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Site selection strategy for environmental monitoring in connection with shale-gas exploration, Vale of Pickering, Yorkshire and Fylde, Lancashire

Groundwater Programme

Open Report OR/15/067

BRITISH GEOLOGICAL SURVEY

OPEN REPORT OR/15/067

Site selection strategy for environmental monitoring in connection with shale-gas exploration: Vale of Pickering, Yorkshire and Fylde, Lancashire

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Front cover

View north across the Vale of Pickering from Staxton, North Yorkshire

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Foreword

This report describes the site selection procedures undertaken in respect of baseline environmental monitoring connected with unconventional hydrocarbon extraction in northern England. The project has been grant-funded by the Department for Energy & Climate Change (DECC) and is being undertaken during the period September 2015 to March 2016.

Acknowledgements

Special thanks are extended to James Rose, Policy Manager of the Office of Unconventional Gas & Oil, DECC, for client administration of the grant and to BGS project support staff for grant administration and support. We also acknowledge the cooperation of all Vale of Pickering and Fylde householders and landowners who have allowed access to take samples, carry out survey activities and install environmental monitoring equipment, without whom, much of this research programme would not have been possible.

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This report outlines the strategies for site selection adopted as part of a baseline environmental monitoring investigation in connection with shale-gas exploration and development in the Vale of Pickering, North Yorkshire. The project forms an extension to an ongoing baseline investigation being carried out in the Fylde, Lancashire, and the current project incorporates an air-quality monitoring component that was not within the original remit of the Fylde study. The DECC-funded investigation is led by the British Geological Survey, and is being carried out as a collaboration with the Universities of Birmingham, Bristol, Liverpool, Manchester and York (National Centre for Atmospheric Science, NCAS) and Public Health England (PHE). The project incorporates work packages in monitoring of water quality, air quality and greenhouse gases, soil gas, ground motion and seismicity, and air radon and is being carried out over the period September 2015 to March 2016.

Site selection is a critical consideration in setting up a monitoring programme as chosen sites need to be representative of conditions to be tested. While sites will necessarily be subject to practical constraints (land access agreements, existing infrastructure, geological conditions, cost implications etc), site selection has a large part to play in ensuring collection of quantifiable, unbiased data. This report sets out the rationale for site selection in each of the work packages and the steps taken to ensure defensible site-selection decisions and to minimise the impact of practical constraints.

1 Introduction

A programme of environmental baseline monitoring has been initiated in the Vale of Pickering, North Yorkshire, in response to a planning application for shale-gas exploration, submitted by Third Energy in June 2015. The application is to carry out hydraulic fracturing and associated investigations in five phases (depth ranges 2123–3044 m below ground level) within the Kirby Misperton 8 borehole [SE77136 79004], hereinafter described as KM8.

The BGS-led environmental baseline monitoring incorporates seven work packages (WPs) covering six aspects of environmental investigation:

WP1 Water monitoring (surface water and groundwater);

WP2 Seismicity;

WP3 Ground motion;

WP4 Air composition;

WP5 Soil gas;

WP6 Radon in air;

WP7 Project management, communications and dissemination.

WP4 incorporates additional air-quality monitoring by the University of York (NCAS) in Fylde, Lancashire, as part of a sister baseline investigation. This adds air-quality monitoring to the portfolio of environmental work carried out by the above partner organisations in Fylde and brings into line the scope of monitoring of the two investigations.

This report outlines the site-selection strategies used for each of the monitoring work packages for acquiring representative baseline environmental data against which potential future changes and impacts of shale-gas exploration and development can be assessed.

2 Work packages

2.1 WATER MONITORING

2.1.1 Overview

The aim of the water monitoring component of the project is to characterise the chemical composition of groundwater and surface water around the proposed shale-gas exploration site at KM8 under baseline conditions. This should provide the framework to detect any subsequent temporal changes under shale-gas exploration conditions, should planning consent be granted.

Components of the water monitoring investigation involve:

- development of an initial conceptual model of geological strata, properties, structure and fluid flow as a basis for designing the monitoring programme (e.g. location of sites, frequency of measurement etc);
- characterisation of groundwater and surface-water baseline (i.e. pre-development) conditions including spatial and temporal variability;
- establishment of a monitoring network to enable short-term monitoring which could extend to a future longer-term programme suitable for detecting environmental change resulting directly or indirectly from shale-gas operations and other anthropogenic influences.

The objective of the water monitoring design is to establish a sampling network which will enable characterisation of the baseline and any future impact of development on a range of analytes indicative of groundwater and surface water quality.

The baseline monitoring must account for the inherent variability in concentrations of analytes of interest in both space and time, and at varied spatial and temporal scales. Because of this, the detection of any future impact cannot simply be a matter of comparing contemporary measurements to a notional pre-development baseline as spatial and temporal variability gives rise to uncertainty in those pre-development concentrations. With only a period of months for baseline monitoring within the timescale of the project, it is not possible to characterise fully the temporal variation of analytes of interest at all temporal scales. This is a general challenge for environmental monitoring (and hence will apply to other work packages) and has been recognised in the development of appropriate sampling designs for so-called Before and After Control/Impact (BACI) sampling problems. By using the BACI approach, it will be possible to compare the concentration of analytes after development starts with values observed before. As part of this, domains are being identified using the hydrogeological conceptual model and a statistical model developed for the spatio-temporal variation of analytes across the domains so that any future shale-gas-related effects can be detected in the presence of any trends due to other factors.

2.1.2 Initial characterisation

Existing geological and hydrogeological (groundwater quality, levels and aquifer properties) information is being reviewed to develop a 3D conceptual model of the study area. This provides a basis for identifying groundwater flow paths, potential receptors and contaminant migration pathways in order to determine optimum locations for sampling and monitoring, requirements for the location of new monitoring infrastructure and for interpretation of acquired monitoring data. It also allows existing infrastructure (boreholes) to be identified and assessed for their suitability as monitoring sites.

The conceptual model is currently being used to identify domains of interest for development of the monitoring/sampling design. Two domains have been identified in the Vale of Pickering: the Corallian (Jurassic) limestone aquifer and Quaternary superficial deposits covering the central part of the vale. Each has been divided further into subdomains on the basis of potential influence from shale-gas development ("area of potential influence" API, versus control area).

Definition of API is being determined by factors including lateral distance from the KM8 site, proximity to recognised faults in Jurassic and pre-Jurassic strata, fault displacements, groundwater flow paths and baseline groundwater chemical composition. In practice, this has involved collating available data from borehole inventories from BGS geological and groundwater databases and the Environment Agency’s groundwater abstraction licence database, geological and structural information available from borehole logs, BGS geological maps and archive seismic investigation data and any water-chemistry data from geological logs and published reports.

2.1.3 Site selection

An inventory of all known water boreholes within an approximate 12 km radius of KM8 has been collated, with information gathered by database evaluation and field visits. This collation identified the scale of available, operational, suitable and accessible boreholes to include in a potential monitoring network. A shortlist of boreholes was drawn up by discounting sites which were disused or unknown to the landowners, lacked access to ‘representative’ groundwater or were inaccessible due to landowner unwillingness. These proximal sites were almost all located within Quaternary superficial sediments on the basin floor. In addition, further sites were investigated in the Corallian limestone aquifer at greater distances from KM8, on the margins of the basin. Though further away from the proposed area of exploration, these sites are in a principal aquifer that provides a significant supply of water for the region and has therefore been included in the monitoring protocol. The chosen Corallian boreholes on the margins of the basin will constitute control sites. To the best of our knowledge, no boreholes exist proximal to (within 5 km lateral distance of) KM8 that penetrate to the confined Corallian aquifer, i.e. that confined below the Ampthill and Kimmeridge Clay formations.

These investigations demonstrated that the availability of suitable sites for sampling, particularly proximal to KM8, is limited. This has in turn limited the survey design and entailed a near-exhaustive approach within the vale at <5 km distance from KM8. A shortlist of 23 suitable groundwater sites in total (API and control) has been defined, within the Quaternary and Corallian aquifers.

For surface waters, the same API/control design has been attempted, with reconnaissance of suitable first-order streams by both Ordnance Survey map consultation and field visits. In practice, numerous watercourses within the basin were found to be dry, canalised, non-flowing or visibly contaminated and so choices of these were also limited. Some higher-order streams were selected as a result, but with a spatial spread across the valley base. A total of 10 stream sites were identified and selected (5 API, 5 control, defined on the basis of proximity to KM8).

Sampling of existing boreholes has been carried out monthly for a broad suite of analytes since project initiation, but will reduce to quarterly once an initial set of baseline analyses has been acquired. This is to minimise inconvenience to site owners while maintaining capability to establish any seasonal variation.

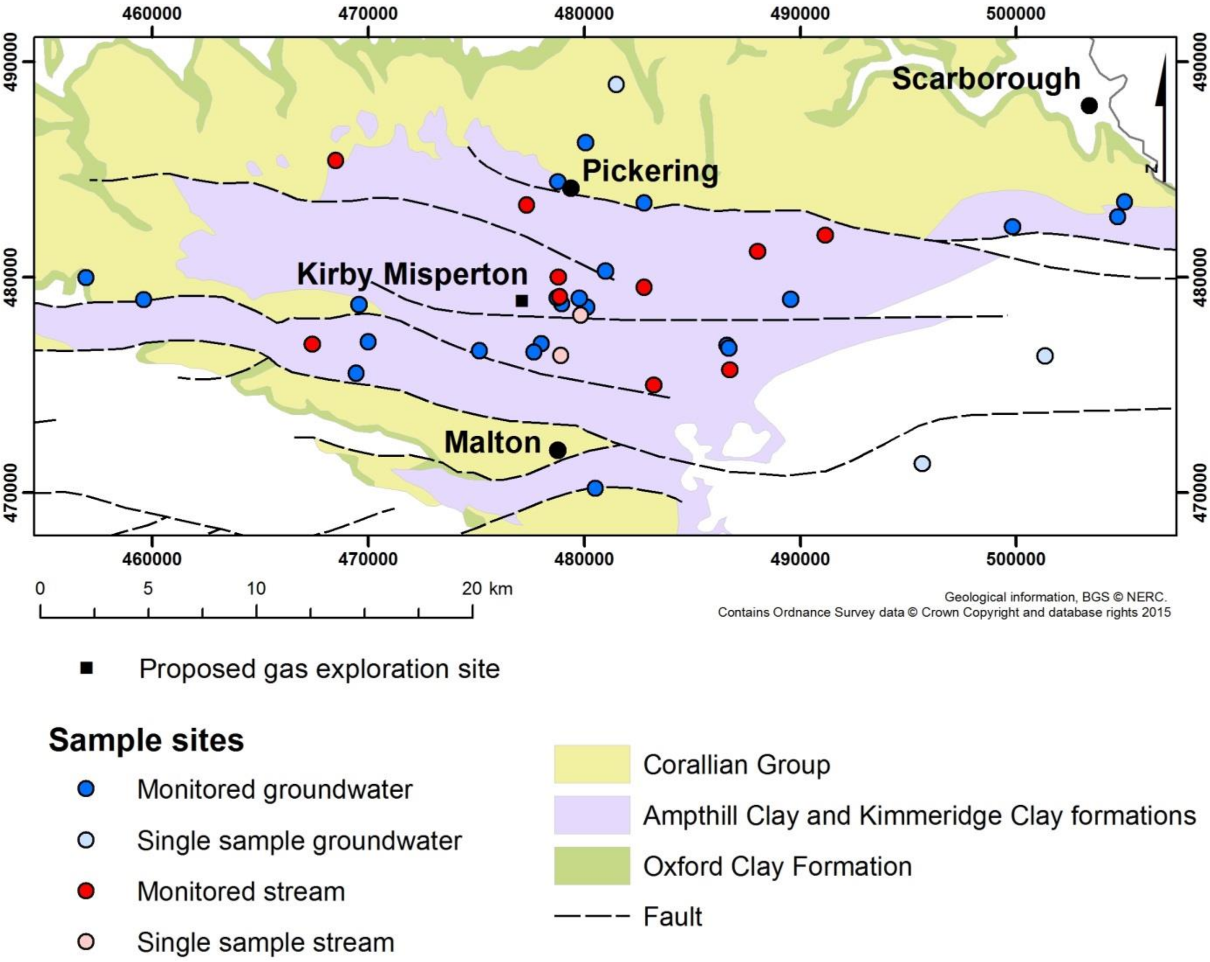

Figure 1. Simplified geological map of the Vale of Pickering showing sampled water points (groundwater, streams)

2.1.4 Borehole installation

A further objective of the water monitoring programme is to install new purpose-drilled boreholes to provide infrastructure for near real-time monitoring and telemetry, to provide further data for characterising the baseline and to enable any existing gaps in the groundwater network to be filled.

A key sampling decision will be the selection of sites for the new boreholes. Sites will be optimised with respect to geology and geological structure, hydrogeology and to representation by existing borehole infrastructure. They will also be subject to access constraints, although some optimisation will be possible. We will use the concept of 'balanced' sampling whereby a sample design is balanced for some ancillary variable if the temporal sample mean of the ancillary variable at the sample sites equals the spatial mean of that variable across the domain. We will use interpolated groundwater level, spatial coordinates and other available covariates selected during the conceptual model phase as balancing variables, and optimise the location of new boreholes accordingly. This should minimise the uncertainty of resulting estimates of spatial means in so far as this depends on the location of the new boreholes.

It is the intention to install up to six pairs of shallow boreholes (10–40 m deep) within the superficial deposits that form one or more shallow secondary aquifers, and two deep boreholes (200–370 m deep) into the underlying principal bedrock Corallian Limestone aquifer. Investigations of the geology of the superficial deposits indicate an increased prevalence of sandy horizons along the margins of the Vale of Pickering, at least in some areas, within the dominantly argillaceous sediments (Ford, 2015). Evidence also suggests downgradient flow of groundwater within the sandy horizons of the shallow superficial deposits from the marginal areas towards the lowest-lying part of the basin. The structure of the Corallian is shown to be highly faulted, with E-W faulting particularly prevalent (Newell et al., 2015), with depths of the formation of order of 200–350 m below OD in the central part of the basin.

The new groundwater monitoring boreholes will be located within a radius of approximately 10 km of KM8. Locations will seek to establish baseline chemistry of groundwater at close proximity (<3 km) to KM8 as well as more distal sites (>5 km lateral distance) to obtain a balance between API and control conditions. We will also seek to investigate shallow groundwater chemistry and hydrogeological conditions in the superficial aquifer along a selected groundwater flow line from the margin to the centre of the basin. Consideration of fault structures will also be made in locating deep boreholes penetrating the Corallian. Design and installation of all boreholes will comply with best practice, e.g. BS ISO 5667 Part 22 and new Environment Agency guidance. Monthly sampling of these boreholes will be attempted if practical and accessible.

A period of commissioning will take place before near real-time monitoring instrumentation can be installed and the routine sampling programme established. The frequency of measurement for the parameters measured in real time will initially be at <hourly to allow site set-up and optimise sampling frequency. It is anticipated that ultimate data recording will be of the order of daily. Data will be telemetered to BGS and displayed on the BGS website.

A further strand of activity concerns acquiring access to the operator's own water monitoring boreholes. This will only be possible after planning permission has been granted and the owner gives permission. Spot sampling of any monitoring infrastructure installed by the operator(s) will follow the same protocol as that for the purpose-drilled boreholes.

2.1.5 Sample statistics

As the monitoring will be strongly constrained by dependence on existing boreholes, and the limited number of new boreholes, an independent random sampling scheme is not possible. Therefore a model-based analysis of data will be needed to derive correlations between monitoring boreholes, estimates of the between-site variance and associated uncertainties.

The objective of sampling will be, for any analyte, to allow:

- estimation of the spatial mean across each domain (e.g. Corallian Limestone aquifer or shallow superficial aquifer), and within each subdomain (API or control), at any given time with associated confidence intervals to express the uncertainty of that estimate; and
- estimation of the difference between the spatial means of the control and API subdomains of each domain at any time, with an associated confidence interval of the estimate. This confidence interval will ultimately be used for our key inference: whether the spatial means of the API and control subdomains can be regarded as equal after shale-gas development has started or whether differences emerge. This further association is probably only testable beyond the current project lifetime and is of course contingent upon planning consent.

2.2 SEISMICITY

2.2.1 Overview

The primary aim of the seismicity work package is to deploy a network of seismic sensors to monitor background seismic activity in the vicinity of proposed shale-gas exploration and production at KM8. The data collected will allow reliable characterisation of baseline levels of natural seismic activity in the region. This will facilitate discrimination between any natural seismicity and induced seismicity related to the shale gas exploration and production. A further aim is to make recommendations for a suitable traffic-light system to mitigate earthquake risk. This section describes the procedures that were used for selecting appropriate seismic monitoring sites.

2.2.2 Monitoring equipment

There is a wide range of sensors available for measuring transient ground motions from earthquakes and other sources of seismic energy, ranging from high-frequency geophones commonly used in hydrocarbon exploration to very-broadband seismometers that are used to record long-period signals from large earthquakes. For this project, we have chosen to use Güralp CMG-3ESP seismometers, which are compact, three-component broadband sensors, suitable for rapid installation in a shallow pit or posthole. These will be deployed across the

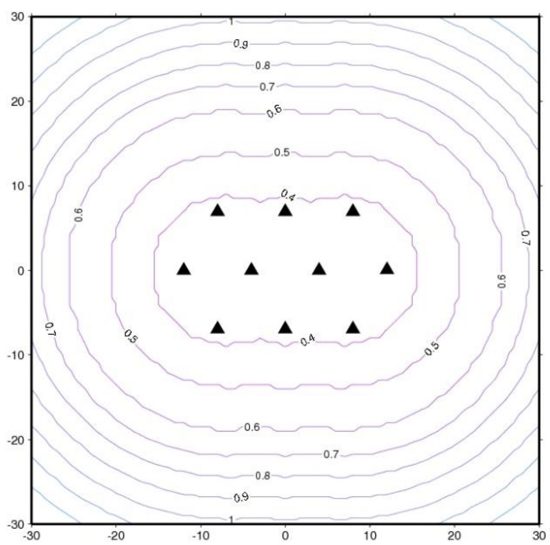

Figure 2. Modelled detection capability for a network of eight sensors (black triangles), with a uniform spacing of 8 km sensors, within a 30 km by 30 km area, showing the spatial variation in magnitudes that can be detected. The detection requires a signal in excess of three times the background noise to be recorded at three or more stations

study area to record the weak motions from both background earthquake activity and any induced seismicity. In addition, because of the requirement to detect and monitor very small earthquakes that may be induced by any hydraulic fracturing operations, we will also install sensors in four shallow boreholes close to the Kirby Misperton drill site. Research has shown that installation within boreholes significantly improves signal-to-noise ratios, which is critical for measurement of small earthquakes. The borehole instruments will include three 4.5 Hz three-component geophones and one Nanometrics Trillium Compact posthole seismometer.

Data at all sites will be digitised using a high-dynamic-range digitiser and stored locally on a data logger. In addition, we will use wireless routers to transmit data in near real-time to the British Geological Survey using mobile phone internet connections, a method of telemetry used for a number of existing permanent stations. The equipment at all sites will be powered by batteries charged by solar panels.

2.2.3 Network Design

The number of stations in any network depends on both the extent of the area of interest and the minimum magnitude of the events to be detected. In this case the aim is to detect reliably and locate earthquakes with magnitudes of 0.5 and above within a 20 km by 20 km area. Reliable and uniform detection of seismic events across a given area of interest requires a uniform distribution of monitoring stations. The density of the stations along with the noise levels at each station control the lowest magnitudes that can be detected reliably. Higher station densities will be required to detect and locate lower magnitudes. This is because the signal amplitude is a function of both the magnitude of the earthquake and the distance of the earthquake from the recording position, and this decreases with the square of the distance to the station. For small earthquakes, the station needs to be close to the source. Noise levels at individual stations also affect detection capability, and these should be low in order to maximise detection potential.

Figure 2 shows the variation in the magnitude of earthquakes that would be detected by a network of ten sensors with a uniform spacing of 8 km, assuming that a signal in excess of three times the noise level needs to be recorded on at least three sensors for an earthquake to be detected. The noise levels at each station are the same and are representative of average UK ambient noise levels in the 1–10 Hz range. The results suggest that ten sensors with a spacing of 8 km should be sufficient for detection of magnitude 0.4 M_W earthquakes across a 20 km by 20 km area. Further from the centre, only larger magnitudes can be detected, so the network must also extend beyond the limits of the area of interest in order to be able to reliably detect earthquakes that occur close to these limits.

Reliable location and magnitude measurement places additional constraint on network design, since measurements at more stations are needed than for detection alone. In addition, location errors depend on the distribution and density of the recording stations. These errors may be large if the station density is insufficient, or if the closest stations are far from the earthquake source. Large errors are likely to limit the capability to discriminate between induced and natural earthquakes. Again, a uniform station density is required to ensure comparable location accuracy across the region of interest, with monitoring stations extending beyond the area of interest.

2.2.4 Site selection

Once the number and density of stations has been decided, approximate positions for each station are located on a map, making sure to preserve the desired network geometry. In addition, the stations need to be positioned so that any possible events of interest from specific sites can be located accurately. This means ensuring good azimuthal coverage around the site and also having at least one station close to the site.

When the approximate locations have been assigned, map and satellite image data are used to examine each site and establish the site geology and proximity of cultural noise sources such as roads, towns and villages, as well as possible logistical constraints. The aim of this is to choose a site with good coupling to bedrock and a minimum of cultural noise. If any of these factors suggest that the site is unsuitable, an alternative location will need to be found. In practice, more than one potential site should be identified in each approximate location, preferably one land belonging to different owners.

Both bedrock and superficial geological maps are used to determine the geology at the site. In addition, it is also useful to use contour maps, as high points and steep slopes often indicate shallow bedrock. Hard, dense rocks which have high seismic velocities are most suitable.

It has been found that thick clay layers at the surface tend to trap seismic noise. Sediments such as clays or poorly-consolidated soils, which have a low seismic velocity, can also act as efficient waveguides for ambient noise from cultural sources. Data recorded in such environments can have low signal-to-noise ratios. Therefore efforts need to be made to avoid deploying in such situations, particularly where cultural noise levels are high.

Figure 3 shows the BGS 1:625k geological map of the study area. The Kirby Misperton drill site is shown by the yellow star. It is clear that the near-surface deposits in the immediate area around the site and through most of the Vale of Pickering, are predominantly clay and fluvial, lacustrine or glacial deposits. Outside the basin, the surface geology is mainly limestone or sandstone.

The next step is to identify possible cultural noise sources and assess land use in the chosen vicinity. This can be done using Ordnance Survey maps, aerial photographs or satellite images. Google Earth can be particularly useful. It is important to avoid roads, railways and centres of population, as well as any industry or other activity that will generate seismic noise. This is often referred to as cultural noise. Ambient seismic noise from cultural sources propagates mainly as high-frequency surface waves (>1–10 Hz, 1–0.1 sec) that attenuate within a few kilometres of the noise source. The minimum distance from a road depends on the size of the road and the volume of traffic (this is often reassessed when visiting the site for the first time). It is usually necessary to be at least 5 km from a motorway or dual carriageway but stations may be closer to

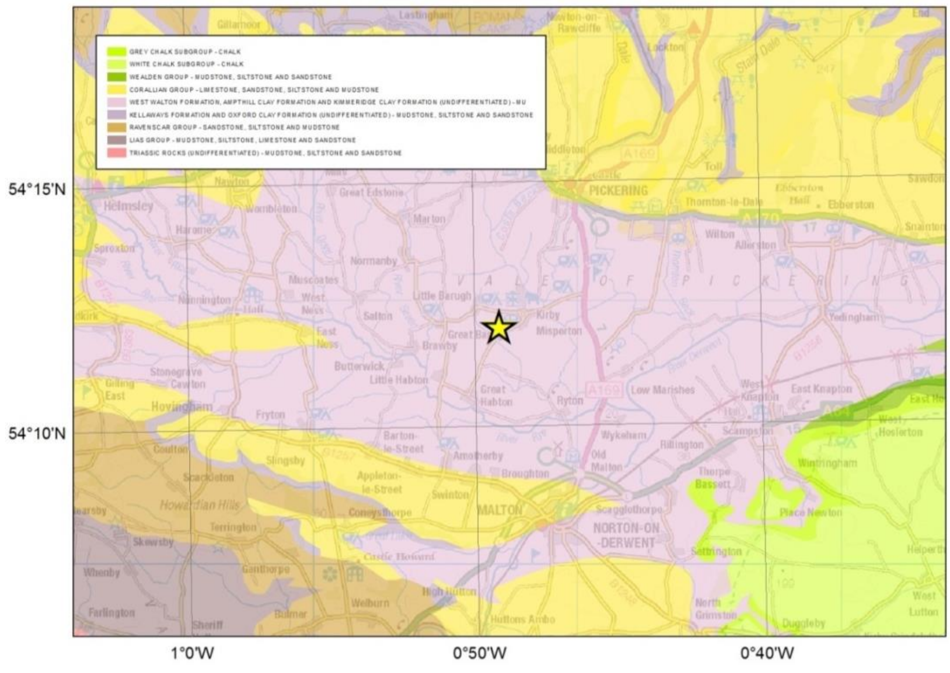

Figure 3. BGS geological map (1:625,000 scale) of the Vale of Pickering superimposed on a 1:50,000 scale Ordnance Survey map

quiet lanes that have only intermittent vehicle noise. It is also important that a station not be in the immediate vicinity of trees: a rule of thumb is that a station should be at least the height of a tree away from the tree in question. Fields can be problematic if likely to be used for cattle, although this can be remedied to some degree with a fence around the station. The map and image data can also be used to infer which farms or other landowners are likely to own it.

2.2.5 Visiting the Sites

Once precise positions have been identified on the map, a site survey is required. The largest part of such a survey is finding the owner of a suitable site and ascertaining the prospect for hosting a seismic station. This can be problematic as farm operators are often tenants, and additional agreements need to be reached with agents and/or landowners. It can also be difficult to contact farmers once farm ownership has been ascertained. If a farmer or other landowner is agreeable to having a site on their land, the location identified by map needs to be reassessed on the ground. A precise location then needs to be sought that is mutually suitable for the objectives of the study and for the farmer. An additional consideration is that land use may have changed since the map was produced or satellite image taken and known future changes in land use also need to be considered.

Once onsite, an auger can be used try to locate bedrock and a farmer should be asked about the depth to bedrock across his land. Once the position on the owners land best suited to both parties has been identified, a decision needs to be made whether it is worth continuing or whether another site should be found in the area. In some cases it has been necessary to abandon a site after digging the hole as decent coupling was impossible.

2.3 GROUND MOTION

2.3.1 Overview

The proposed investigation in this work package is to monitor the surface ground motion (subsidence, uplift or stability) of the target area using satellite radar interferometry (InSAR). InSAR is ideal for this purpose because archive radar data (acquired by satellites since 1992) are available and can be utilised to ascertain a baseline of motion or lack of motion prior to any permitted gas exploration and production. ESA has recently launched a new radar satellite Sentinel 1A that is acquiring data over the UK and elsewhere. BGS will investigate ground motion using available archive radar data and will seek to incorporate Sentinel 1A satellite data (when available) to establish baseline ground conditions in the study area.

2.3.2 Data selection

'Historic' ground surface motion data for pre-development (baseline) operations includes data from the ERS-1/2 satellite acquired over the period 1992–2000, and the ENVISAT satellite data acquired during 2002–2007. There is no satellite coverage in the region between 2007 and 2014 due to orbital decay of ENVISAT and no alternative commercial data are available due to lack of coverage in this time period. Nonetheless, the period 1992–2007 is sufficient to provide a meaningful baseline assessment of ground motion. For the Vale of Pickering, ESA's archives include two data stacks of ERS-1/2 and ENVISAT scenes that cover a standard satellite frame extending 100 by 100 km (see red polygons in Figure 4). 75 ERS-1/2 SAR scenes for 1992–2000 and 25 ENVISAT ASAR scenes for 2002–2009 are available along satellite track 366 in descending mode. These data (1992–2000 and 2002–2009) will be processed using InSAR techniques.

ESA launched Sentinel-1A in April 2014, with data being made available to users as of October 2014. The catalogue of these data is growing and it is anticipated that a sufficient stack may be available by the end of 2015. If available, this interval of data will also be processed to determine more recent baseline ground conditions in the study area.

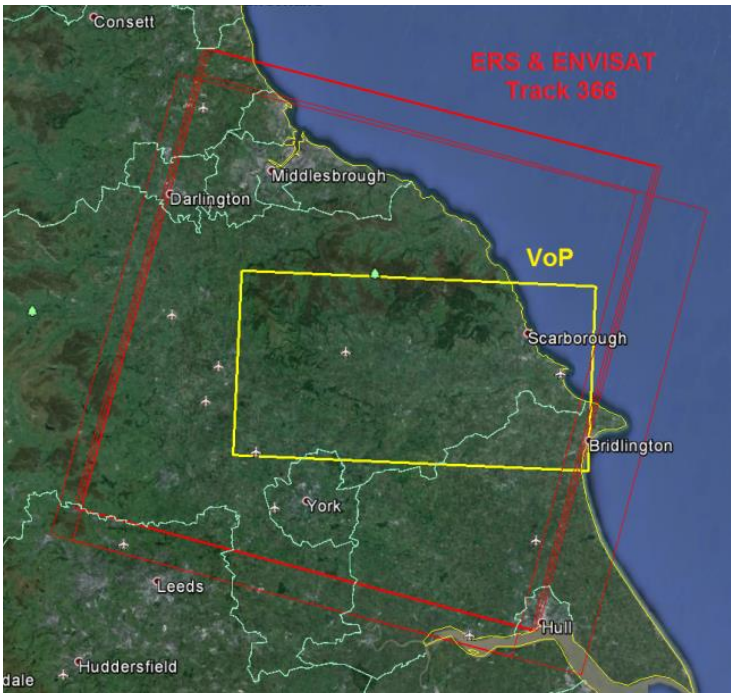

Figure 4. Region of interest for the ground motion analysis (VoP; yellow rectangle) and ERS-1/2 and ENVISAT satellite data footprints of the available scenes from ESA's archives (red rectangles). Image ©2015 Google

Choice of areal satellite data coverage will depend on options offered by the satellite data operator but the selection will be optimised to maximise onshore coverage and to cover the Vale of Pickering Basin, as far as possible centred on KM8.

2.4 AIR COMPOSITION

2.4.1 Overview

The air composition work package incorporates baseline monitoring for air-quality and greenhouse gases in the Vale of Pickering, Yorkshire and includes an additional air-quality component within the Fylde, Lancashire, to make consistent the scope of monitoring activities in the two study areas. These activities will establish the baseline for a broader range of pollutant concentrations in each area.

The proposed monitoring will involve:

- selection of a suitable monitoring site in the Vale of Pickering following initial characterisation of potential sources of gas emissions. This will include assessment of any pre-existing air compositional data and the need for the site to remain directly useful as a comparator during any future shale-gas site operations (Yorkshire);
- measurement of a continuous greenhouse gas (GHG) concentration in air dataset, simultaneous with measurements of wind and local thermodynamics and meteorology at a fixed measurement site (Yorkshire);
- continuous high precision measurements (at 1 Hz) of airborne concentrations of PM2.5 and regulated (air quality) reactive trace gases (O_3, NO_2 and NO) using dedicated instrumentation with low limits of detection and fine resolution/sensitivity at the same location as above (Yorkshire and Lancashire);
- weekly collection of samples and analysis for concentrations of C_2–C_8 non-methane hydrocarbons and VOCs, H_2S and benzene, to provide averaged statistics on background concentrations near to the site (Yorkshire and Lancashire);

- carbon-isotopic case studies: collection of quarterly air samples from both the Lancashire and Yorkshire sites for laboratory analysis of carbon-isotopic-composition of sampled methane. This will inform an assessment of the utility of this additional dataset in better constraining the quantification of thermogenic-biogenic methane partitioning and resulting source apportionment during future operational monitoring if it goes ahead (Yorkshire and Lancashire);
- identification of any significant changes in the local area in terms of potential new (or removed) emission sources such as transient industry or works in the local area, nominally within 2 km of the monitoring site, during the period of baseline measurement (Yorkshire).

2.4.2 Site selection

LANCASHIRE SITE

The Lancashire site has been in operation since November 2014, operated by Allen and Mead from University of Manchester. The site is situated on farmland near to Preston New Road, Blackpool (Figure 5). Its position, in a field local to areas under consideration for potential shale-gas operations, will provide a contextual dataset that represents pre-existing sources of pollution such as nearby roads and industrial and agricultural activity. It is also positioned to receive air from the coastal environment.

The long-term and continuous measurement strategy at both this site and in Yorkshire is consistent with a philosophy of characterising greenhouse gases and air quality representative of the local environment and takes advantage of the various wind directions and temporally (and seasonally) varying sources of both natural and manmade pollution, including those blown in from afar, e.g. from cities further upwind and beyond.

The site has been providing climatological baseline data for CH_4 and CO_2 baseline concentrations (so far) for the 12-month period from November 2014 to November 2015. The site will be expanded in late November 2015 to include the air-quality instruments for measurement of NO, NO_2, PM and O_3. Data will be streamed wirelessly from this point, removing the need for manual data collection, although monthly site inspections and servicing

Figure 5. The current greenhouse gas and meteorological measurement site at Preston New Road (near Blackpool, Lancashire) as of November 2015

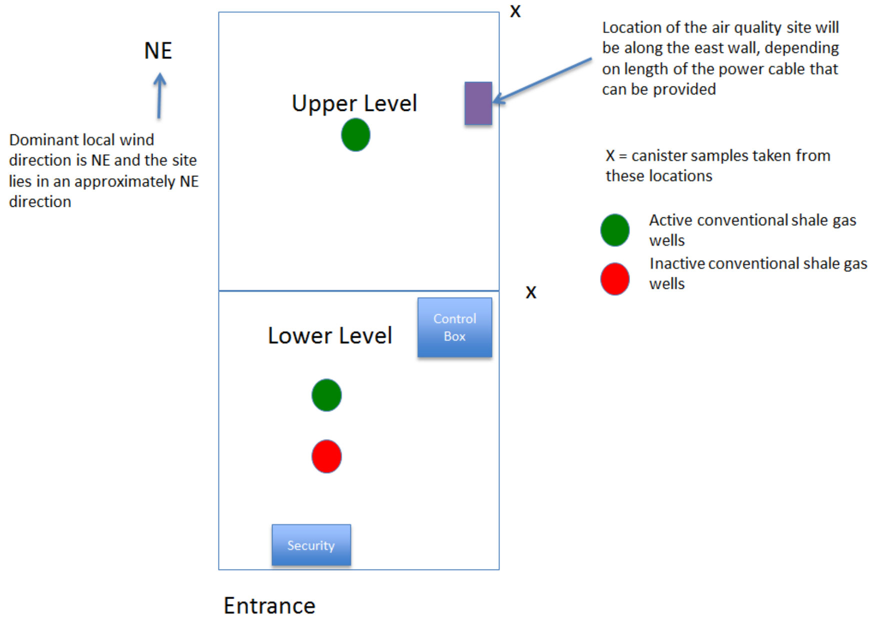

Figure 6. Schematic of the site layout and measurement station at KM8, Yorkshire

will continue. Cloud logging will ultimately enable automated data reporting at the site.

YORKSHIRE SITE

The air-quality, greenhouse-gas and meteorology station will be situated at the KM8 site. The station will be situated along the east wall of the site, constrained by availability of power. An existing borehole at the site is proposed for hydraulic stimulation and for this reason, it was decided that this was the best place to be situated for future science applicability and consistency with the Lancashire monitoring site. Another advantage is the ready provision of secure power and 24-hour manned security available at the site to minimise risk of data interruptions or interference (see Figure 6, Figure 7).

Figure 7. Google Earth image of the lower level site at Kirby Misperton (note the higher level shown in Figure 6 was not built at the time of this Google Earth image

2.5 SOIL GASES

2.5.1 Overview

The objective of this work package will be to collect baseline measurements of soil gas, soil gas flux to atmosphere and atmospheric gas in the area of proposed shale-gas development. This will include field measurement of methane, CO_2 (which could be produced from methane oxidation), O_2 (useful in helping determine the source of CH_4 and CO_2) and Rn (possible tracer of gas migration pathways). We also propose collection of samples from a smaller number of sites of interest for subsequent laboratory analysis by GC (both as a check of field measurements and for the determination of trace components) and mass spectrometry (for C isotopes in gaseous CH_4 and CO_2) and continuous monitoring.

2.5.2 Soil and surface gas sampling

Surveying for discrete surface gas outlets is best conducted with mobile equipment to identify locations of specific interest. However, due to dilution in air, sensitivity is reduced. Single-point measurements provide the highest sensitivity as the gas is extracted from the soil or soil surface where concentrations are highest, and a sufficient number of analyses over a site provide a good indication of the range of baseline conditions.

Continuous measurements at a small number of sites will also provide information on temporal variations (e.g. diurnal or seasonal variations).

The study will include:

- field-scale surveys with detailed coverage of near-ground atmospheric methane and CO_2 using mobile open-path lasers. Site selection will use the geological/hydrogeological conceptual model and random sampling network/programme design;
- broad-scale grids of point measurements of soil gas (CO_2, CH_4, O_2, H_2, Rn) and flux (CO_2) in the field with subsequent analysis of selected gas samples in the laboratory;
- for specific sites and for a fixed time period, continuous measurement of atmospheric

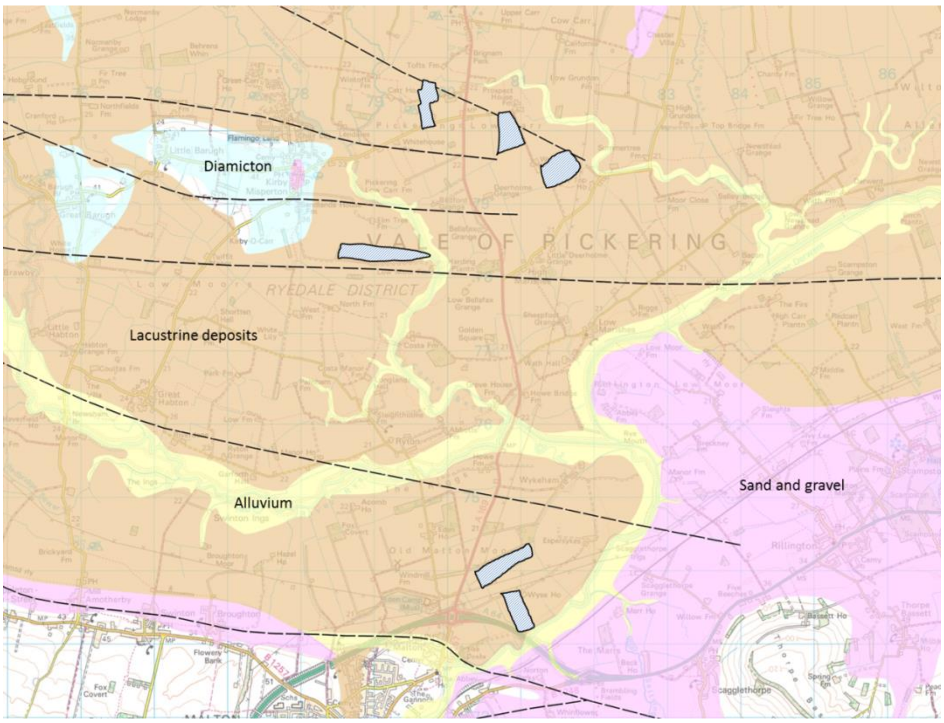

Figure 8. Potential field sites identified for soil-gas survey, with variable superficial lithology and proximity to faults

methane using a scanning open-path laser, plus CO_2 flux using accumulation chambers and eddy covariance techniques. Also at specific sites, for longer time periods, continuous measurements of soil-gas CO_2 concentrations using buried probes.

Site selection will incorporate:

- a range of baseline measurements over superficial lacustrine deposits (e.g. differing lithologies, soil types, crop types, damper/drier ground, farmed/undisturbed);
- a range of baseline measurements over Corallian Limestone (different conditions as above);
- higher-density sampling around proposed exploration sites to provide more data in case of future ‘borehole-related’ anomalies;
- traverses across selected major faults in the area that are known to have conducted gas at depth in the geological past to reveal whether methane is naturally migrating to the surface.

Locations of any buried gas pipelines will be noted and avoided. The aim will be to characterise the baseline for a range of typical soil, ground-use types and ground conditions and to investigate the impact of faults in the area as fluid flow pathways. This could be indicated by coincident anomalies of different gases such as CO_2 and Rn.

A set of suitable field options with variations in location, proximity to KM8, proximity to high-methane groundwaters identified by groundwater sampling and proximity to faults, has been identified (Figure 8).

2.6 RADON IN AIR

2.6.1 Overview

The work outlined in this work package aims to obtain baseline results for the indoor and outdoor radon levels in air at various locations around KM8 and in control areas in other parts of the Vale.

2.6.2 Indoor radon

This component will measure the baseline indoor radon distribution in homes in the study area and will require the recruitment of volunteer householders for radon monitoring of their homes. Recruited householders, randomly selected from addresses in Kirby Misperton, Little Barugh,

Figure 9. PHE standard pack of passive radon detectors

Figure 10. PHE outdoor radon monitoring pack

Yedingham, Pickering and Malton have been invited to participate by post, following a well-established PHE procedure.

Selected villages/towns have been chosen on the basis of i) proximity to the KM8 site, and ii) radon potential using existing mapping (http://www.ukradon.org). The villages of Kirby Misperton and Little Barugh represent locations proximal to KM8 (<2 km distance), within an area of low radon potential (<1% probability of exceeding the radon Action Level of 200 Bq/m^3), Yedingham represents a more distant site in the vale (ca. 10 km distance) with a similar low radon potential. Pickering and Malton each represent more distant sites (5–10 km distance) with higher radon potential (5–10% probability of exceedance of the Action Level).

A total cohort of 160 householders is proposed. The PHE's standard packs of passive detectors (Figure 9) will be sent by post for two consecutive periods of 3 months. In addition, each home will receive a pack to carry out monitoring for a longer period. The measurements will run concurrently in sufficient houses to give statistically useful data.

2.6.3 Outdoor radon

This component will establish the baseline outdoor level of radon in air, that is typically <10 Bq/m^3. Outdoor radon monitoring will be carried out in a range of locations around KM8 and in control areas in other parts of the vale as well Oxfordshire (close to PHE HQ, an area with low radon potential).

Passive radon monitors (Figure 10), very similar to those used routinely in homes, have been placed in small aluminium wrapped weather-proof plastic pots in discreet but open-air locations for 3 months or longer.

3 References

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