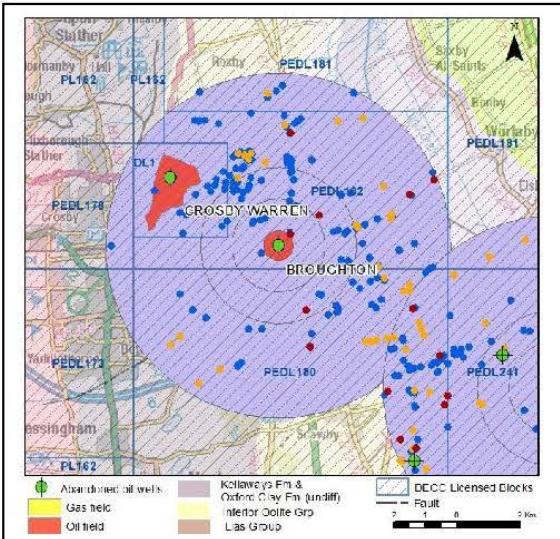
Bedrock aquifer: Lincolnshire Limestone Formation, Principle

Superficial aquifer: None

GW levels (main aq): can see large seasonally variation.

GW flow direction: Eastwards

Other aquifer props: The Lincs Lst is part of the Inferior Oolite Grp, a major aquifer. Fracture flow.



Groundwater

Potential groundwater sampling points':

	Wellmaster	EA Licence	EA database
Within field	0	0	0
1km	8	0	1
2km	37	0	3
5km	148	47	10

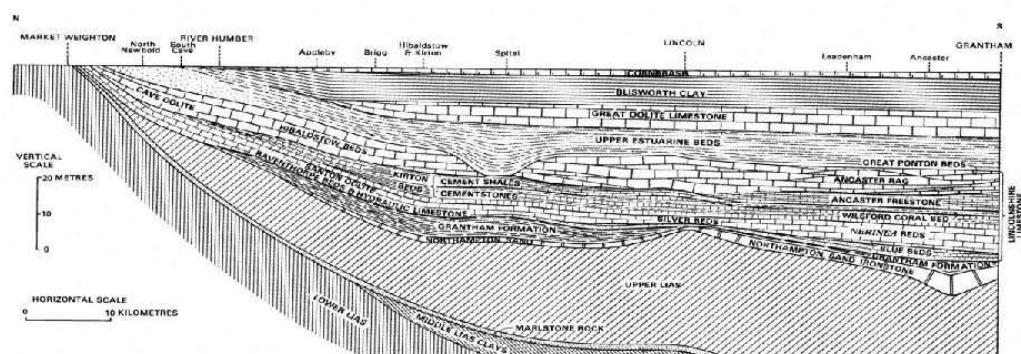
Key

	EA monitoring network
	EA Licensed boreholes
	Wellmaster Boreholes
	Buffer Zone



Name of field: BROUGHTON

Cross section:

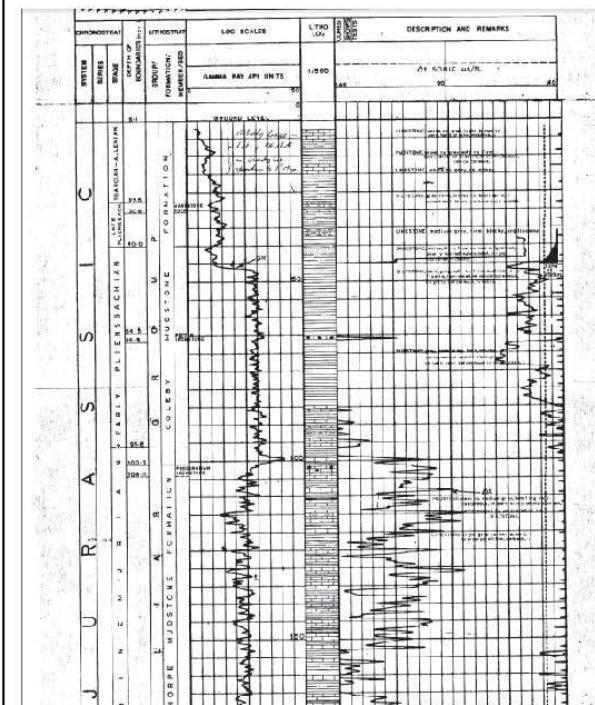


Stratigraphy and aquifers (in blue):

Geology		Top (mbgl)	Base (mbgl)	Thickness (m)
Age	Formation			
Jurassic	Lincolnshire Limestone Formation	Surface	~15?	~15?
Lower Jurassic	Lias Group – Coleby Mudstone Fm, Scunthorpe Mudstone Fm		185	
Triassic	Mercia Mudstone, Sherwood Sandstone	184	802	618
Permian	Zechstein	802	1130	328
Carboniferous	Westphalian, Namurian, Dinantian	1130	1920	790

One of the versions of this log (below) has Lincs Lst Fm as the possible top bed which ties in with the placement on the map. More detailed description in log.

Hydrocarbon well log:



Name and type of field: CAUNTON oil field

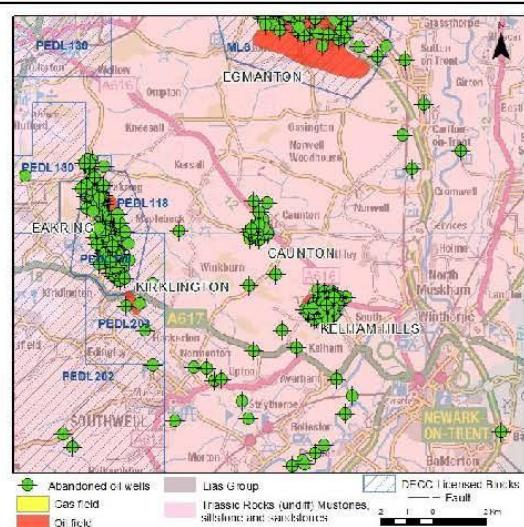
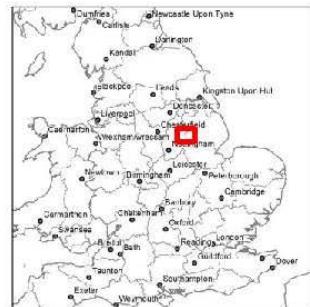
Grid reference of primary well: 473798 360555

Number of wells in field: Nineteen, Caunton 2 described below

Licence number: No PEDL number.

BGS reference: SK76SW/BJ/2

Location: Caunton, Nottinghamshire



Hydrocarbon well information:

*All depths in mbgl

Depth: 699 m

Hydrocarbon (oil and gas) shows: Oil shows below 672 m

Water strikes: No details.

Comments: Within the Caunton 1 log is a report and conceptual model of the Caunton and Kelham hills oilfields. Page 16 – 17 'The relationship of Igneous Rocks to Oil accumulation'. Additional HC wells within buffer zones; 0-1 km 5 Caunton wells, 1-2 km 1 Winkburn and 1 Knapthorpe, 2-5 km Kelham Hills, Eakring, Kirlington well fields.

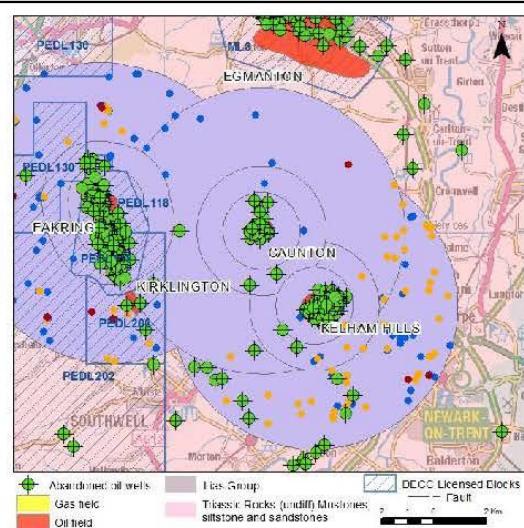
Bedrock aquifer: Mercia Mudstone, Secondary B

Superficial aquifer: Unproductive / Secondary A

GW levels (main aq):

GW flow direction:

Other aquifer props: MMG - Keuper Marls are an aquitard, Waterstone Fm and Green beds minor aquifer.



Groundwater

Potential groundwater sampling points:

	Wellmaster	EA Licence	EA database
Within field	23	1	3
1km	28	1	3
2km	32	1	3
5km	133	15	6

Key

●	EA monitoring network
○	EA Licensed boreholes
●	Wellmaster Boreholes
●	Buffer Zone



Name of field: CAUNTON

Cross section:

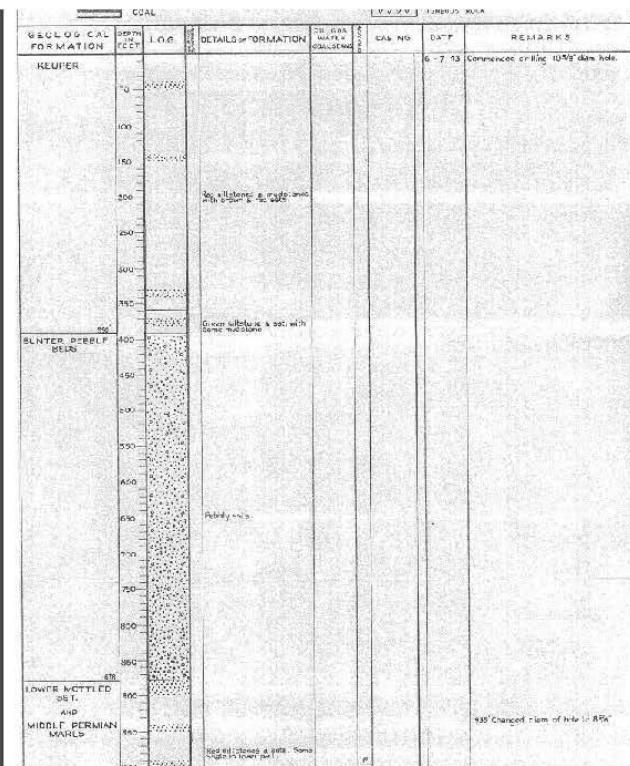
Not available.

Stratigraphy and aquifers (in blue):

Geology		Top (mbgl)	Base (mbgl)	Thickness (m)
Age	Formation			
Triassic	Keuper (Mercia Mudstone Group)	surface	119	119
Triassic	Bunter pebble beds, (Sherwood Sandstone Group)	116	268	152
Triassic - Permian	Lower Mottled Sandstones Middle Permian Marls, Magnesian Limestone	268	392	124
Carboniferous	Coal measures, Millstone grit series Carboniferous limestone	392	699	307

Contained within the Caunton 1 log is a report on the igneous rocks below the Caunton and Kelham hills oilfields that includes a conceptual model of the geology of the area. Caunton 1 is just outside of the well field.

Hydrocarbon well log:



Name and type of field: COLD HANWORTH oil field

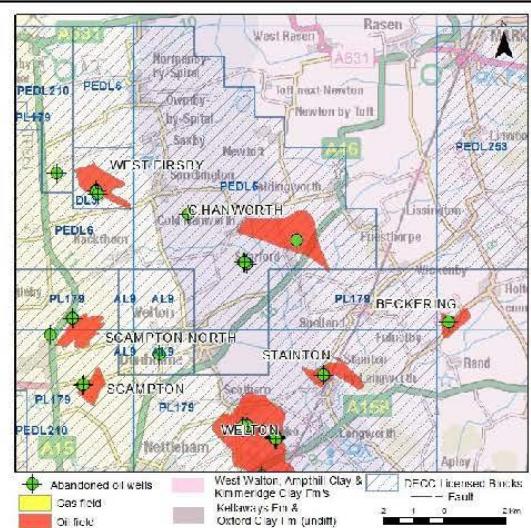
Grid reference of primary well: 505391, 382955

Number of wells in field: One, Cold Hanworth 1 described below

Licence number: PEDL6

BGS reference: TF08SE/BJ/3

Location: Cold Hanworth, Lincolnshire



Hydrocarbon well information:

*All depths in mbel

Depth: 1760 m

Hydrocarbon (oil and gas) shows: Possibly but some of the information has been obscured. Oil staining, hydrocarbon odour and fluorescence tests noted in sample descriptions.

Water strikes: No details

Comments: Additional HC wells within the buffer zones 0-1 km 5 Cold Hanworth wells, 1-2 km 1 Spridlington, 2-5km 1 Dunholme, 5 Stanton (and well field), 5 West Firsby (and well field), 1 Beckering (and well field).

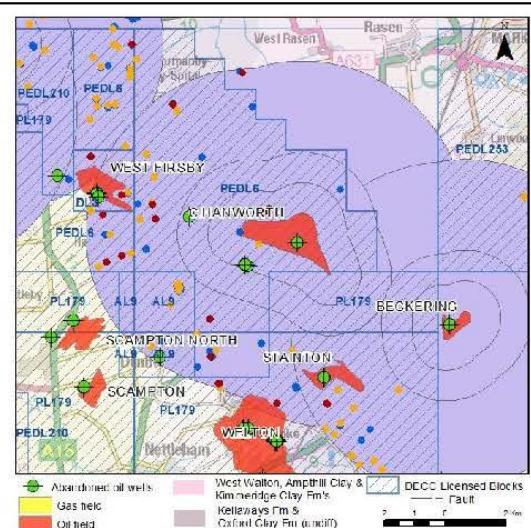
Bedrock aquifer: West Walton Fm, unproductive.

Superficial aquifer: Secondary.

GW levels (main gal):

GW flow direction:

Other aquifer props.



Groundwater

Potential groundwater sampling points:

	<i>Wellmaster</i>	<i>EA Licence</i>	<i>EA database</i>
Within field	1	0	0
1km	2	1	2
2km	3	1	2
5km	40	32	20

Key

- | | |
|--|-----------------------|
| | EA monitoring network |
| | EA Licensed boreholes |
| | Wellmaster Boreholes |
| | Buffer Zone |



Name of field: COLD HANWORTH

Cross section:

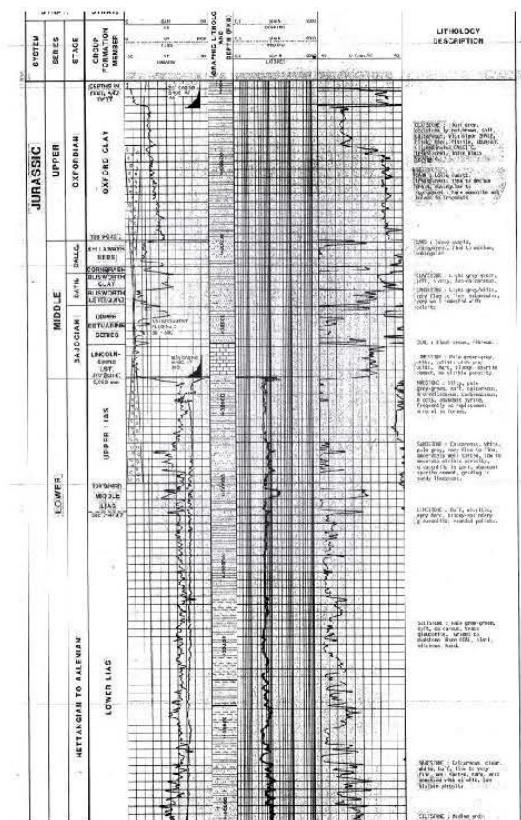
Not available.

Stratigraphy and aquifers (in blue):

Geology		Top (m)	Base (m)	Thickness (m)
Age	Formation			
Upper Jurassic	Oxford Clay	surface	60	60
Middle Jurassic	Kellaways, Cornbrash, Blisworth clay and Lst, Upper Estuarine Series, Lincolnshire Lst	60	113	53
Lower Jurassic	Upper, middle, lower Lias	113	355	242
Triassic	Penarth Grp, Mercia Mudstone Grp, Sherwood Sandstone Grp	355	808	453
Permian	Zechstein	808	1110	302
Carboniferous	Westphalian A to D, Dinantian	1110	1760	650

[More information on the log.](#)

Hydrocarbon well log:



Name and type of field: EAKRING oil field

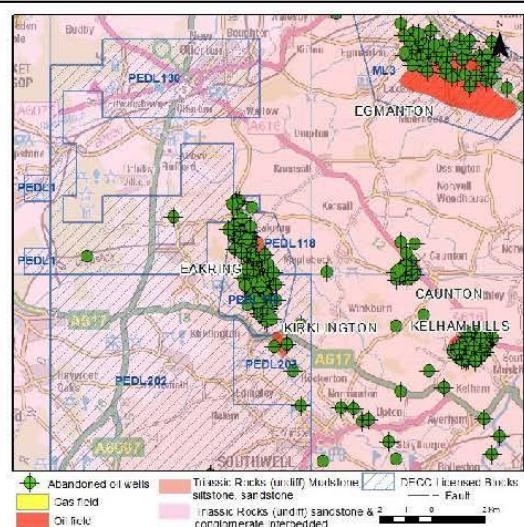
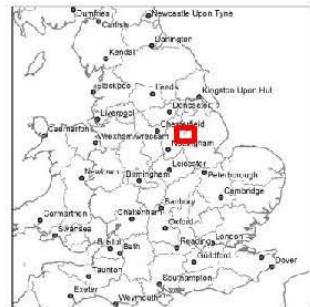
Grid reference of primary well: 47605 361321

Number of wells in field: 65, Eakring 1 described below.

Licence number: PEDL118

BGS reference: SK66SE/BJ/1

Location: Eakring, Nottinghamshire



Hydrocarbon well information:

*All depths in mbgl

Depth: 819 m

Hydrocarbon (oil and gas) shows: Core samples show a little oil. Oil in borehole at 596 m, 632 m, 677 m

Water strikes: Water in borehole 689 m, 811 m,

Comments: '806 to 819 m core contains pockets of oil but flows water.'

HC wells in the buffered zones

0 – 1 km: 102 Eakring and 1 Mill Hill,

1-2 km: 29 Eakring

2-5km: no Eakring, 2 Hockerton, 3 Kirlington, 1 Maplebeck, 1 Rufford.

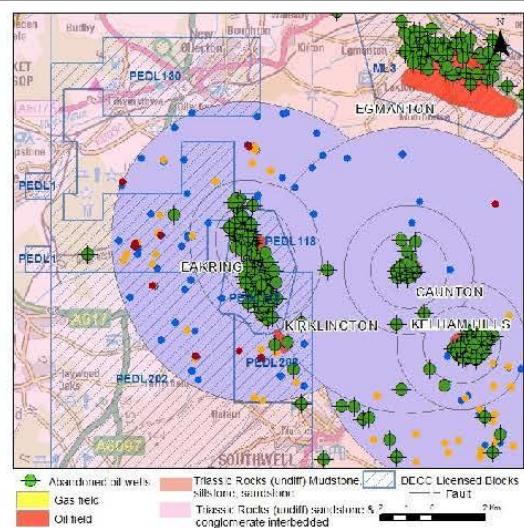
Bedrock aquifer: Mercia Mudstone Group, Secondary B

Superficial aquifer: None

GW levels (main aq):

GW flow direction:

Other aquifer props: MMG - Keuper Marls are an aquitard, Waterstone Fm and Green beds minor aquifer.



Groundwater

Potential groundwater sampling points:

	Wellmaster	EA Licence	EA database
Within field	70	0	0
1km	174	0	0
2km	209	2	3
5km	277	31	23

Key

●	EA monitoring network
○	EA Licensed boreholes
●	Wellmaster Boreholes
●	Buffer Zone



Name of field: EAKRING

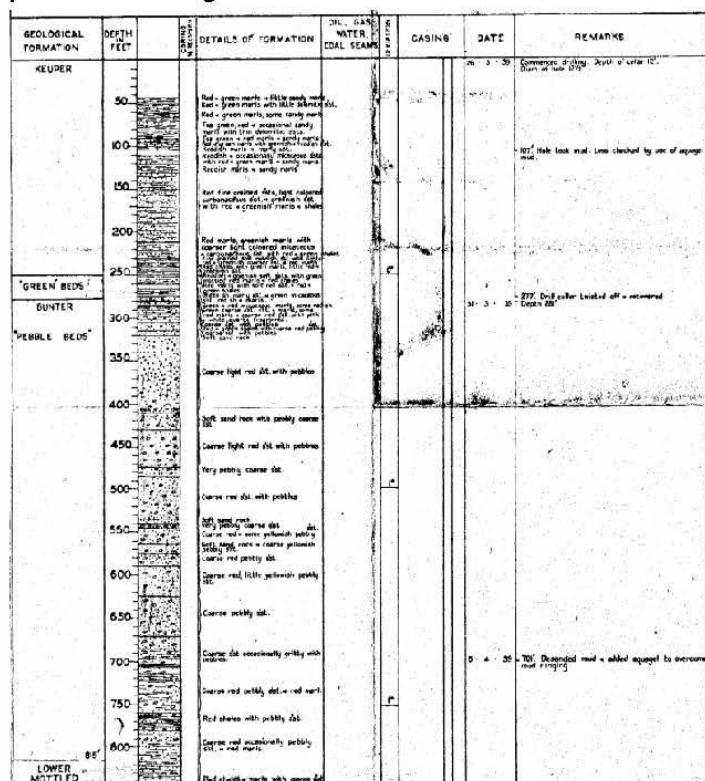
Cross section:

Not available.

Stratigraphy and aquifers (in blue):

Geology		Top (mbgl)	Base (mbgl)	Thickness (m)
Age	Formation			
Triassic	Keuper, Green Beds (Mercia Mudstone Group)	surface	84	84
Triassic	Bunter pebble beds, Lower Mottled Sandstones (Sherwood Sandstone Group)	84	268	184
Permian	Middle Marls and sands, Magnesian Limestone	268	359	91
Carboniferous	Coal measures, Millstone grit series? Carboniferous limestone	359	819	460

Hydrocarbon well log:



Name and type of field: FORMBY oil field

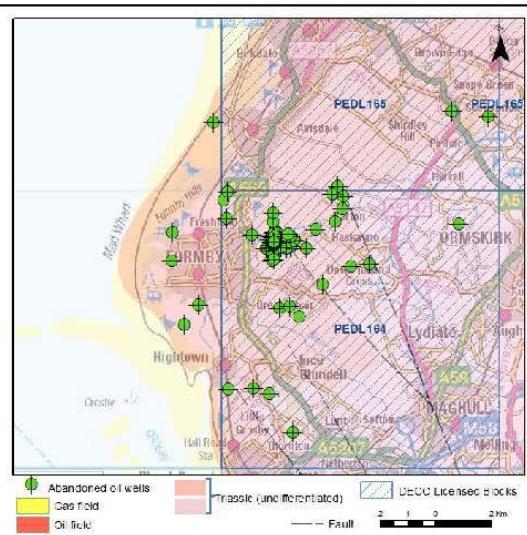
Grid reference of primary well: 331880, 408040

Number of wells in field: 61, Formby 1 described below

Licence number: PEDL 164

BGS reference: SD30NW/BJ/22

Location: Formby, Merseyside



Hydrocarbon well information:

*All depths in mbgl

Depth: 2340 m

Hydrocarbon (oil and gas) shows: Free oil and oil staining 30 to 55 m; 104 – 113 m. Gas odour 711-712 m.

Water strikes: Not recorded

Comments: BP. No gas field, current wells present and lots of abandoned wells. About 61 Formby HC wells in the field and 19 Formby HC wells in the 1km, 2km, 5 km buffer together with 5 Barton Moss, 2 Flea Moss, Freshfield HC wells. Formby 3, G13 and G109 are outside the 5km buffer zone

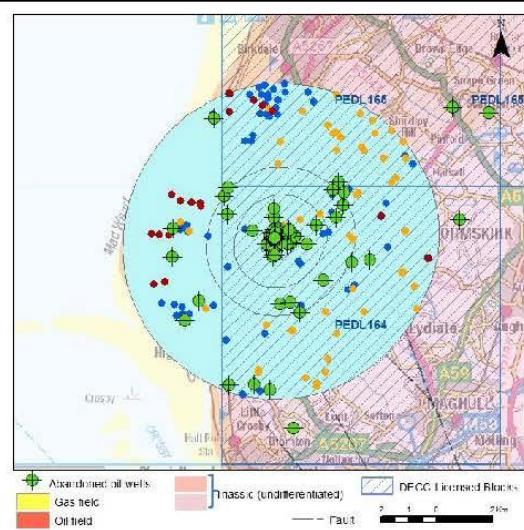
Bedrock aquifer: Mercia Mudstone, Secondary A

Superficial aquifer: Peat, Unproductive superficial aquifer.

GW levels (main aq):

GW flow direction:

Other aquifer props: Interbedded mudstones, siltstones and sandstones



Groundwater

Potential groundwater sampling points:

	Wellmaster	EA Licence	EA database
Within field	16	1	0
1km	25	2	0
2km	38	5	0
5km	149	55	25

Key

- | | |
|---|-----------------------|
| ● | EA monitoring network |
| ○ | EA Licensed boreholes |
| ■ | Wellmaster Boreholes |
| ● | Buffer Zone |



Name of field: FORMBY

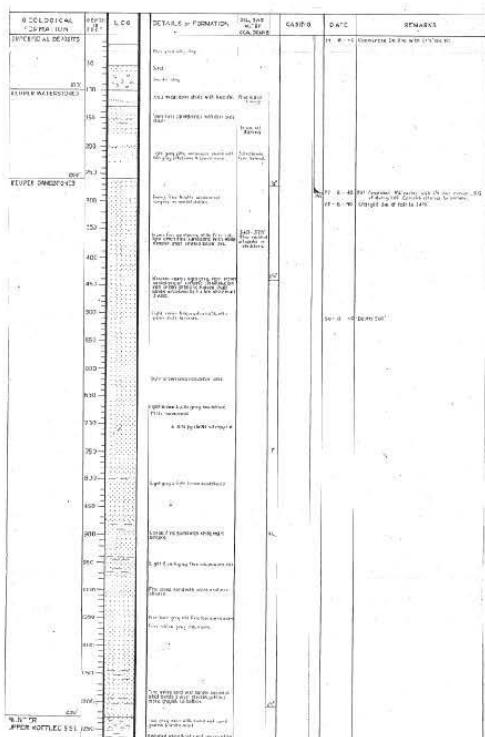
Cross section:

Not available.

Stratigraphy and aquifers (in blue):

Geology		Top (mbgl)	Base (mbgl)	Thickness (m)
Age	Formation			
Recent	Superficial deposits	surface	30	30
Triassic	Mercia Mudstone (Keuper Waterstones, Keuper sandstones)	30	375	345
Triassic	Sherwood Sst Bunter Sst, Bunter pebble beds, lower mottled Sst (Lenton Sandstone Fm?),	375	~1080	705
Permian	Collyhurst Sst	~1080	1790	710
Carboniferous	Wilpshire Grit Grp, Bowland Shales, Pendleside Grit, Pendleside Lst, Worston Shales	1790	2340	550

Hydrocarbon well log:



Name and type of field: GLENTWORTH oil field

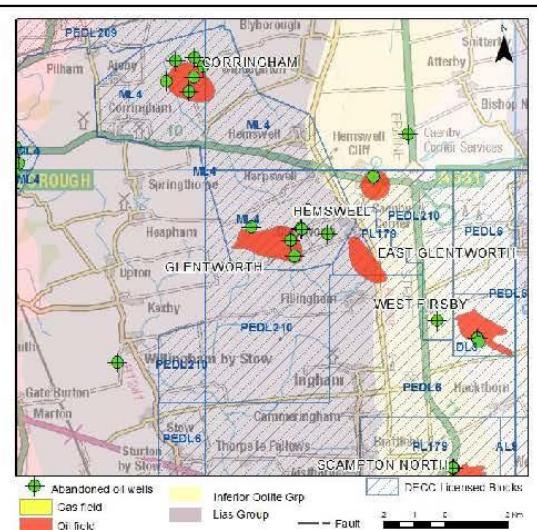
Grid reference of primary well: 493120, 388059

Number of wells in field: Two, Glentworth 2 described below.

Licence number: ML4

BGS reference: SK98NW/BJ/2

Location: Glentworth, Lincolnshire



Hydrocarbon well information:

*All depths in mbgl

Depth: 1666 m

Hydrocarbon (oil and gas) shows: Traces, no production.

Water strikes: Millstone Grit 1650-1670 m 550 m³/day

Comments: Glentworth 1 (outside the field) 'Excellent on production test' from the Coal Measures sandstone. Wells 2 and 7 within the field no production on test.

Additional HC wells in buffer zones; 0-1km 5 Glentworth, 2-5km Hemswell field and 2 wells, 1 Spital, 1 Ingham, 1 Corringham (and field)

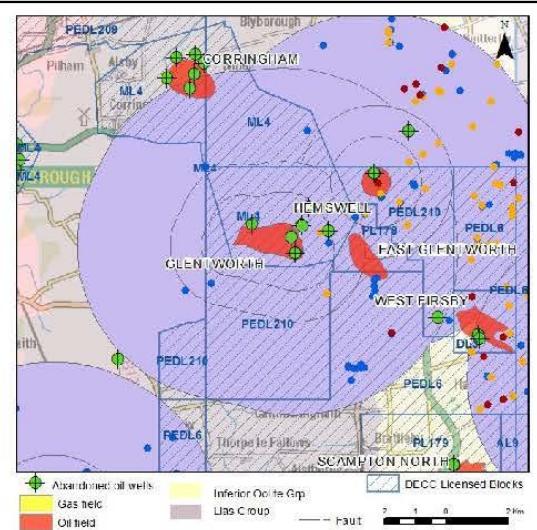
Bedrock aquifer: Charnmouth Mudstone Fm, Lower Lias, Secondary Undiff

Superficial aquifer: Till, Secondary Undiff

GW levels (main aq):

GW flow direction:

Other aquifer props: Log shows interbedded Lst, mudstone, siltstone and sst. Compartmentalised aquifer.



Groundwater

Potential groundwater sampling points:

	Wellmaster	EA Licence	EA database
Within field	1	0	0
1km	5	1	0
2km	7	2	0
5km	33	12	3

Key

- EA monitoring network
- EA Licensed boreholes
- Wellmaster Boreholes
- Buffer Zone



Name of field: GLENTWORTH

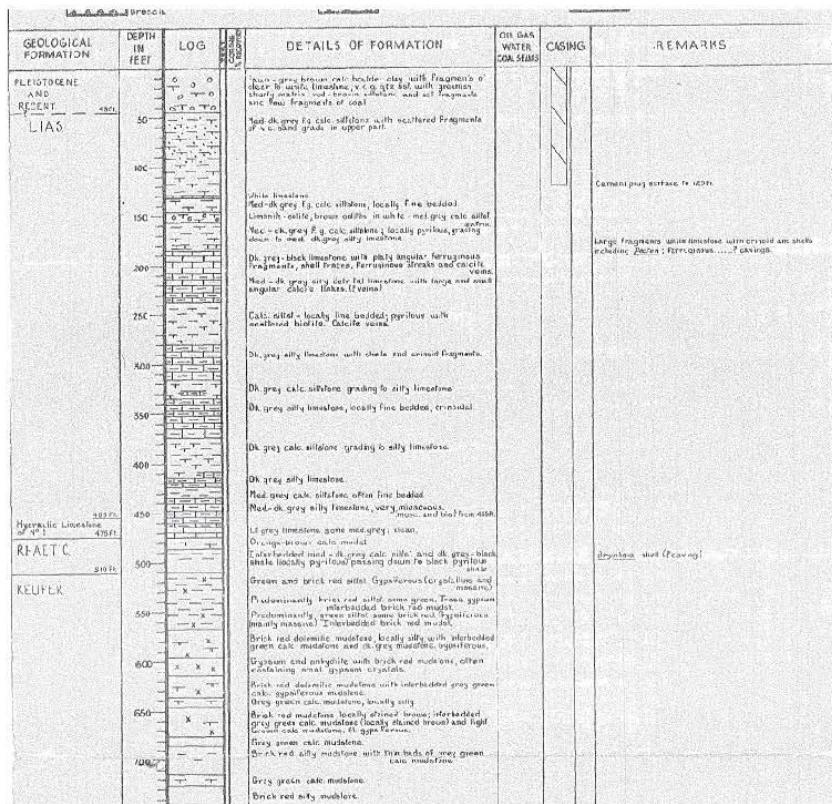
Cross section:

Not available.

Stratigraphy and aquifers (in blue):

Geology		Top (mbgl)	Base (mbgl)	Thickness (m)
Age	Formation			
Recent	Boulder Clay	surface	14	14
Jurassic	Lower Lias	14	145	131
Triassic	Rheatic; Keuper, Bunter (Mercia Mudstone and Sherwood Sandstone)	145	706	561
Permian	Upper beds, Upper mag Lst, Middle Marls, Lower Mag Lst, Lower Marls	706	933	227
Carboniferous	Coal measures, Millstone Grit	933	1666	733

Hydrocarbon well log:



Name and type of field: HEMSWELL oil field

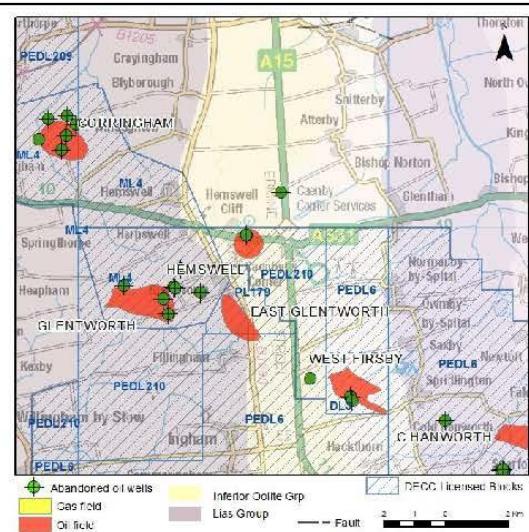
Grid reference of primary well: 495437 389781

Number of wells in field: Two, Hemswell 1 described below.

Licence number: PEDL210

BGS reference: SK98NE/BJ/8

Location: Hemswell, Lincolnshire



Hydrocarbon well information:

*All depths in mbgl

Depth: 1669 m

Hydrocarbon (oil and gas) shows: Oil ~1390 to 1410 m 1530 m and 1570 m. Gas shows throughout Coal Measures and Millstone Grit.

Water strikes: Water intermittent throughout Coal Measures and Millstone Grit.

Comments: Three further HC well fields within the buffered zone. Additional HC wells within the buffered zones: 1 to 2 km buffer 1 Spital and 4 Glentworth HC well; 2-5 km buffer 1 Ingham, 3 Glentworth HC wells

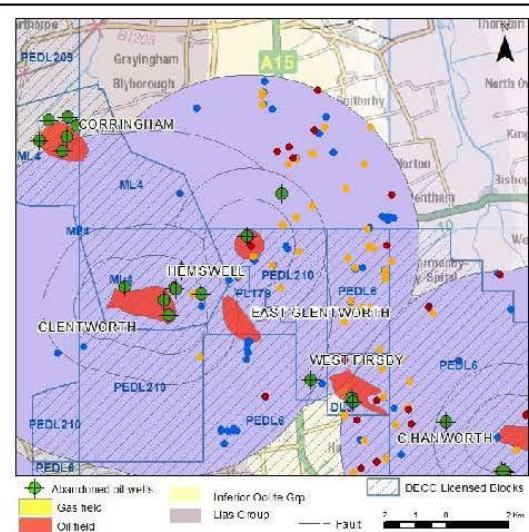
Bedrock aquifer: Lincolnshire Limestone Fm, Inferior Oolite Group. Principle

Superficial aquifer: None.

GW levels (main aq): Seasonable variable, flashy.

GW flow direction: Eastwards.

Other aquifer props: Fracture flow. Complex interactions with surface waters.



Groundwater

Potential groundwater sampling points:

	Wellmaster	EA Licence	EA database
Within field	1	1	2
1km	7	5	2
2km	9	12	2
5km	54	62	12

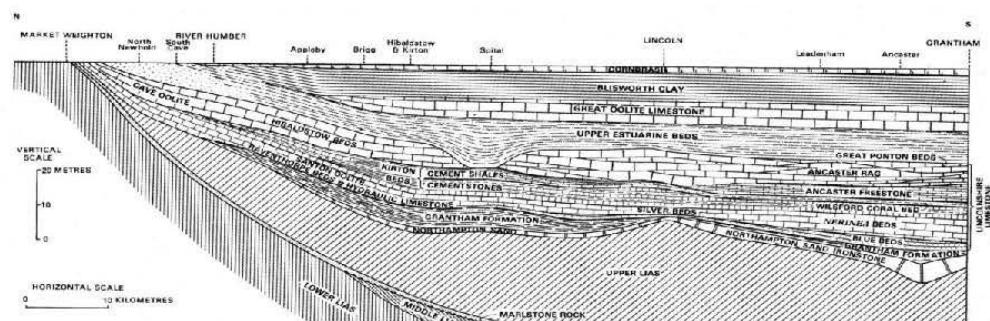
Key

	EA monitoring network
	EA Licensed boreholes
	Wellmaster Boreholes
	Buffer Zone



Name of field: HEMSWELL

Cross section:

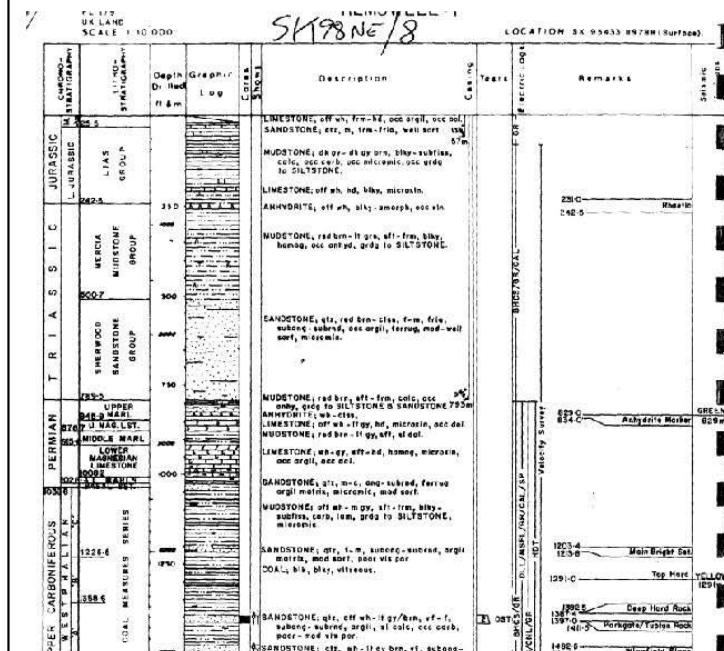


Stratigraphy and aquifers (in blue):

Age	Formation	Top (mbgl)	Base (mbgl)	Thickness (m)
Jurassic	Lincolnshire Limestone	4.2?	25.5	21.3
Jurassic	Lias Group	25.5	231	206
Triassic	Rheatic; Mercia Mudstone Group and Sherwood Sandstone	231	790	559
Permian	Upper Marls, Upper mag Lst, Middle Marls, Lower Marls, Basal SST	790	1040	250
Carboniferous	Westphalian A, B and C (Coal Measures Series), Namurian (Millstone Grit), Dinantian	1040	1670	630

Detailed log starts at 4.2 m.

Hydrocarbon well log:



Name and type of field: KELHAM HILLS oil field

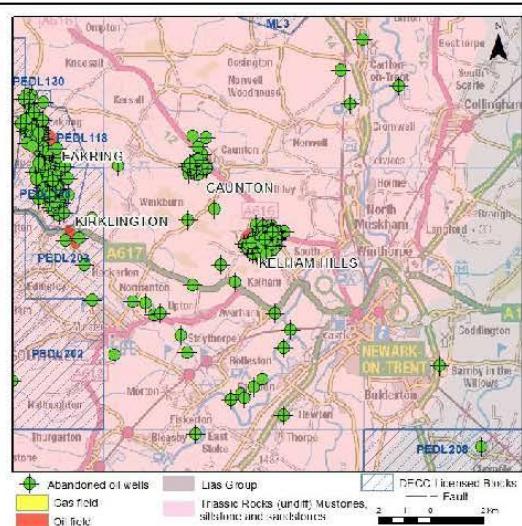
Grid reference of primary well: 475945, 357615

Number of wells in field: 20, Kelham Hills 1 described below.

Licence number: No PEDL number

BGS reference: SK75NE/BJ/1

Location: Kelham Hills, Nottinghamshire



Hydrocarbon well information:

*All depths in mbgl

Depth: 767.8 m

Hydrocarbon (oil and gas) shows: Oil 458m, 465 m, 476 m

Water strikes: Artesian water 212 m. Salt water 732 m to 748 m

Comments: See Caunton 1 log for a report containing a conceptual model of the geology of the area. Caunton well field within buffer zones. Additional HC wells within; 0 – 1km 47 Kelham hills; within 1 – 2 km 1 Knapthorpe, 1 Averham Park, 1 Kelham Hills; 2-5 km Caunton well field and additional 13 HC wells.

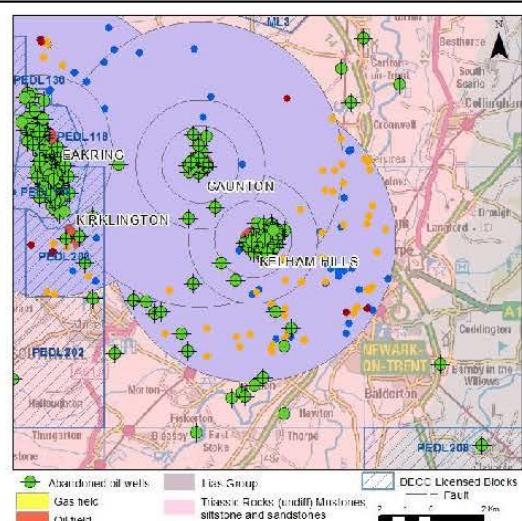
Bedrock aquifer: Mercia Mudstone Group, Secondary B

Superficial aquifer: None.

GW levels (main aq):

GW flow direction:

Other aquifer props: MMG - Keuper Marls are an aquitard, Waterstone Fm and Green beds minor aquifer.



Groundwater

Potential groundwater sampling points:

	Wellmaster	EA Licence	EA database
Within field	21	0	2
1km	70	1	2
2km	77	6	2
5km	168	53	7

Key

	EA monitoring network
	EA Licensed boreholes
	Wellmaster Boreholes
	Buffer Zone



Name of field: KELHAM HILLS

Cross section:

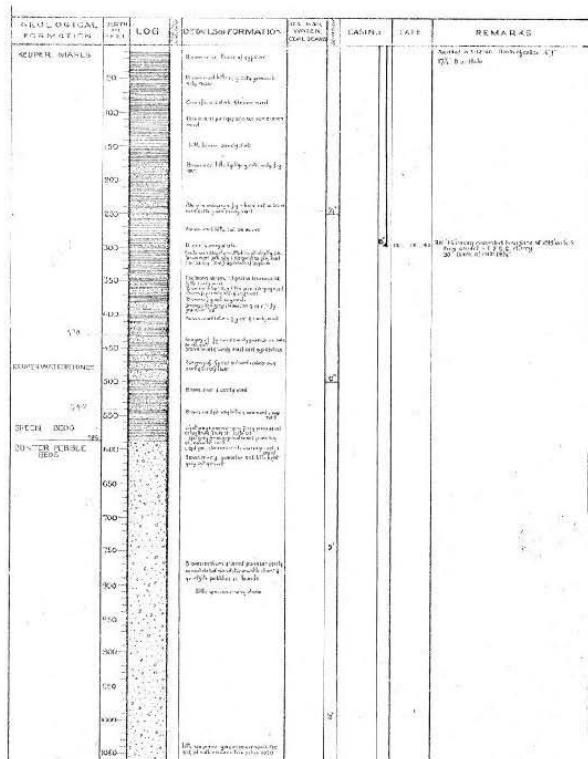
Not available

Stratigraphy and aquifers (in blue):

Geology		Top (mbgl)	Base (mbgl)	Thickness (m)
Age	Formation			
Triassic	Keuper Marl, Waterstones, Green Beds (Mercia Mudstone Group)	surface	178	178
Triassic	Bunter pebble beds Lower Mottled Sandstones (Sherwood Sandstone Group)	178	354	176
Permian	Middle Permian Marls, Magnesian Limestone	354	437	83
Carboniferous	Coal measures, Millstone grit series Carboniferous limestone	437	768	331

Contained within the Caunton 1log is a report on the igneous rocks below the Caunton and Kelham hills oilfields that includes a conceptual model of the geology of the area.

Hydrocarbon well log:



Name and type of field: LOMER oil field

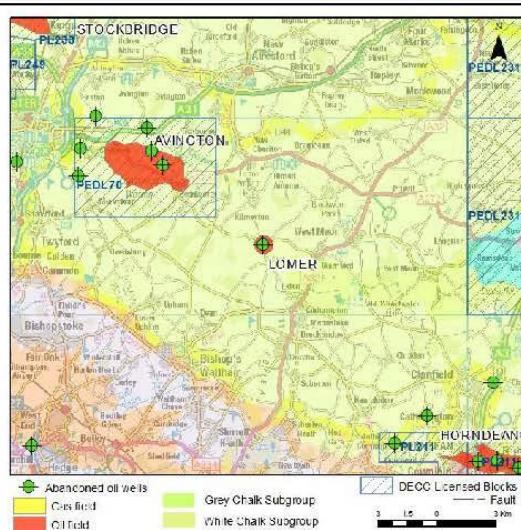
Grid reference of primary well: 459587, 123564

Number of wells in field: One, Lomer 1

Licence number: No PEDL.

BGS reference: SU52SE/BJ/18

Location: West Meon, Hampshire



Hydrocarbon well information:

*All depths in mbgl

Depth: 2120 m

Hydrocarbon (oil and gas) shows: Oil shows from 1360 m to 1390 m. Intermittent gas shows, 872 m to end

Water strikes: No details

Comments: There are more details including a chromatogram and fluorescence tests of the core in the log. The information above is an amalgamation of that from the 3 different logs.

Oil well only, not field – not developed. No additional HC wells within the buffer zone.

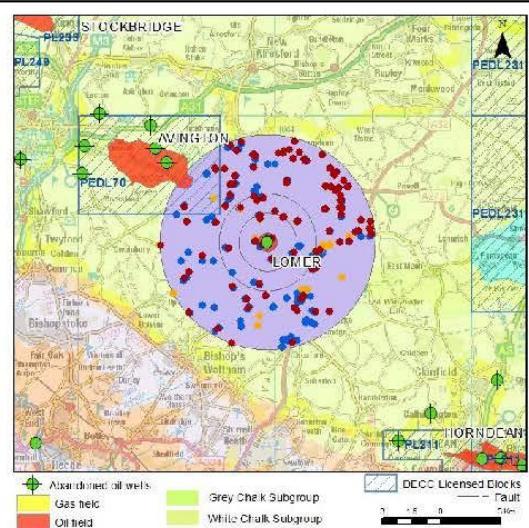
Bedrock aquifer: Seaford Chalk (White Chalk Subgroup), Principle

Superficial aquifer: None

GW levels (main aq): Seasonally variable

GW flow direction:

Other aquifer props: Fracture flow, transmissivity declines with depth and distance from valleys. Faulting and folding in Hampshire basin.



Groundwater

Potential groundwater sampling points:

	Wellmaster	EA Licence	EA database
Within field	3	0	2
1km	10	3	9
2km	26	5	19
5km	158	29	106

Key

●	EA monitoring network
○	EA Licensed boreholes
●	Wellmaster Boreholes
●	Buffer Zone



Name of field: LOMER

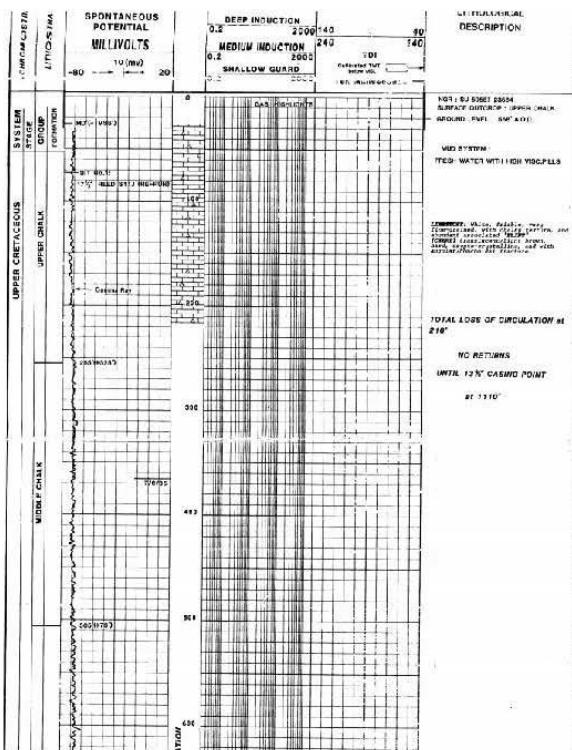
Cross section:

Not available.

Stratigraphy and aquifers (in blue):

Geology		Top (mbgl)	Base (mbgl)	Thickness (m)
Age	Formation			
Cretaceous	Upper Chalk	0	78	78
Cretaceous	Middle & Lower Chalk, Upper & Lower Greensand, Atherfield Clay, Wealden Clays, Hastings Beds, Upper & Middle Purbeck	78	765	687
Upper Jurassic	Middle and Lower Purbeck, Portland Beds, Kimmeridge Clay, Corallian, Oxford Clay, Kelaway Beds	765	1360	595
Middle and Lower Jurassic	Cornbrash, Great and Inferior Oolite, upper, middle and lower Lias	1360	2040	680
Permo – Triassic Devonian?	Rhaetian, Mercia Mudstone	2040	2120	80

Hydrocarbon well log:



Name and type of field: TORKSEY oil field

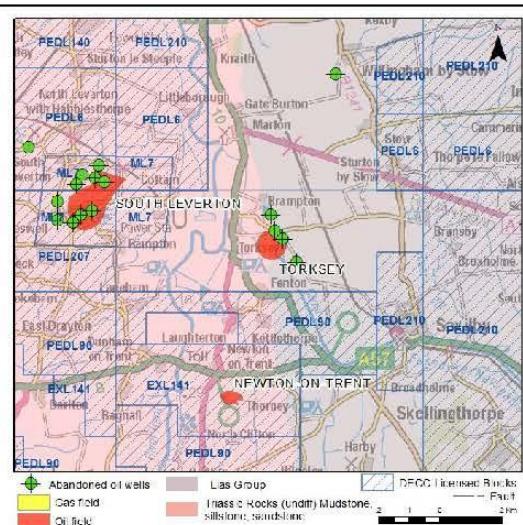
Grid reference of primary well: 485200, 378680

Number of wells in field: One, Torksey 3 described below.

Licence number: No PEDL

BGS reference: SK87NE/BJ/1

Location: Torksey, Lincolnshire



Hydrocarbon well information:

*All depths in mbgl

Depth: 1427 m

Hydrocarbon (oil and gas) shows: 1360-1430 m 0.09 m³/day Gas 1410 – 1430 m 0.23 m³/day Gas and a trace of oil

Water strikes: Between 1130 – 1150 m 0.8 m³/day, between 1360-1430 m 0.5 m³/day 1410 – 1430 m 3.4 m³/day

Comments: (only Torksey 3 in field).

Additional 3 Torksey HC wells within the 0-1 km buffer zone.

Bedrock aquifer: Scunthorpe Mudstone Fm, Lower Lias, Secondary A

Superficial aquifer: Holme Pierrepont Sand and Gravel Member. Secondary A

GW levels (main aq):

GW flow direction:

Other aquifer props: Previously 'Hydraulic Lst'. Interbedded Mdsts & Lsts. Lias is a compartmentalised aquifer.

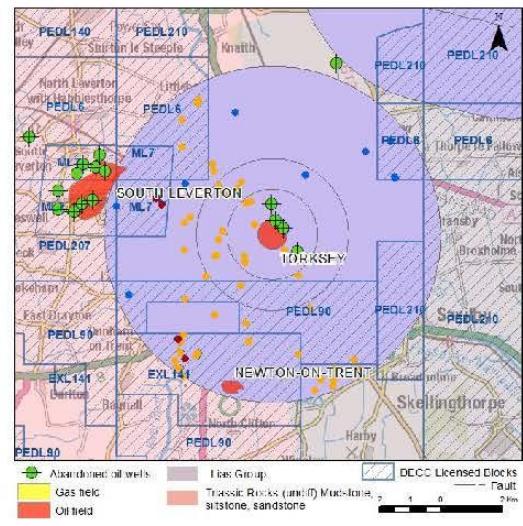
Groundwater

Potential groundwater sampling points:

	Wellmaster	EA Licence	EA database
Within field	2	1	0
1km	4	7	0
2km	5	17	0
5km	22	57	4

Key

●	EA monitoring network
●	EA Licensed boreholes
●	Wellmaster Boreholes
●	Buffer Zone





Name of field: TORKSEY

Cross section:

Not available.

Stratigraphy and aquifers (in blue):

Geology		Top (mbgl)	Base (mbgl)	Thickness (m)
Age	Formation			
Recent	Superficial (not on log)	Surface	?	
Jurassic	Lias (Rhaetic)	?	21	
Triassic	Keuper Marl, Bunter (Mercia Mudstone and Sherwood Sandstone)	21	530	509
Permian	Upper Permian Marls, Upper mag Lst, Middle Marls, Lower Mag Lst, Lower Permian Marls and Basal beds	530	716	186
Carboniferous	Coal measures, Millstone Grit?	716	1430	714

Hydrocarbon well log:

