An environmental risk assessment for coal bed, coal mine and abandoned mine methane operations in England

Report – SC130029/R

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Why produce an Environmental Risk Assessment?

There is currently limited practical experience of coal bed methane production in England. This Environmental Risk Assessment (ERA) identifies the main environmental risks, in line with Defra guidelines (Defra 2011) and is intended to support the Environment Agency's technical guidance for onshore oil and gas operations in England. It follows the production of a similar document covering shale gas exploration (Environment Agency 2013a).

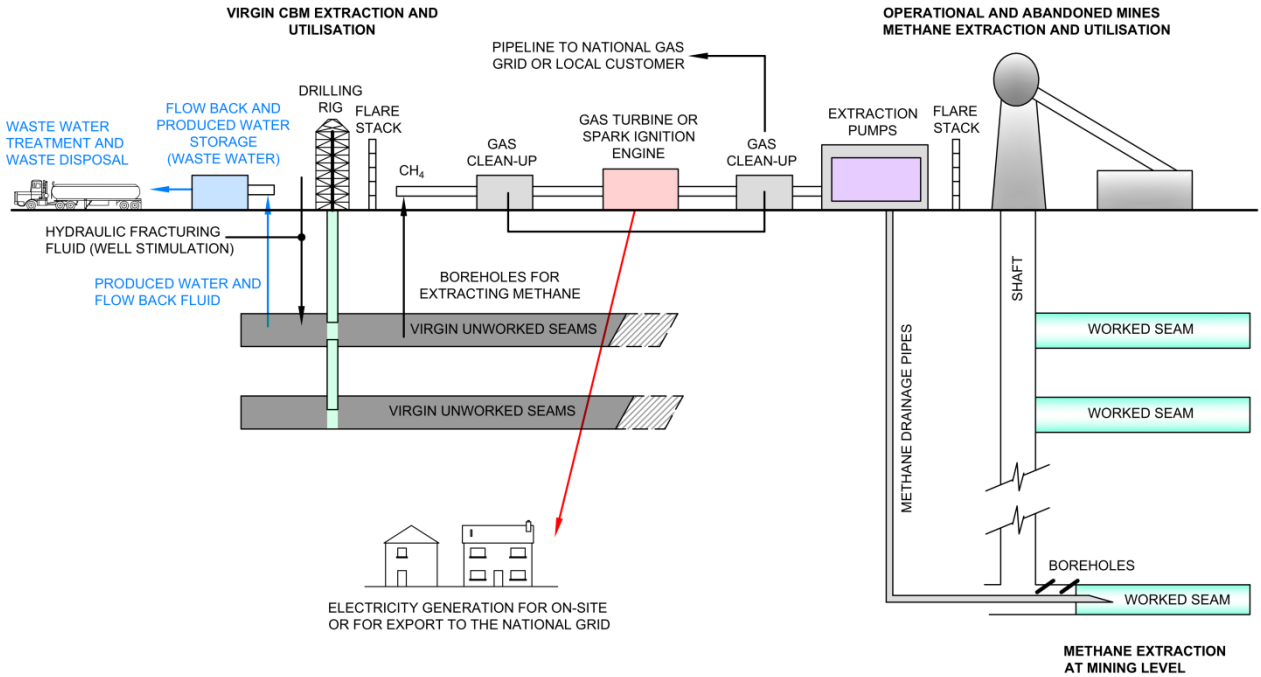
Scope of assessment

This assessment covers three processes of natural gas production where methane is recovered from coal seams. In each process the methane formed during coal formation is released by depressuring of the seams, though each process is slightly different.

- **Coal bed methane (CBM),** also known as virgin coal bed methane (VCBM) or coal seam gas (CSG) in Australia, refers to the recovery of natural gas from unmined coal seams. Enhanced coal bed methane (ECBM) is the recovery of CBM by injecting carbon dioxide or nitrogen.
- **Coal mine methane (CMM)** refers to the recovery of methane from active mines, either as pre-drainage prior to coal extraction, or, as most commonly happens in the UK, from the disturbed strata immediately following coal extraction.
- **Abandoned mine methane (AMM)** refers to the removal of methane following cessation of coaling operations and mine closure.

Of these, CBM represents the largest potential growth area in the UK and is the main emphasis of this document. The three processes are illustrated in Figure 1.

Figure 1: Options for methane extraction and utilisation (adapted from DTI 2001a)



Method

The ERA is limited to the Environment Agency's regulatory and geographical remit in England and covers the lifecycle of gas production through its different phases. These are defined in this report as:

- **Exploration** – prospecting (as defined by Article 3(21) of the Mining Waste Directive) including drilling, coring and sampling to establish the presence, nature and quality of the hydrocarbon reserves to ascertain whether they have economic value, including potential well abandonment
- **Appraisal** – pre-production well testing and stimulation prior to full-scale operation, including possible well abandonment
- **Operation** – all activities included in full-scale operation, including the production of commissioned wells, field expansion with additional well drilling and stimulation (if required), gas collection and treatment, treatment and disposal of produced water/flowback water, pipeline to the National Grid or customer, electricity generation for use onsite or export, well suspension and potential well abandonment. This phase applies to standalone sites and hubs.
- **Abandonment** – decommissioning and permanent removal of wells and infrastructure.

To carry out the ERA the Environment Agency consulted other regulators in the UK and operational and regulatory experts in related fields from within the UK and abroad, predominantly the USA and Australia.

The hazard matrix that forms the basis of the ERA was developed initially at a technical workshop attended by industry professionals experienced in the areas of conventional coal mining, gas production, fugitive emissions, water pollution, and regulation. The workshop developed a conceptual model that identified the processes involved in CBM and associated risks. A collaborative process was used to identify and categorise risks based on relevant experience. The risk matrix was then subjected to internal and external peer review.

Overview of coal bed methane production techniques

CBM production is relatively new to the UK, with exploration undertaken in northern England, Scotland and Wales. However, there is much more operational experience in the USA and Australia.

The methane discussed in this assessment is natural gas created during the formation of coal. It is adsorbed on to the surfaces within the coal and is held in place by the hydrostatic pressure of the formation water which resides naturally within the coal seam.

The coal measures from which CBM can be extracted are generally found at depths of between 200 and 1,100 m. The virgin coal seams in the UK are typically several metres in thickness, whereas those in the USA and Australia tend to have greater thicknesses. Data collated by the Department of Energy and Climate Change (DECC) from the National Coal Board database indicate that, in general, gas content increases with coal seam depth, rank and thickness (DECC 2012), though this pattern is not invariable. It is possible that the increased gas content with depth may be explained as a consequence of Hilt's law, which predicts an increase in coal maturity with depth, although exceptions to this theory have been observed. Furthermore although bituminous coals of the Birch borehole in the North Staffordshire Coalfield were identified to show increasing methane contents down to the Rowhurst Rider seam at 790 m, coals below 800 m were identified to have lower than expected methane contents, partially offset by an increase in ethane content below this depth. Similar trends in gas content with depth have been observed in the USA.

CBM is recovered by drilling down to the target coal seam or seams and then often drilling horizontally along the seam(s). A sump is set below the seam(s) and formation water from the coal

is pumped out, a process known as dewatering. This reduces the pressure within the coal and so allows the methane to desorb and flow to the primary well and then to the surface.

CBM production wells in the USA generate quantities of produced water of between 33 and 100 m^3/day with an average of 78 m^3/day. In the UK, indications from current pilots are that the coal seams may be drier (probably because they are deeper and thus have lower cleat permeability) and that the volumes of produced water are in the range 1 to 40 m^3/day per well.

Permeability within the coal seam is necessary to produce CBM. Many coal seams have a natural system of fractures or 'cleats,' formed initially by moisture loss during the peat to lignite phase of coalification, or later in response to crustal deformation (DECC 2012), which provide a natural permeability to the seams. Experience in the USA and Australia has shown that, in many cases, the natural permeability caused by the cleat systems is sufficient to release methane once the seams are depressurised by pumping water.

If the natural permeability of the coal seam is low, however, stimulation (hydraulic fracturing) may be required to improve connectivity between the borehole and the cleat system (DECC 2010). This process is termed 'enhanced CBM'. Stimulation may be carried out to increase gas flow. This stimulation is usually carried out using water or a water and sand mix in a similar way to fracking in shale gas, but at lower pressures. The pressures required to extend and expand the natural fractures in a coal cleats are depth dependent, but are commonly reported to be between 3,500 psi and 5,000 psi (24 MPa and 34 MPa), around 50–70% lower than those needed to create fractures in shale. Where low volume hydraulic fracturing is employed, between 200 m^3 and 1,500 m^3 of water per well may be required. Alternatively nitrogen foams with proppants have been used to stimulate cleats in the UK.

ECBM involves the preferential displacement of methane using carbon dioxide sequestration techniques. Trials have been undertaken in the USA and Canada as sequestration of carbon dioxide has the potential to reduce greenhouse gas emissions while increasing CBM recovery. CBM production by injection of carbon dioxide may be more efficient than current techniques that require the production and disposal of large volumes of formation water. However, the sequestration capacity of coal basins has yet to be quantified (for example, Reznik et al. 1982, Gale and Freund 2001, Schroeder et al. 2002). Because of the uncertainty associated with this technique and its relevance within the UK, it has not been considered in this ERA.

Of the three techniques covered by this report, CBM generally provides the highest concentration of methane recoverable from coal seams due to the lack of exposure to air from mining. Recovered concentrations often exceed 95% methane, making the gas suitable for use as a direct replacement for conventional natural gas in pipeline networks. By comparison, CMM sources typically contain 35–75% methane and AMM sources 35–90% methane (DTI 2001b), with the balance largely made up of air (oxygen and nitrogen) and carbon dioxide.

Coal mine methane and abandoned mine methane

CMM is the long established process of removing methane from a working mine to enable planned coal production rates to be achieved safely by capturing methane at high concentrations before it enters the mine roadways. Gas emissions into the face or longwall can then be satisfactorily diluted by ventilation air (DTI 2001b). This in turn makes ventilation and therefore operation more efficient. The methods used can be classified as either pre-drainage or post-drainage.

Pre-drainage involves removing methane from coal seams, usually the 'worked seam', in advance of mining; however this is not practised in the UK and post-drainage is the favoured technique. This involves capturing methane from strata above and below the worked seam (but not from the worked seam itself) which have been disturbed by coal extraction. The most effective post-drainage method in common use in modern, deep gassy longwall coal mines is cross-measures methane drainage. Boreholes are drilled at an angle above, and also in some instances below, the worked-out coal seam (goaf). The boreholes are cased and suction is applied from surface or underground pumps, and the gas is drawn to a discharge point or utilisation plant. The methane is

invariably diluted with ventilation air during suction. Typically 30–70% of the total gas released in a longwall working can be captured (DTI 2001b).

AMM schemes recover gas that accumulates in abandoned mines which would otherwise find its way to the surface in an undesirable manner. Preferred sites are those where minewater recovery rates are very low, or where dewatering is being continued, as useful volumes of gas cannot be extracted from waterlogged workings. Drilling techniques may be used to connect workings to aid minewater drainage away from prime production zones, link adjoining mines where workings interleave but do not directly connect, and/or improve existing underground connectivity.

The most important distinction between the three processes is that CBM and AMM are ‘primary’ processes with the principal aim of energy recovery, whereas CMM is a ‘secondary’ process utilised to improve the ventilation efficiency and safe operation of mining. This ERA therefore only considers CMM within the operational phase. Furthermore, hydraulic fracturing is not a requirement of either AMM or CMM techniques. In CBM, gas recovery is undertaken by means of depressurisation through dewatering, whereas in AMM and CMM the gas is released via suction. In the UK the requirement for dewatering to access gas for AMM in waterlogged workings is likely to result in the process being unviable. Dewatering activities for CMM are considered to be managed by the existing minewater management. For this reason risks associated with produced water have only been assessed in relation to CBM.

Stages

The ERA covers the following stages which may apply to each phase of CBM production:

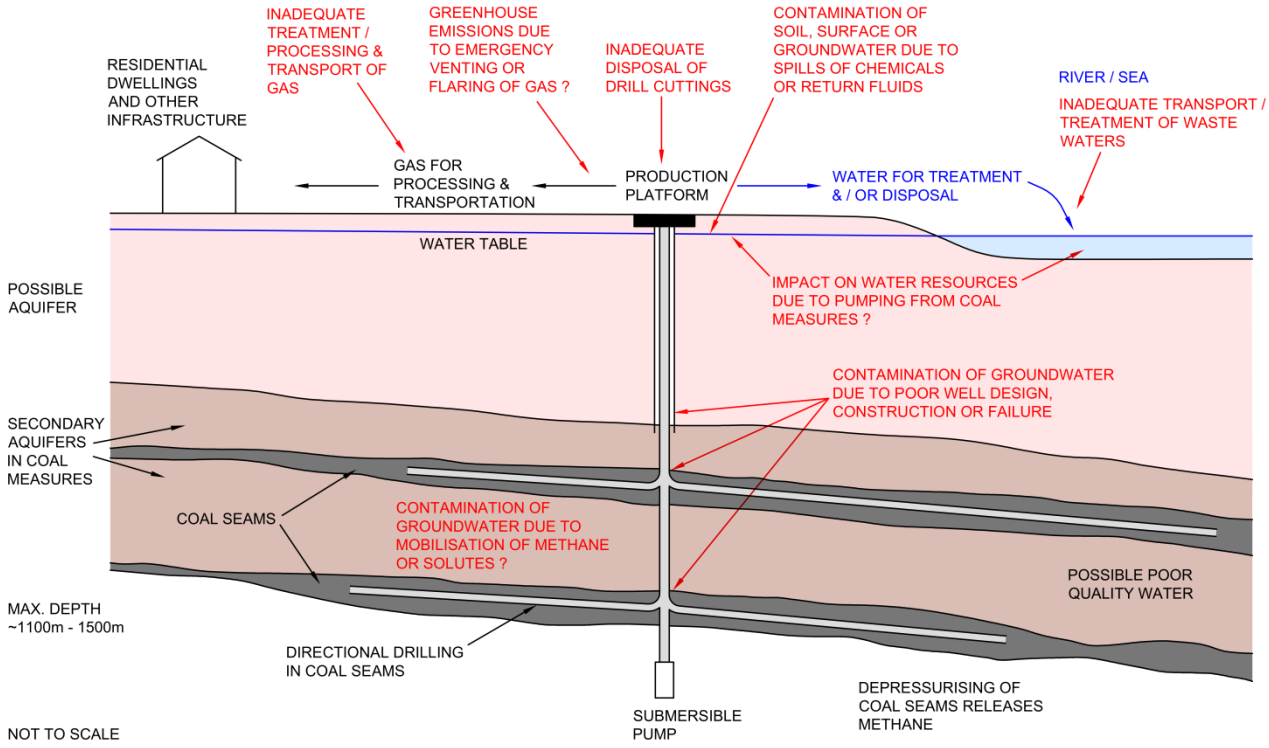
- groundworks
- water acquisition
- chemical mixing
- borehole design, installation and integrity
- hydraulic fracturing
- management of fluids, including produced water and flowback fluids
- gas management including onsite compressors, combustion plant, and clean-up plant
- land stability
- offsite disposal or reuse
- well closure and abandonment

A well-established approach to determine the potential risks from CBM production was adopted using a standard source–pathway–receptor model. This approach can be summarised as follows:

- identification of hazards
- identification of consequences
- estimation of the probability of the hazards occurring
- estimation of the magnitude of the unmitigated risk with industry standard controls in place
- identification of risk management options
- estimation of the residual risk after the use of regulatory controls

To aid this process a conceptual model of the environmental risks posed by a single well pad and borehole was produced. This model, which is shown in Figure 2, identified the main sources, pathways and receptors presented during the CBM lifecycle.

Figure 2: Potential environmental risks from CBM production activities



Risk classification

The magnitude of the unmitigated risk is a combination of the probability or likelihood of an event occurring and the consequences for people and the environment if it does. The risk magnitude matrix is shown in Table 1.

Table 1: Risk magnitude matrix

Consequence	Probability			
	Very low	Low	Medium	High
Very low	Low	Low	Low	Low
Low	Low	Low	Medium	Medium
Medium	Low	Medium	Medium	High
High	Medium	Medium	High	High

Definitions

- Probability categories: very low – rarely encountered, never reported or highly unlikely; low – infrequent occurrences; medium – can be expected to occur several times per year; high – repeated occurrences
- Consequence categories: very low – slight environmental effect that does not exceed a regulatory standard; low – minor environmental effect which may breach a regulatory standard but is localised to the point of release with no significant impact on the environment or human

health; medium – moderate, localised effect on people and the environment in the vicinity of the incident; high – a major environmental incident resulting in significant damage to the environment and harm to human health

Results

The following tables summarise the environmental risks associated with CBM, AMM and CMM. This is the combined risk incorporating all identified stages of the three processes as assessed in turn within the subsequent sections.

Overall environmental risks – coal bed methane

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Negative environmental impact to water as a resource, wildlife and their habitats, the atmosphere, human health, property and infrastructure caused as a direct result of an activity undertaken as part of one of the four phases of CBM extraction			
Pathway – How might the receptor come into contact with the source?	Uncontrolled release of pollutants to ground, air or water, physical disturbance of ground or infrastructure			
Receptor – What is at risk?	Groundwater, surface water, wildlife and their habitats, the atmosphere, human health, property and infrastructure			
Harm – What are the harmful consequences if things go wrong?	Breach of an environmental standard; loss or damage to a habitat or resource; injury, ill health or death; damage to property or infrastructure; air pollution			
Probability of exposure – How likely is this contact?	Low	Medium	Medium	Low
Consequence – How severe will the consequences be if this occurs?	Medium	Medium	High	Low
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	High	Low
Justification for magnitude	The process is new to the UK and its particular geology. There is mixed evidence from overseas activity. Independent experts note the potential consequences are high if the process is not regulated properly or industry best practice is not followed.			

	Exploration	Appraisal	Operation	Abandonment
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Water Resources Act 1991 Water Framework Directive (2000/60/EC) Groundwater Daughter Directive (2006/118/EC) Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Control of Pollution (Amendment) Act 1989 The Waste (England and Wales) Regulations 2011 – registration of waste carrier and brokers			
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments. Offshore Installations and Wells (Design and Construction, etc) Regulations 1996 Borehole Sites and Operations Regulations 1995 The Hydrocarbons Licensing Directive Regulations 1995 The Petroleum Act 1998 The Coal Industry Act 1994			
Residual risk – What is the magnitude of the risk after management?	Low. The Environment Agency will use appropriate controls under the legislation above (where it is the competent authority) to manage the identified risks, supported by monitoring and compliance work (for example, site inspections).			

Overall environmental risks – abandoned mine methane

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Negative environmental impact to water as a resource, wildlife and their habitats, the atmosphere, human health, property and infrastructure caused as a direct result of an activity undertaken as part of one of the four phases of AMM extraction			
Pathway – How might the receptor come into contact with the source?	Uncontrolled release of pollutants to ground, air or water, physical disturbance of ground or infrastructure			
Receptor – What is at risk?	Groundwater, surface water, wildlife and their habitats, the atmosphere, human health, property and infrastructure			
Harm – What are the harmful consequences if things go wrong?	Breach of an environmental standard; loss or damage to a habitat or resource; injury, ill health or death; damage to property or infrastructure; air pollution			
Probability of exposure – How likely is this contact?	Low	Low	Low	Low
Consequence – How severe will the consequences be if this occurs?	Medium	Medium	High	Low
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	Medium	Low
Justification for magnitude	The process is not new to the UK, with a number of schemes currently in operation. Independent experts note the potential consequences are high if the process is not regulated properly or industry best practice is not followed.			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Water Resources Act 1991 Water Framework Directive (2000/60/EC) Groundwater Daughter Directive (2006/118/EC) Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations			

	Exploration	Appraisal	Operation	Abandonment
	2010 (as amended) Control of Pollution (Amendment) Act 1989 The Waste (England and Wales) Regulations 2011 – registration of waste carrier and brokers			
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments. Offshore Installations and Wells (Design and Construction, etc) Regulations 1996 Borehole Sites and Operations Regulations 1995 The Hydrocarbons Licensing Directive Regulations 1995 The Petroleum Act 1998 The Coal Industry Act 1994			
Residual risk – What is the magnitude of the risk after management?	Low. The Environment Agency will use appropriate controls under the legislation above (where it is the competent authority) to manage the identified risks, supported by monitoring and compliance work (for example, site inspections).			

Overall environmental risks – coal mine methane

	Operation
Source (hazard) – What is the agent or process with the potential to cause harm?	Negative environmental impact to water as a resource, wildlife and their habitats, the atmosphere, human health, property and infrastructure caused as a direct result of an activity undertaken as part of one of the four phases of AMM extraction
Pathway – How might the receptor come into contact with the source?	Uncontrolled release of pollutants to ground, air or water, physical disturbance of ground or infrastructure
Receptor – What is at risk?	Groundwater, surface water, wildlife and their habitats, the atmosphere, human health, property and infrastructure
Harm – What are the harmful consequences if things go wrong?	Breach of an environmental standard; loss or damage to a habitat or resource; injury, ill health or death; damage to property or infrastructure; air pollution
Probability of exposure – How likely is this contact?	Low
Consequence – How severe will the consequences be if this occurs?	High
Magnitude of risk – What is the overall magnitude of the risk?	Medium
Justification for magnitude	The process is not new to the UK, with a number of schemes currently in operation. Independent experts note the potential consequences are high if the process is not regulated properly or industry best practice is not followed.
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Water Resources Act 1991 Water Framework Directive (2000/60/EC) Groundwater Daughter Directive (2006/118/EC) Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended)

	Operation
	Control of Pollution (Amendment) Act 1989 The Waste (England and Wales) Regulations 2011 – registration of waste carrier and brokers
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments. Offshore Installations and Wells (Design and Construction, etc) Regulations 1996 Borehole Sites and Operations Regulations 1995 The Hydrocarbons Licensing Directive Regulations 1995 The Petroleum Act 1998 The Coal Industry Act 1994
Residual risk – What is the magnitude of the risk after management?	Low. The Environment Agency will use appropriate controls under the legislation above (where it is the competent authority) to manage the identified risks, supported by monitoring and compliance work (for example, site inspections).

Coal bed methane (CBM)

Groundworks

Groundworks are temporary to develop the infrastructure for the well pad including soil management facilities, water holding and management facilities, gas treatment facilities, gas transmission lines and access.

Materials released during site preparation

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by materials released during site preparation			
Pathway – How might the receptor come into contact with the source?	Exposure to releases to air, land and water			
Receptor – What is at risk?	Surface waters, groundwater wildlife and their habitats, human health (contractors and staff, local community) and soils			
Harm – What are the harmful consequences if things go wrong?	Contamination and loss of resource, injury, ill health, loss of habitat			
Probability of exposure – How likely is this contact?	Very low	Very low	Low	Very low
Consequence – How severe will the consequences be if this occurs?	Medium	Medium	Medium	Medium
Magnitude of risk – What is the overall magnitude of the risk?	Low	Low	Medium	Low

	Exploration	Appraisal	Operation	Abandonment
Justification for magnitude	This aspect of operations is not new to the UK. The risks are well understood and readily controllable by operators. Increased probability at operational scales due to potential for multiple sites/pads, increased infrastructure and cumulative impacts			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Water Resources Act 1991			
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments.			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Surface spills from onsite equipment

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by materials (fuels, oils) released from onsite equipment			
Pathway – How might the receptor come into contact with the source?	Accidental releases through defective equipment			
Receptor – What is at risk?	Groundwater and surface waters and soils			
Harm – What are the harmful consequences if things go wrong?	Contamination and loss of resource, injury, ill health, loss of habitat			
Probability of exposure – How likely is this contact?	Low	Low	Medium	Low
Consequence – How severe will the consequences be if this occurs?	Medium	Medium	Medium	Medium
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	Medium	Medium
Justification for magnitude	This aspect of operations is not new to the UK. The risks are well understood and readily controllable by operators. Increased probability at operational phase due to potential for multiple sites/pads, increased infrastructure and cumulative impacts.			
Current	The Environmental Permitting (England and Wales) Regulations 2010 (as			

	Exploration	Appraisal	Operation	Abandonment
regulatory controls – On what regulatory basis can the Environment Agency impose controls?	amended) Substance assessment following the requirements of the Groundwater Daughter Directive (2006/118/EC) Notice of intention under Section 199 of the Water Resources Act 1991(as amended by the Water Act 2003)			
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments.			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Site clearance

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Biodiversity – direct/indirect loss or harm of flora/fauna			
Pathway – How might the receptor come into contact with the source?	Loss of flora/fauna due to site clearance			
Receptor – What is at risk?	Wildlife and their habitats			
Harm – What are the harmful consequences if things go wrong?	Loss of habitat			
Probability of exposure – How likely is this contact?	Medium	Low	Medium	Very Low
Consequence – How severe will the consequences be if this occurs?	Medium	Medium	High	Medium
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	High	Low
Justification for magnitude	This aspect of operations is not new to the UK. The risks are well understood and readily controllable by operators. Probability medium at exploration and operational phases to account for initial site clearance required for exploration and then subsequent clearance for additional pads, infrastructure and so on at the operational phase. Probability reduced to very low at abandonment due to limited requirement for site clearance at this stage. Increased risk at operational phase due to potential for multiple sites/pads, increased infrastructure and cumulative impacts.			
Current regulatory controls – On what	The Environmental Permitting (England and Wales) Regulations 2010 (as amended)			

	Exploration	Appraisal	Operation	Abandonment
regulatory basis can the Environment Agency impose controls?				
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments. The Conservation of Habitats and Species Regulations 2010			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Noise/ acoustics

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Uncontrolled noise			
Pathway – How might the receptor come into contact with the source?	Uncontrolled noise associated with site plant and operations			
Receptor – What is at risk?	Employees, visitors, contractors and staff, local community, local wildlife			
Harm – What are the harmful consequences if things go wrong?	Risk of hearing related injury, nuisance			
Probability of exposure – How likely is this contact?	Low	Low	Medium	Low
Consequence – How severe will the consequences be if this occurs?	Medium	Medium	Medium	Medium
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	Medium	Medium
Justification for magnitude	This aspect of operations is not new to the UK. The risks are well understood and readily controllable by operators. Noise from excavation, earth moving, plant and vehicle transport during site preparation has a potential impact on both residents and local wildlife, particularly in sensitive areas, but is not considered to differ greatly in nature from other comparable large-scale construction activity (Broomfield 2012). Noise levels vary during the different stages in the preparation and production cycle. Well drilling and the hydraulic fracturing process itself are the most significant sources of noise. Flaring of gas can also be noisy (Broomfield 2012).			

	Exploration	Appraisal	Operation	Abandonment
	Increased probability at operational phase due to potential for multiple sites/pads, increased infrastructure and cumulative impacts.			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	The Environmental Permitting (England and Wales) Regulations 2010 (as amended)			
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments. Control of Noise (Codes of Practice for Construction and Open Sites) (England) Order 2002 Environmental Noise (England) Regulations 2006 Environmental Noise (England) (Amendment) Regulations 2009 Noise and Statutory Nuisance Act 1993			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	Low
Justification for residual risk	Effective noise abatement measures will reduce the impact in most cases. The identified risks can be mitigated given proper enforcement of regulatory controls.			

Loss of produced water (at surface)

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by the introduction of potentially contaminated water to the environment through the loss of produced water (associated with dewatering and/or gas release)			
Pathway – How might the receptor come into contact with the source?	Leaks and spills into surface water drains, direct spills onto the ground or leaks from damaged drainage systems followed by infiltration into groundwater and surface waters			
Receptor – What is at risk?	Surface waters and groundwater and any user of those waters or habitats relying on them			
Harm – What are the harmful consequences if things go wrong?	Pollution of groundwater and surface water restricting its use as a resource or requiring clean-up prior to use Potential impacts on human health or natural ecosystems in the event of exposure to contaminated waters			
Probability of exposure – How likely is this contact?	N/A	Low	Medium	N/A
Consequence – How severe will the consequences be if this occurs?	N/A	Medium	Medium	N/A
Magnitude of risk – What is the overall magnitude of the risk?	N/A	Medium	Medium	N/A
Justification for magnitude	Produced water not relevant at exploration or abandonment phase. Produced waters are typically highly saline containing dissolved sodium chloride, calcium, magnesium, sulphates, bicarbonates, boron and iron. The concentrations in fluid may reach percentage levels but any loss would be diluted.			
Current regulatory controls – On what regulatory basis can	Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations			

	Exploration	Appraisal	Operation	Abandonment
the Environment Agency impose controls?	2010 (as amended) Substance assessment following the requirements of the Groundwater Daughter Directive (2006/118/EC) Notice of intention under Section 199 of the Water Resources Act 1991(as amended by the Water Act 2003)			
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments.			
Residual risk – What is the magnitude of the risk after management?	N/A	Low	Low	N/A
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Water acquisition

For the purpose of drilling

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Increased water demand from surface waters, groundwater, river or the sea, which may include the use of potable supplies			
Pathway – How might the receptor come into contact with the source?	Potentially reduced water availability for the natural environment and increased competition for limited supplies of water that can be sustainably abstracted			
Receptor – What is at risk?	Environments dependent on water resources (for example, wetlands and aquatic ecosystems) and potentially other industrial water consumers			
Harm – What are the harmful consequences if things go wrong?	Damage to local ecosystems and interruptions either to the supply to other industrial water consumers or the CBM operators themselves			
Probability of exposure – How likely is this contact?	Medium	Medium	Medium	Very low
Consequence – How severe will the consequences be if this occurs?	Low	Low	Low	Low
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	Medium	Low
Justification for magnitude	Low volumes required for drilling, and likely to be imported with drilling muds. The total potential amount of water used in exploratory operations over a period of years is likely to be low compared with other industrial uses and potable supply. Consequence may be geographically dependent – some regions in England are already water scarce while others have water available for abstraction.			

	Exploration	Appraisal	Operation	Abandonment
	Increased consequence at operational phase due to potential for multiple sites/pads, increased infrastructure and cumulative impacts Operational risk category unchanged due to low probability for cumulative impact			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Water Resources Act 1991 The Water Environment (Water Framework Directive) (England and Wales) Regulations 2003			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	Low
Justification of residual risk	Insignificant quantities anticipated and are likely to be imported. The Environment Agency's groundwater guidance states that it will object, through planning or permitting controls, to CBM extraction infrastructure or activity within Source Protection Zone 1 (SPZ1) and/or where the activity would have an unacceptable effect on groundwater (CIWEM 2014, p. 35).			

For the purpose of hydraulic fracturing (fracking)

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Increased water demand from surface waters, groundwater, river or the sea, which may include the use of potable supplies			
Pathway – How might the receptor come into contact with the source?	Potentially reduced water availability for the natural environment and increased competition for limited supplies of water that can be sustainably abstracted			
Receptor – What is at risk?	Environments dependent on water resources (for example, wetlands and aquatic ecosystems) and potentially other industrial water consumers			
Harm – What are the harmful consequences if things go wrong?	Damage to local ecosystems and interruptions either to the supply to other industrial water consumers or the CBM operators themselves			
Probability of exposure – How likely is this contact?	N/A	Medium	Medium	N/A
Consequence – How severe will the consequences be if this occurs?	N/A	Low	Low	N/A
Magnitude of risk – What is the overall magnitude of the risk?	N/A	Medium	Medium	N/A
Justification for magnitude	Hydraulic fracturing not relevant to exploration or abandonment phases. Operational risk category unchanged due to low probability for cumulative impact. Depressurisation by dewatering may be sufficient to release gas without need for fracking. Where hydraulic fracturing is used, between 200 m^3 and 1,500 m^3 may be required per well. However fracking for CBM may not be required in all cases, and where it is required, low volume fracking is likely. Consequence may be geographically dependent – some regions in England are already water scarce while others have water available for			

	Exploration	Appraisal	Operation	Abandonment
	abstraction. In water stressed areas, water for fracking may be tankered in. The amount of water required could pose a local issue unless properly managed, but would not significantly affect water resource demands on a regional or catchment basis. The total potential amount of water used in exploratory operations over a period of years is likely to be low compared with other industrial uses and potable supply.			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Water Resources Act 1991			
Residual risk – What is the magnitude of the risk after management?	N/A	Low	Low	N/A
Justification for residual risk	Insignificant quantities anticipated and are likely to be imported. The Environment Agency's groundwater guidance, states that it will object, through planning or permitting controls, to CBM extraction infrastructure or activity within Source Protection Zone 1 (SPZ1) and/or where the activity would have an unacceptable effect on groundwater (CIWEM 2014).			

Dewatering to access/ release gas

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Increased water demand from surface waters, groundwater, river or the sea, which may include the use of potable supplies			
Pathway – How might the receptor come into contact with the source?	Potentially reduced water availability for the natural environment and increased competition for limited supplies of water that can be sustainably abstracted			
Receptor – What is at risk?	Environments dependent on water resources (for example, wetlands and aquatic ecosystems) and potentially other industrial water consumers			
Harm – What are the harmful consequences if things go wrong?	Damage to local ecosystems and interruptions either to the supply to other industrial water consumers or the CBM operators themselves			
Probability of exposure – How likely is this contact?	N/A	Medium	Medium	N/A
Consequence – How severe will the consequences be if this occurs?	N/A	Low	Medium	N/A
Magnitude of risk – What is the overall magnitude of the risk?	N/A	Medium	Medium	N/A
Justification for magnitude	Dewatering not relevant to exploration or abandonment phases. US wells produce between 33 and 130 m^3/day (23 and 90 l/min) and an average of 78 m^3/day. In the UK, indications from current pilots are that the seams are drier and that the levels of produced water are lower, in the range 1 to 40 m^3 per well per day. Relatively low volumes of produced water would be expected during the appraisal phase. Higher volumes of produced water would be expected at the operational/production phase associated with multiplied well systems. There is increased risk at operational phase due to potential for			

	Exploration	Appraisal	Operation	Abandonment
	multiple sites/pads, increased infrastructure and cumulative impacts. The total potential amount of water used in exploratory operations over a period of years is likely to be low compared with other industrial uses and potable supply. Consequence may be geographically dependent – some regions in England are already water scarce while others have water available for abstraction.			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Water Resources Act 1991			
Residual risk – What is the magnitude of the risk after management?	N/A	Low	Low	N/A
Justification for residual risk	Insignificant quantities anticipated and are likely to be imported. The Environment Agency's groundwater guidance, states that it will object, through planning or permitting controls, to CBM extraction infrastructure or activity within Source Protection Zone 1 (SPZ1) and/or where the activity would have an unacceptable effect on groundwater (CIWEM 2014).			

Chemical mixing

Use of proprietary chemicals for borehole drilling

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by the use of proprietary chemicals for drilling and sealing purposes – polymers, grouts			
Pathway – How might the receptor come into contact with the source?	Spills at the surface, followed by infiltration into groundwater and surface waters			
Receptor – What is at risk?	Surface waters and groundwater and any user of those waters or habitats relying on them			
Harm – What are the harmful consequences if things go wrong?	Contamination and loss of resources, injury, ill health, loss of or damage to a habitat			
Probability of exposure – How likely is this contact?	Medium	Medium	Medium	Medium
Consequence – How severe will the consequences be if this occurs?	Medium	Medium	Medium	Medium
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	Medium	Medium
Justification for magnitude	Potential for spillages at the delivery, storage and mixing stages. Risk category unchanged at operational phase due to low probability for cumulative impact. Using information from the drilling operator, the Environment Agency will assess whether an additive is hazardous or a non-hazardous pollutant using a methodology that follows the requirements of the Groundwater Daughter Directive and under the Environment Agency technical guidance WM2. The Environment Agency expects drilling operators to propose only non-hazardous substances (CIWEM 2014).			

	Exploration	Appraisal	Operation	Abandonment
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Substance assessment following the requirements of the Groundwater Daughter Directive (2006/118/EC) Environment Agency Hazardous Waste WM2 Guidance (2013)			
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments.			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Use of proprietary chemicals for fracturing fluids

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by the introduction of chemicals to the environment through the loss of fracturing fluid at the surface – the chemicals used will depend on factors such as the fracturing fluid requirements of the CBM formation which may be added to act as biocides, acids, friction reducers, corrosion inhibitors, gelling agents, scale inhibitors, pH adjusting agents and so on. A list of fracture fluid additives is given in the Appendix.			
Pathway – How might the receptor come into contact with the source?	Leaks and spills into surface water drains, direct spills onto the ground or leaks from damaged drainage systems , followed by infiltration into groundwater and surface waters			
Receptor – What is at risk?	Surface waters and groundwater and any user of those waters or habitats relying on them			
Harm – What are the harmful consequences if things go wrong?	Pollution of groundwater and surface water restricting its use as a resource or requiring clean-up prior to use Potential impacts on human health or natural ecosystems in the event of exposure to contaminated waters			
Probability of exposure – How likely is this contact?	N/A	Low	Medium	N/A
Consequence – How severe will the consequences be if this occurs?	N/A	Medium	Medium	N/A
Magnitude of risk – What is the overall magnitude of the risk?	N/A	Medium	Medium	N/A
Justification for magnitude	Depressurisation by dewatering may be sufficient to release gas without the need for fracking. Hydraulic fracturing is not applicable to exploration or abandonment phases. There is increased probability at operational phase due to potential for multiple sites/pads, increased infrastructure and cumulative impacts. The chemicals used to make up the fracturing fluid are delivered in concentrated form, and need to be stored and handled appropriately.			

	Exploration	Appraisal	Operation	Abandonment
	There is the potential for spillages at the transportation, delivery, storage and mixing stages. The concentrations in fluid may reach percentage levels but any loss would be diluted. Using information from the CBM operator, the Environment Agency will assess whether an additive is hazardous or a non-hazardous pollutant using a methodology that follows the requirements of the Groundwater Daughter Directive and under the Environment Agency technical guidance WM2. The Environment Agency expects CBM operators to propose only non-hazardous substances.			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	The Environmental Permitting (England and Wales) Regulations 2010 Substance assessment following the requirements of the Groundwater Daughter Directive (2006/118/EC) Environment Agency Hazardous Waste WM2 Guidance (2013)			
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments.			
Residual risk – What is the magnitude of the risk after management?	N/A	Low	Low	N/A
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Proppant delivery and mixing

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Proppant delivery and mixing – a range of proppants are in use globally, with sand currently favoured in the UK			
Pathway – How might the receptor come into contact with the source?	Breathing in dust and airborne particulate matter (PM) categorised as PM10 and PM2.5, and potentially containing silicates			
Receptor – What is at risk?	Employees, visitors and the local community			
Harm – What are the harmful consequences if things go wrong?	Risk of silicosis or other respiratory disease			
Probability of exposure – How likely is this contact?	N/A	Very Low	Very Low	N/A
Consequence – How severe will the consequences be if this occurs?	N/A	High	High	N/A
Magnitude of risk – What is the overall magnitude of the risk?	N/A	Medium	Medium	N/A
Justification for magnitude	Hydraulic fracturing is not relevant to exploration or abandonment phases. The risk category at operational phase is unchanged due to low probability for cumulative impact. Sand is normally delivered in a bulk tanker and pumped by the transport operator to a silo for storage pending use. This happens infrequently, particularly during the exploration phase. Standard items of equipment in the construction sector are used and the only likely releases are during			

	the filling of the silo when some dust may be produced through the top breather valve as the sand displaces air. Mixing with water is normally automated and self-contained.			
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments.			
Residual risk – What is the magnitude of the risk after management?	N/A	Low	Low	N/A
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Borehole installation and integrity

Fugitive releases of formation fluids and gases from the borehole

The principal constituent of CBM is methane (typically 80–95%) with small concentrations of other gases such as nitrogen, hydrogen sulphide and carbon dioxide, and heavier hydrocarbons such as ethane, propane and butane.

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by fugitive releases of fracturing and flowback fluids, and formation gases – methane and other volatile organic compounds (VOCs) from the borehole			
Pathway – How might the receptor come into contact with the source?	Vertical migration from the borehole via gaps in the usually cemented annulus between the casing and the drilled borehole wall. leading either to emissions to air or to groundwater			
Receptor – What is at risk?	Fluids – groundwater aquifers (both potable and saline), adjacent boreholes and potentially surface waters, with attendant risks to wildlife and water users Gases – the atmosphere, property, wildlife, employees, visitors and the local community			
Harm – What are the harmful consequences if things go wrong?	Contamination and potential loss of any water resources encountered, loss of or damage to a habitat, respiratory illnesses caused by VOCs, asphyxiation, explosion and fire risks from methane Methane is a potent greenhouse gas that contributes to anthropogenic climate change.			
Probability of exposure – How likely is this contact?	Low	Low	Medium	Low
Consequence – How severe will the consequences be if this occurs?	High	High	High	High
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	High	Medium
Justification for	Groat and Grimshaw (2012) indicated that a significant percentage of offshore wells have shown some degree of well integrity issues.			

magnitude	However, HSE's design and construction requirements provide a high degree of environmental protection (Environment Agency 2012a). Increased probability at operational phase due to potential for multiple sites/pads, increased infrastructure and cumulative impacts. During drilling, the operator must case off the aquifer and pressure test each casing before changing to a non-freshwater mud or on encountering hydrocarbons. Cementing is a critical part of well construction and is a fully designed and engineered process. Operators should use Best Available Techniques (BAT) and industry standards for cement to ensure risks are minimised. Cement bond logs can be used to support other evidence to determine if the casing has been successful or not (CIWEM 2014).			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Water Framework Directive (2000/60/EC) Groundwater Daughter Directive (2006/118/EC) Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Notice of intention under Section 199 of the Water Resources Act 1991(as amended by the Water Act 2003)			
Current regulatory controls – On what basis can others impose controls?	Offshore Installations and Wells (Design and Construction, etc) Regulations 1996 Borehole Sites and Operations Regulations 1995 Water supply (Water Quality) Regulations 2000			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Disturbance of in situ substances

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by the disturbance of in situ substances, including gases, by the drilling process			
Pathway – How might the receptor come into contact with the source?	Release and migration of pollutants via preferential pathways (such as the well bore and/or fractures) during the drilling process and from there, emissions to atmosphere and/or groundwater			
Receptor – What is at risk?	The atmosphere, groundwater, property, wildlife, employees, visitors and the local community			
Harm – What are the harmful consequences if things go wrong?	Contamination and potential loss of any water resources encountered, loss of or damage to a habitat, respiratory illnesses caused by VOCs, asphyxiation, explosion and fire risks from methane Methane is a potent greenhouse gas that contributes to anthropogenic climate change.			
Probability of exposure – How likely is this contact?	Very Low	Low	Medium	Very Low
Consequence – How severe will the consequences be if this occurs?	High	High	High	High
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	High	Medium
Justification for magnitude	There are no reports of impacts like this being associated with drilling boreholes. Increased risk at operational phase due to potential for multiple sites/pads, increased infrastructure and cumulative impacts During drilling, the operator must case off the aquifer and pressure test each casing before changing to a non-freshwater mud or on encountering hydrocarbons. Cementing is a critical part of well construction and is a fully designed and engineered process. Operators should use BAT and industry standards for cement to ensure risks are minimised. Cement bond logs can be used to support other evidence to determine if the casing has been successful or not			

	(CIWEM 2014).			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Water Framework Directive (2000/60/EC) Groundwater Daughter Directive (2006/118/EC) Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Notice of intention under Section 199 of the Water Resources Act 1991(as amended by the Water Act 2003)			
Current regulatory controls – On what basis can others impose controls?	Offshore Installations and Wells (Design and Construction, etc) Regulations 1996 Borehole Sites and Operations Regulations 1995 The Coal Industry Act 1994 Water supply (Water Quality) Regulations 2000			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Drill cuttings and spent drilling muds

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by inappropriate management of drill cuttings and spent drilling muds			
Pathway – How might the receptor come into contact with the source?	Surface contamination of the well pad followed by infiltration into groundwater and surface waters Also direct contact with wildlife, employees and visitors			
Receptor – What is at risk?	Groundwater and surface water resources and wildlife that depends on them Health of employees and site visitors			
Harm – What are the harmful consequences if things go wrong?	Contamination and potential loss of any water resources encountered, loss of or damage to a habitat, potential illness as a result of exposure			
Probability of exposure – How likely is this contact?	Low	Low	Medium	Low
Consequence – How severe will the consequences be if this occurs?	Medium	Medium	Medium	Medium
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	Medium	Medium
Justification for magnitude	It is common practice to store drill cuttings and spent drilling muds onsite pending disposal. Increased probability at operational phase due to potential for multiple sites/pads, increased infrastructure and cumulative impacts.			
Current regulatory controls – On	Mining Waste Directive (2006/21/EC) Water Framework Directive (2000/60/EC)			

	Exploration	Appraisal	Operation	Abandonment
what regulatory basis can the Environment Agency impose controls?	Groundwater Daughter Directive (2006/118/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended)			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	Low
Justification for re4sidual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Hydraulic fracturing (fracking)

Impacts of seismic activity (low volume fracking)

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by the impacts of seismic activity generated by low volume fracking			
Pathway – How might the receptor come into contact with the source?	Through damage to onsite infrastructure (including but not limited to the borehole), resulting in loss of containment Also potentially through damage to offsite infrastructure			
Receptor – What is at risk?	Aquifers (both potable and saline), groundwater, surface waters, ecosystems that rely on these sources of water Offsite structures			
Harm – What are the harmful consequences if things go wrong?	Contamination and potential loss of any water resources encountered, loss of or damage to a habitat, release of fugitive gas emissions with attendant risks (see above), damage to property			
Probability of exposure – How likely is this contact?	N/A	Low	Medium	N/A
Consequence – How severe will the consequences be if this occurs?	N/A	Low	Low	N/A
Magnitude of risk – What is the overall magnitude of the risk?	N/A	Low	Medium	N/A
Justification for magnitude	Fracking is not relevant to exploration or abandonment phases. There is increased risk at operational phase due to potential for multiple sites/pads, increased infrastructure and cumulative impacts. Seismic activity is unlikely to be associated with low volume fracking. Depressurisation by dewatering may be sufficient to release gas without need for fracking. Low level seismic activity resulting from activities in the coal, oil, gas			

	Exploration	Appraisal	Operation	Abandonment
	and geothermal energy sectors is well known. The level of seismicity means that impacts are generally minimal, though there are circumstances in which the consequences could be more severe. In line with guidelines for shale gas from the United Kingdom Onshore Operators Group (UKOOG), it is suggested that operators develop a Hydraulic Fracturing Programme (HFP) 'that describes the control and mitigation measures for fracture containment and for any potential induced seismicity' (CIWEM 2014).			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	The Environment Agency does not regulate seismic activity directly but does regulate its environmental impacts through: Water Resources Act 1991 Water Framework Directive (2000/60/EC) Groundwater Daughter Directive (2006/118/EC) Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended)			
Current regulatory controls – On what basis can others impose controls?	The Hydrocarbons Licensing Directive Regulations 1995 The Petroleum Act 1998 DECC's 'Traffic light' monitoring system (https://www.gov.uk/government/publications/traffic-light-monitoring-system-shale-gas-and-fracking)			
Residual risk – What is the magnitude of the risk after management?	N/A	Low	Low	N/A

Propagation of fractures beyond the target zone

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Propagation of fractures beyond the target zone which then create vertical and horizontal pathways for pollution to travel into other geological strata			
Pathway – How	Fractures propagating beyond the target zone			

	Exploration	Appraisal	Operation	Abandonment
might the receptor come into contact with the source?				
Receptor – What is at risk?	Groundwater, adjacent boreholes and potentially surface waters, with attendant risks to wildlife and water users			
Harm – What are the harmful consequences if things go wrong?	Contamination and potential loss of any water resources encountered, loss of or damage to a habitat, potential illness as a result of exposure			
Probability of exposure – How likely is this contact?	N/A	High	High	N/A
Consequence – How severe will the consequences be if this occurs?	N/A	Medium	Medium	N/A
Magnitude of risk – What is the overall magnitude of the risk?	N/A	High	High	N/A
Justification for magnitude	Fracking is not relevant to exploration or abandonment phases. There is increased risk at operational phase due to potential for multiple sites/pads, increased infrastructure and cumulative impacts. Depressurisation by dewatering may be sufficient to release gas without need for fracking. UK coal seams are typically thin and consequently fractures may propagate beyond the target zone without good controls. USEPA (2004) data on studies of fracture propagation and fluid movement using typical hydraulic fracturing processes in fairly typical CBM geological conditions indicate sand-filled (propped fractures) extended between 2 and 526 feet in length (between <1 and 191 m) and sand-free extensions of propped fractures to 870 feet (266m) from the borehole. Fluorescent paint injection studies found paint typically extending between 200 and 300 feet (61– 91 m) beyond the sand-filled portion of the fractures Of the studies undertaken in the USA and Australia, a high proportion identified fractures penetrating beyond the coal beds into the roof rock (rock overlying the coal in the mined areas). Data also indicate that fractures that are created at shallow depths (<1,000 feet or 300 m) typically consist more of a horizontal than a vertical component. Vertical fractures created at greater depth may propagate vertically to shallower depth where they may develop a horizontal component. Fracture behaviour depends on thickness, in situ stress differences			

	Exploration	Appraisal	Operation	Abandonment
	between the target seam and surrounding strata, and the presence of pre-existing natural fractures (USEPA 2004). In line with UKOOG guidelines for shale gas, it is suggested that operators develop a Hydraulic Fracturing Programme (HFP) 'that describes the control and mitigation measures for fracture containment and for any potential induced seismicity' (CIWEM 2014).			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Water Framework Directive (2000/60/EC) Groundwater Daughter Directive (2006/118/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Notice of intention under Section 199 of the Water Resources Act 1991(as amended by the Water Act 2003)			
Residual risk – What is the magnitude of the risk after management?	N/A	Medium	Medium	N/A
Justification of residual risk	Uncertainties remain regarding the potential for fracture propagation associated with low volume fracking at relatively shallow depth in the UK context. As CBM extraction progresses, further UK studies are needed as current evidence is limited.			

Onsite treatment of produced water

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Short-term releases of methane and VOCs dissolved in produced water associated with onsite treatment of produced water to separate out the solids and gases from the liquid			
Pathway – How might the receptor come into contact with the source?	Emissions to atmosphere			
Receptor – What is at risk?	The atmosphere, wildlife, employees and visitors			
Harm – What are the harmful consequences if things go wrong?	Potential harm to health or amenity (that is, from odours) from VOCs – contamination, asphyxiation, odour, fire or explosion Methane is a potent greenhouse gas that contributes to anthropogenic climate change.			
Probability of exposure – How likely is this contact?	N/A	Medium	Medium	N/A
Consequence – How severe will the consequences be if this occurs?	N/A	Medium	High	N/A
Magnitude of risk – What is the overall magnitude of the risk?	N/A	Medium	High	N/A
Justification for magnitude	Produced water is not relevant at exploration and abandonment phase. There is increased risk at operational phase due to potential for multiple sites/pads, increased infrastructure and cumulative impacts. The design of the well, with the separation at depth of the produced water from the gas, means that in the pilot/ appraisal phase there is likely to be little or no methane entrained in the relatively small volumes of produced waters. Entrained gas would become more apparent when moving into the production phase, with higher volumes			

	Exploration	Appraisal	Operation	Abandonment
	of produced water from multiple well systems introducing the need for 'green completions' infrastructure. With green completion, the number of additional physical linkages and additional equipment may increase the chances of fugitive releases. In the green completion process, the gun barrel tank – a further two-phase separator for condensate and water – does have a fugitive release issue, termed flash emissions (Environment Agency 2012b). Releases to atmosphere and green completion technology to capture these releases are common practice in the USA. The volume of methane released, especially during extended well tests, could be significant.			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Onshore Oil and Gas Exploratory Operations: Technical Guidance (consultation draft) (Environment Agency 2013b)			
Residual risk – What is the magnitude of the risk after management?	N/A	Low	Low	N/A
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Release of gases dissolved in flowback fluids

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Short-term releases of methane and VOCs dissolved in flowback fluids			
Pathway – How might the receptor come into contact with the source?	Emissions to atmosphere			
Receptor – What is at risk?	The atmosphere, employees and visitors			
Harm – What are the harmful consequences if things go wrong?	Potential harm to health or amenity (that is, from odours) from VOCs Methane is a potent greenhouse gas that contributes to anthropogenic climate change.			
Probability of exposure – How likely is this contact?	N/A	Low	Medium	N/A
Consequence – How severe will the consequences be if this occurs?	N/A	Medium	Medium	N/A
Magnitude of risk – What is the overall magnitude of the risk?	N/A	Medium	Medium	N/A
Justification for magnitude	Fracking is not relevant at exploration and abandonment phases. There is increased risk at operational phase due to potential for multiple sites/pads, increased infrastructure and cumulative impacts. Depressurisation by dewatering may be sufficient to release gas without need for fracking. Best practice would consist of at least full containment and preferably a green completion type gas recovery system integrated into the separator. With green completion, the number of additional physical linkages and additional equipment may increase the chances of fugitive releases. In the green completion process, the gun barrel tank – a further two-phase separator for condensate and water – does have a			

	Exploration	Appraisal	Operation	Abandonment
	fugitive release issue, termed flash emissions (Environment Agency, 2012b).			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Onshore Oil and Gas Exploratory Operations: Technical Guidance (consultation draft) (Environment Agency 2013b)			
Residual risk – What is the magnitude of the risk after management?	N/A	Low	Low	N/A
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Surface spills of flowback fluids

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Surface spills of flowback fluids			
Pathway – How might the receptor come into contact with the source?	Accidental releases through defective pipework and/or storage tanks or spills when transferring the fluids from storage into a tanker			
Receptor – What is at risk?	Groundwater and surface waters			
Harm – What are the harmful consequences if things go wrong?	Pollution of groundwater and surface water restricting its use as a resource or requiring clean-up prior to use Potential impacts on human health or natural ecosystems in the event of exposure to contaminated waters			
Probability of exposure – How likely is this contact?	N/A	Low	Medium	N/A
Consequence – How severe will the consequences be if this occurs?	N/A	Medium	Medium	N/A
Magnitude of risk – What is the overall magnitude of the risk?	N/A	Medium	Medium	N/A
Justification for magnitude	Fracking is not relevant at exploration and abandonment phases. There is increased risk at operational phase due to potential for multiple sites/pads, increased infrastructure and cumulative impacts. Depressurisation by dewatering may be sufficient to release gas without need for fracking. Experience of regulating industrial sites indicates that accidents can and do happen. However, there are few reports of significant pollution incidents from this source in the USA.			
Current regulatory controls – On what	Mining Waste Directive (2006/21/EC)			

	Exploration	Appraisal	Operation	Abandonment
regulatory basis can the Environment Agency impose controls?	The Environmental Permitting (England and Wales) Regulations 2010 (as amended)Water Framework directive (2000/60/EC) Groundwater Daughter Directive (2006/118/EC) Notice of intention under Section 199 of the Water Resources Act 1991(as amended by the Water Act 2003)			
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments.			
Residual risk – What is the magnitude of the risk after management?	N/A	Low	Low	N/A
Justification of residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Onsite treatment of flowback fluids

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Onsite treatment of flowback fluids to separate out the solids and gases from the liquid			
Pathway – How might the receptor come into contact with the source?	Emissions to atmosphere			
Receptor – What is at risk?	The atmosphere, wildlife, employees and visitors			
Harm – What are the harmful consequences if things go wrong?	Contamination, asphyxiation, odour, fire or explosion Methane is a potent greenhouse gas that contributes to anthropogenic climate change.			
Probability of exposure – How likely is this contact?	N/A	Low	Medium	N/A
Consequence – How severe will the consequences be if this occurs?	N/A	Medium	Medium	N/A
Magnitude of risk – What is the overall magnitude of the risk?	N/A	Medium	Medium	N/A
Justification for magnitude	Fracking is not relevant at exploration and abandonment phases. There is increased probability at operational phase due to potential for multiple sites/pads, increased infrastructure and cumulative impacts. Depressurisation by dewatering may be sufficient to release gas without need for fracking. Releases to atmosphere and green completion technology to capture these releases are common practice in the USA. The volume of methane released, especially during extended well tests, could be significant.			

	Exploration	Appraisal	Operation	Abandonment
	With green completion, the number of additional physical linkages and additional equipment may increase the chances of fugitive releases. In the green completion process, the gun barrel tank – a further two-phase separator for condensate and water – does have a fugitive release issue, termed flash emissions (Environment Agency, 2012b).			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Onshore Oil and Gas Exploratory Operations: Technical Guidance (consultation draft) (Environment Agency 2013b)			
Residual risk – What is the magnitude of the risk after management?	N/A	Low	Low	N/A
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Build-up of naturally occurring radioactive material (NORM)

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Build-up of naturally occurring radioactive material (NORM) in site infrastructure (for example, tanks, pipework, valves)			
Pathway – How might the receptor come into contact with the source?	NORM brought up in flowback fluid can collect in storage tanks and pipework, either as sediment or scale			
Receptor – What is at risk?	Employees and visitors			
Harm – What are the harmful consequences if things go wrong?	Exposure to accumulated NORM			
Probability of exposure – How likely is this contact?	N/A	Low	Medium	Medium
Consequence – How severe will the consequences be if this occurs?	N/A	Medium	Medium	Medium
Magnitude of risk – What is the overall magnitude of the risk?	N/A	Medium	Medium	Medium
Justification for magnitude	Not relevant at exploration phase. Increased probability at operational and abandonment phases due to potential for multiple sites/pads, increased infrastructure, and build-up over time. This is a recognised issue in the oil and gas industry for both conventional and unconventional developments. The presence of low concentrations of NORM within produced water is currently being investigated within the UK. Studies to date have shown that, although lower in concentration than shale gas flowback fluid, CBM flowback fluids have sufficient NORM to be above the Environmental Permitting Regulations (EPR) thresholds for permitting. NORM scale and sediment requires conditioning and disposal at			

	Exploration	Appraisal	Operation	Abandonment
	landfill sites; there is a small residual exposure pathway at the conditioning and disposal end of the process.			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Basic Safety Standards Directive (96/29/EURATOM) Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended) [CBM is an EPR NORM industrial activity because it fits at least one of the following categories: - the production of oil and gas - the removal and management of radioactive scales and precipitates from equipment associated with industrial activities - any activity related to coal mine dewatering plants Furthermore, CBM is very likely to be a 'radioactive substances activity', and so a Radioactive Substances Regulation (RSR) permit will be required for accumulation and disposal of CBM produced water and solids.]			
Residual risk – What is the magnitude of the risk after management?	N/A	Low	Low	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Accumulation of solids containing NORM

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Accumulation of solids containing NORM after separation from flowback fluids			
Pathway – How might the receptor come into contact with the source?	Exposure to radiation as a result of onsite storage of NORM or movement of the solids to transport them offsite for treatment			
Receptor – What is at risk?	Employees and visitors			
Harm – What are the harmful consequences if things go wrong?	Exposure to accumulated NORM			
Probability of exposure – How likely is this contact?	Low	Low	Medium	Medium
Consequence – How severe will the consequences be if this occurs?	Low	Medium	Medium	Medium
Magnitude of risk – What is the overall magnitude of the risk?	Low	Medium	Medium	Medium
Justification for magnitude	NORM cuttings and drill muds may be associated with deep drilling. The volume of solids associated with a single exploratory well is likely to be low. The radioactivity associated with this material, although high enough to trigger the need for a permit, is still relatively low. The presence of low concentrations of NORM within produced water is currently being investigated within the UK. Studies to date have shown that although lower in concentration than shale gas flowback fluid, CBM flowback fluids have sufficient NORM to be above the EPR thresholds for permitting. NORM scale and sediment requires conditioning and disposal at landfill sites; there is a small residual exposure pathway at the			

	Exploration	Appraisal	Operation	Abandonment
	conditioning and disposal end of the process. Increased probability at operational phase due to potential for multiple sites/pads, increased infrastructure and build-up over time.			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Basic Safety Standards Directive (96/29/EURATOM) Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010(as amended) [CBM is an EPR NORM industrial activity because it fits at least one of the following categories: - the production of oil and gas - the removal and management of radioactive scales and precipitates from equipment associated with industrial activities - any activity related to coal mine dewatering plants Furthermore, CBM is very likely to be a 'radioactive substances activity', and so an RSR permit will be required for accumulation and disposal of CBM produced water and solids.]			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Gas management

Gas management of produced water

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Fugitive releases of methane and trace components (for example, other VOCs and gaseous NORM hydrogen sulphide) from site infrastructure after their separation from produced water			
Pathway – How might the receptor come into contact with the source?	Leaks from infrastructure like valves, pipework and flares			
Receptor – What is at risk?	The atmosphere, wildlife, employees and visitors			
Harm – What are the harmful consequences if things go wrong?	Contamination, asphyxiation, odour, fire or explosion Methane is a potent greenhouse gas that contributes to anthropogenic climate change.			
Probability of exposure – How likely is this contact?	N/A	Low	Medium	N/A
Consequence – How severe will the consequences be if this occurs?	N/A	High	High	N/A
Magnitude of risk – What is the overall magnitude of the risk?	N/A	Medium	High	N/A
Justification for magnitude	Produced water is not relevant at exploration or abandonment phase. There is increased risk at operational phase due to potential for multiple sites/pads, increased infrastructure and cumulative impacts. Entrained gas within produced water is likely to be more apparent within the production phase, with higher volumes of produced water from multiplied well systems, introducing the need for green completions infrastructure. With green completion, the number of additional physical linkages and additional equipment may increase the chances of fugitive			

	Exploration	Appraisal	Operation	Abandonment
	releases. In the green completion process, the gun barrel tank – a further two-phase separator for condensate and water – does have a fugitive release issue, termed flash emissions (Environment Agency, 2012b)			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Onshore Oil and Gas Exploratory Operations: Technical Guidance (consultation draft) (Environment Agency 2013b) [It is probable that the quality of the gas being extracted for CBM may mean that it does not require much treatment. For example, it may not fall within refining as defined under the Industrial Emissions Directive and Environment Agency Regulatory Guidance Series No. RGN 2 (Understanding the meaning of regulated facility) and therefore may not fall within EPR (or Pollution Prevention Control) and maybe not be covered by the Mining Waste Directive (if no waste is being produced). This would mean that the above regulatory mechanisms would not be available.]			
Residual risk – What is the magnitude of the risk after management?	N/A	Low	Low	N/A
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Gas management of flowback fluids

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Fugitive releases of methane and trace components (for example, other VOCs and gaseous NORM hydrogen sulphide) from site infrastructure after their separation from flowback fluids			
Pathway – How might the receptor come into contact with the source?	Leaks from infrastructure like valves, pipework and flares			
Receptor – What is at risk?	The atmosphere, wildlife, employees and visitors			
Harm – What are the harmful consequences if things go wrong?	Contamination, asphyxiation, odour, fire or explosion Methane is a potent greenhouse gas that contributes to anthropogenic climate change.			
Probability of exposure – How likely is this contact?	N/A	Low	Medium	N/A
Consequence – How severe will the consequences be if this occurs?	N/A	High	High	N/A
Magnitude of risk – What is the overall magnitude of the risk?	N/A	Medium	High	N/A
Justification for magnitude	Fracking is not relevant at exploration or abandonment phases. There is increased risk at operational phase due to potential for multiple sites/pads, increased infrastructure and cumulative impacts. Depressurisation by dewatering may be sufficient to release gas without need for fracking. Methane emissions from the flowback/well completion step may be controlled through the use of green completions. With green completion, the number of additional physical linkages and additional equipment may increase the chances of fugitive releases. In the green completion process, the gun barrel tank – a further two-phase separator for condensate and water – does have a fugitive release issue, termed flash emissions (Environment Agency			

	Exploration	Appraisal	Operation	Abandonment
	2012b)			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Onshore Oil and Gas Exploratory Operations: Technical Guidance (consultation draft) (Environment Agency 2013b)			
Residual risk – What is the magnitude of the risk after management?	N/A	Low	Low	N/A
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Controlled venting of gases

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Controlled venting of methane trace components (for example, other VOCs and gaseous NORM hydrogen sulphide). In emergency only.			
Pathway – How might the receptor come into contact with the source?	Emissions to atmosphere			
Receptor – What is at risk?	The atmosphere, wildlife, employees and visitors			
Harm – What are the harmful consequences if things go wrong?	Odour, exposure to low levels of radioactivity Methane is a potent greenhouse gas that contributes to anthropogenic climate change.			
Probability of exposure – How likely is this contact?	Low	Low	Low	Low
Consequence – How severe will the consequences be if this occurs?	Medium	Medium	High	Medium
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	Medium	Medium
Justification for magnitude	Increased risk at operational phase due to potential for multiple sites/pads, increased infrastructure and cumulative impacts The main risk is to the atmosphere. Gases entrained in flowback fluids and produced water may be flared or cold vented until such a time as the flow is deemed of adequate quality for capture and processing for sale. Venting would be a last option for waste gases and mainly a safety feature. Components of green completion systems avoid the need to cold vent or excessively flare the natural gas.			

	Exploration	Appraisal	Operation	Abandonment
	USEPA data indicate emissions of methane from oil and gas production account for 63% of the total sector emissions, with the production emissions dominated by venting and flaring (Environment Agency 2012b). There are strong safety, environmental and economic pressures for operators to control and reduce natural gas losses. For specific production equipment, understanding the rate of leakage will form part of the regular measurement regime and part of any equipment performance acceptance test. Further away from the local production equipment, it is important to know that methane is not significantly above the background level at or beyond the plant boundary. This is often tested using fenceline monitoring (Environment Agency 2012b).			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Onshore Oil and Gas Exploratory Operations: Technical Guidance (consultation draft) (Environment Agency 2013b)			
Current regulatory controls – On what basis can others impose controls?	The Hydrocarbons Licensing Directive Regulations 1995 The Petroleum Act 1998			
Residual risk – What is the magnitude of the risk after management?	Medium	Medium	Medium	Medium
Justification for residual risk	The incorporation of green completions would reduce the need to excessively vent at the production phase reducing the risk to medium.			

Controlled flaring of gases

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Controlled flaring of methane and trace components (for example, other VOCs and gaseous NORM hydrogen sulphide)			
Pathway – How might the receptor come into contact with the source?	Emissions to atmosphere			
Receptor – What is at risk?	The atmosphere, wildlife, employees and visitors			
Harm – What are the harmful consequences if things go wrong?	Odour, exposure to low levels of radioactivity, combustion products, smoke, noise, heat and light pollution Methane is a potent greenhouse gas that contributes to anthropogenic climate change.			
Probability of exposure – How likely is this contact?	N/A	Medium	Medium	N/A
Consequence – How severe will the consequences be if this occurs?	N/A	Medium	High	N/A
Magnitude of risk – What is the overall magnitude of the risk?	N/A	Medium	High	N/A
Justification for magnitude	Not relevant at exploration and abandonment phases. Increased risk at operational phase due to potential for multiple sites/pads, increased infrastructure and cumulative impacts. The main risk is to the atmosphere. Flaring (as opposed to cold venting) reduces fire hazard onsite and, in transforming methane and other volatile organics to carbon dioxide, reduces the climate change impact of the operation. However, flaring has been associated with local environmental impacts including air quality (NO_x, SO_2, VOCs), light and noise intrusion, and there are efforts to reduce its use in the oil industry (Broderick et al. 2011, after			

	Exploration	Appraisal	Operation	Abandonment
	Sanchez et al. 2008, Christen 2004). Components of green completion systems avoid the need to cold vent or excessively flare the natural gas. Incorporated separators may be used to retain gas for processing and sale. USEPA data indicate emissions of methane from oil and gas production account for 63% of the total sector emissions, with the production emissions dominated by venting and flaring (Environment Agency 2012b). There are strong safety, environmental and economic pressures for operators to control and reduce natural gas losses. For specific production equipment, understanding the rate of leakage will form part of the regular measurement regime and part of any equipment performance acceptance test. Further away from the local production equipment, it is important to know that methane is not significantly above the background level at or beyond the plant boundary. This is often tested using fenceline monitoring (Environment Agency 2012b).			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Industrial Emissions Directive (2010/75/EU) Onshore Oil and Gas Exploratory Operations: Technical Guidance (consultation draft) (Environment Agency 2013b)			
Current regulatory controls – On what basis can others impose controls?	The Hydrocarbons Licensing Directive Regulations 1995 The Petroleum Act 1998			
Residual risk – What is the magnitude of the risk after management?	N/A	Medium	Medium	N/A
Justification for residual risk	The incorporation of green completions would reduce the need to excessively flare at the production phase reducing the risk to medium.			

Exhaust emissions from onsite equipment

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by gases released from onsite equipment; operational noise			
Pathway – How might the receptor come into contact with the source?	Exhausts and noise from engines, generators, compressors and similar combustion equipment			
Receptor – What is at risk?	The atmosphere, wildlife, the local community, employees and visitors			
Harm – What are the harmful consequences if things go wrong?	Reduction in local air quality and increased photochemical pollution			
Probability of exposure – How likely is this contact?	Low	Low	Medium	Low
Consequence – How severe will the consequences be if this occurs?	Low	Low	Low	Low
Magnitude of risk – What is the overall magnitude of the risk?	Low	Low	Medium	Low
Justification for magnitude	Increased probability at operational phase due to potential for multiple sites/pads, increased infrastructure and cumulative impacts. The risks depend on the type of fuel used for onsite generation (diesel, electricity or liquefied petroleum gas) and the sensitivity of the local environment. Emissions from compressor plant may potentially be significant at operational phase and require careful attention from operators and regulators (Environment Agency 2012b).			
Current regulatory controls – On what basis can others	Town and Country Planning (Development Management Procedure) (England) Order 2010			

	Exploration	Appraisal	Operation	Abandonment
impose controls?	Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments. Industrial Emissions Directive (2010/75/EU)			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Explosion and fire (at surface)

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Uncontrolled air/ gas mixtures at surface arising from fugitive emissions			
Pathway – How might the receptor come into contact with the source?	Emissions to atmosphere			
Receptor – What is at risk?	Local community, employees and visitors Site infrastructure			
Harm – What are the harmful consequences if things go wrong?	Damage to property, death			
Probability of exposure – How likely is this contact?	Low	Low	Medium	Very Low
Consequence – How severe will the consequences be if this occurs?	High	High	High	High
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	High	Medium
Justification for magnitude	Increased risk at operational phase due to potential for multiple sites/pads, increased infrastructure and cumulative impacts. Controlled flaring and venting or green completions undertaken to reduce potential for uncontrolled emissions. There are strong safety, environmental and economic pressures for operators to control and reduce natural gas losses. For specific production equipment, understanding the rate of leakage will form part of the regular measurement regime and part of any equipment performance acceptance test. Further away from the local production equipment, it is important to know that methane is not significantly			

	Exploration	Appraisal	Operation	Abandonment
	above the background level at or beyond the plant boundary. This is often tested using fenceline monitoring (Environment Agency 2012b).			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended)			
Current regulatory controls – On what basis can others impose controls?	ATEX regulations [explosive atmospheres] Gas Safety (Management) Regulations 1996			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Gas processing and treatment

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by the use of proprietary chemicals associated with gas treatment (nitrogen, glycol)			
Pathway – How might the receptor come into contact with the source?	Fugitive emissions			
Receptor – What is at risk?	The atmosphere, wildlife, local community, employees and visitors			
Harm – What are the harmful consequences if things go wrong?	Contamination, asphyxiation, odour, fire or explosion Contamination and loss of resources, injury, ill health, loss of or damage to a habitat			
Probability of exposure – How likely is this contact?	N/A	Low	Medium	N/A
Consequence – How severe will the consequences be if this occurs?	N/A	Medium	Medium	N/A
Magnitude of risk – What is the overall magnitude of the risk?	N/A	Medium	Medium	N/A
Justification for magnitude	Not relevant at exploration or abandonment phases. Increased probability at operational phase due to greater potential volumes of gas for treatment. At the processing facility, the raw natural gas will go through a number of stages to remove the following products: acid gases (specifically hydrogen sulphide), water vapour, mercury and nitrogen. Each stage in the natural gas production process has the potential for fugitive emissions (Environment Agency 2012b).			

	Exploration	Appraisal	Operation	Abandonment
	The chemicals used for gas treatment need to be stored and handled appropriately. There is the potential for leakage at the delivery, storage and mixing stages.			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Mining Waste Directive (2006/21/EC) Water Framework Directive (2000/60/EC) Groundwater Daughter Directive (2006/118/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Water Resources Act 1991			
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments. Gas Safety (Management) Regulations 1996			
Residual risk – What is the magnitude of the risk after management?	N/A	Low	Low	N/A
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Gas processing and treatment

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Fugitive releases of methane and VOCs from site processing and transportation infrastructure			
Pathway – How might the receptor come into contact with the source?	Leaks from infrastructure like valves, compressors, pipework and flares			
Receptor – What is at risk?	The atmosphere, wildlife, employees and visitors			
Harm – What are the harmful consequences if things go wrong?	Contamination, asphyxiation, odour, fire or explosion Methane is a potent greenhouse gas that contributes to anthropogenic climate change.			
Probability of exposure – How likely is this contact?	N/A	Low	Medium	N/A
Consequence – How severe will the consequences be if this occurs?	N/A	Medium	Medium	N/A
Magnitude of risk – What is the overall magnitude of the risk?	N/A	Medium	Medium	N/A
Justification for magnitude	Not relevant at exploration or abandonment phases. Increased probability at operational phase due to greater potential volumes of gas for treatment. The main risk is to the atmosphere. Each stage in the natural gas production process has the potential for fugitive emissions (Environment Agency 2012b). There are strong safety, environmental and economic pressures for operators to control and reduce natural gas losses. For specific production equipment, understanding the rate of leakage will form part of the regular measurement regime and part of any equipment performance acceptance test. Further away from the local production equipment, it is important to know that methane is not significantly			

	Exploration	Appraisal	Operation	Abandonment
	above the background level at or beyond the plant boundary. This is often tested using fenceline monitoring (Environment Agency 2012b).			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended)			
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments. Gas Safety (Management) Regulations 1996			
Residual risk – What is the magnitude of the risk after management?	N/A	Low	Low	N/A
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Land stability

Land stability caused by depressurisation

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Instability/subsidence caused by depressurisation of the ground			
Pathway – How might the receptor come into contact with the source?	Instability/subsidence extending beyond local property			
Receptor – What is at risk?	Property, local community			
Harm – What are the harmful consequences if things go wrong?	Damage to property, infrastructure			
Probability of exposure – How likely is this contact?	N/A	Low	Medium	Low
Consequence – How severe will the consequences be if this occurs?	N/A	Medium	Medium	Medium
Magnitude of risk – What is the overall magnitude of the risk?	N/A	Medium	Medium	Medium
Justification for magnitude	Not relevant at exploration phase. Increased probability at operational phase due to greater potential volumes of gas for treatment. Increased pore water pressure over abandonment phase due to groundwater recovery. Depressurisation by dewatering may be sufficient to release gas without need for fracking. At near surface depths, the process of dewatering and gas removal may introduce the risk of ground movement and settlement as the cleats are emptied of water and methane, and the coal itself shrinks.			

	Exploration	Appraisal	Operation	Abandonment
	Although this has been observed overseas particularly on entering the development phase and on near surface coal beds, there are currently no reports of subsidence or settlement attributed to CBM in the UK according to the Coal Authority, based on limited experience to date.			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	The Environmental Permitting (England and Wales) Regulations 2010 (as amended)			
Current regulatory controls – On what basis can others impose controls?				
Residual risk – What is the magnitude of the risk after management?	N/A	Low	Low	Low
Justification for residual risk	Evidence from shale gas indicates that seismic events can be caused by high volume hydraulic fracturing, for example, at Presse Hall (Green et al. 2012). However, even high volume fracking is unlikely to be of sufficient magnitude to cause structural damage on the surface (Broderick et al. 2011). Depressurisation by dewatering may be sufficient to release gas without need for fracking. At most, low volume fracking would be employed and the associated risk is considered low.			

Offsite disposal

Drill cuttings and drilling muds

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution (chemicals and/or NORM) caused through the inappropriate disposal of waste drill cuttings and drilling muds			
Pathway – How might the receptor come into contact with the source?	Direct and indirect contact following land spreading			
Receptor – What is at risk?	People, property and wildlife in or near the site of land spreading			
Harm – What are the harmful consequences if things go wrong?	Local contamination of habitats and resources and exposure of people to that contamination			
Probability of exposure – How likely is this contact?	Medium	Medium	Medium	Medium
Consequence – How severe will the consequences be if this occurs?	Medium	Medium	High	Medium
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	High	Medium
Justification for magnitude	The likely content of the drilling muds and drill cuttings and their potential impact on the environment is well known. Increased risk at operational phase due to potential for multiple sites/pads, increased infrastructure and cumulative impacts.			
Current regulatory controls – On what regulatory basis can the Environment Agency impose	The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Control of Pollution (Amendment) Act 1989			

	Exploration	Appraisal	Operation	Abandonment
controls?	The Waste (England and Wales) Regulations 2011 – registration of waste carrier and brokers			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Transport, storage, treatment and disposal of wastes associated with well stimulation and dewatering

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by the transport, storage, treatment and disposal of wastes produced by low volume hydraulic fracturing operations and/or dewatering (that is, formation fluids, scales and produced waters)			
Pathway – How might the receptor come into contact with the source?	Release of pollutants to air, land and water from transport accidents, storage at transfer stations and treatment plants, discharges to water and land disposal sites			
Receptor – What is at risk?	People, property, wildlife and the wider environment along transport routes and near to storage, treatment and disposal facilities			
Harm – What are the harmful consequences if things go wrong?	Local contamination of habitats and resources and exposure of people to that contamination			
Probability of exposure – How likely is this contact?	Low	Low	Medium	Low
Consequence – How severe will the consequences be if this occurs?	Medium	Medium	Medium	Medium
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	Medium	Medium
Justification for magnitude	The likely content of the wastes and their potential impact on the environment is well known; the risks will depend on the sensitivity of the local environment. Waste carriers and treatment, storage and disposal sites will already be permitted by the Environment Agency. Increased risk at operational phase due to potential for multiple sites/pads, increased infrastructure and cumulative impacts.			
Current regulatory controls – On what regulatory basis can the Environment	The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Control of Pollution (Amendment) Act 1989			

	Exploration	Appraisal	Operation	Abandonment
Agency impose controls?	The Waste (England and Wales) Regulations 2011 – registration of waste carrier and brokers			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Well closure and abandonment

Long-term integrity of well

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by a substance release continues to have an environmental impact beyond the operational phase.			
Pathway – How might the receptor come into contact with the source?	Exposure to releases into air or water			
Receptor – What is at risk?	The local population and surrounding environment			
Harm – What are the harmful consequences if things go wrong?	Exposure to released gases and harmful substances brought to the surface, air pollution, surface or subsurface contamination, ill health, loss or damage to a habitat or resource			
Probability of exposure – How likely is this contact?	Low	Low	Low	Low
Consequence – How severe will the consequences be if this occurs?	High	High	High	High
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	Medium	Medium
Justification for magnitude	This process is well established both onshore and offshore requiring notification to the Health and Safety Executive (HSE) and in accordance with HSE, industry and DECC well abandonment best practice. On completion of drilling, the process of hydraulic fracturing and induced seismicity could itself damage the well casing and affect well integrity (CIWEM 2014). Little data are available on the effects of fracking on the long-term integrity of well casings. This increases the risks posed by well			

	Exploration	Appraisal	Operation	Abandonment
	abandonment; a study for the European Commission study (Broomfield 2012) concluded that these risks are not classifiable based on current information.			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Water Resources Act 1991 Mining Waste Directive (2006/21/EC) Water Framework Directive (2000/60/EC) Groundwater Daughter Directive (2006/118/EC)			
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments. Offshore Installations and Wells (Design and Construction, etc) Regulations 1996 Borehole Sites and Operations Regulations 1995			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	Low
Justification for residual impact	The identified risks can be mitigated given proper enforcement of regulatory controls. The Environment Agency expects that, where a CBM development does proceed, there will be established good practice in groundwater protection applied where any associated drilling or operation of the boreholes or shafts passes through a groundwater resource. Groundwater including any local aquifers should be carefully delineated by the operator as part of the well design and fracturing risk assessment process (CIWEM 2014). During drilling, the operator must case off the aquifer and pressure test each casing before changing to a non-freshwater mud or on encountering hydrocarbons. Operators should use BAT techniques and industry standards for cement to ensure risks are minimised. Cement bond logs can be used to support other evidence to determine if the casing has been successful or not (CIWEM 2014).			

	Exploration	Appraisal	Operation	Abandonment
	DECC licensing requires seismic monitoring to assess likely faults and thus potential impact on well integrity using a traffic light monitoring system. If a seismic event is determined to be large enough by the monitoring system then operations will cease. The well can then be repaired (CIWEM 2014).			

Abandoned mine methane (AMM)

Groundworks

Materials released during site preparation

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by materials released during site preparation			
Pathway – How might the receptor come into contact with the source?	Exposure to releases to air, land and water			
Receptor – What is at risk?	Surface waters, aquifers, wildlife and their habitats, contractors and staff, local community			
Harm – What are the harmful consequences if things go wrong?	Contamination and loss of resource, injury, ill health, death, loss of habitat			
Probability of exposure – How likely is this contact?	Very low	Very low	Very Low	Very low
Consequence – How severe will the consequences be if this occurs?	High	High	High	High
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	Medium	Medium
Justification for magnitude	This aspect of operations is not new to the UK. The risks are well understood and readily controllable by operators.			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Water Framework Directive (2000/60/EC) Groundwater Daughter Directive (2006/118/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Water Resources Act 1991			

	Exploration	Appraisal	Operation	Abandonment
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments.			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Surface spills from onsite equipment

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by materials (fuels, oils) released from onsite equipment			
Pathway – How might the receptor come into contact with the source?	Accidental releases through defective equipment			
Receptor – What is at risk?	Groundwater and surface waters and soils			
Harm – What are the harmful consequences if things go wrong?	Contamination and loss of resource, injury, ill health, loss of habitat			
Probability of exposure – How likely is this contact?	Low	Low	Low	Low
Consequence – How severe will the consequences be if this occurs?	Medium	Medium	Medium	Medium
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	Medium	Medium
Justification for magnitude	This aspect of operations is not new to the UK. The risks are well understood and readily controllable by operators.			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Water Framework Directive (2000/60/EC) Groundwater Daughter Directive (2006/118/EC) Notice of intention under Section 199 of the Water Resources Act 1991(as amended by the Water Act 2003)			
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals			

	Exploration	Appraisal	Operation	Abandonment
	Planning Authority on planning applications and Environmental Impact Assessments.			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Site clearance

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Biodiversity – direct/indirect loss or harm of flora/fauna			
Pathway – How might the receptor come into contact with the source?	Loss of flora/fauna due to site clearance			
Receptor – What is at risk?	Wildlife and their habitats			
Harm – What are the harmful consequences if things go wrong?	Loss of habitat			
Probability of exposure – How likely is this contact?	Medium	Low	Medium	Low
Consequence – How severe will the consequences be if this occurs?	Medium	Medium	Medium	Medium
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	Medium	Medium
Justification for magnitude	This aspect of operations is not new to the UK. The risks are well understood and readily controllable by operators. Likely area of clearance will be limited as will already have been undertaken as part of the operational mine works.			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	The Environmental Permitting (England and Wales) Regulations 2010 (as amended)			
Current regulatory	Town and Country Planning (Development Management Procedure)			

	Exploration	Appraisal	Operation	Abandonment
controls – On what basis can others impose controls?	(England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments.			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Noise/ acoustics

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Uncontrolled noise			
Pathway – How might the receptor come into contact with the source?	Uncontrolled noise associated with site plant and operations			
Receptor – What is at risk?	Employees, visitors, contractors and staff, local community			
Harm – What are the harmful consequences if things go wrong?	Risk of hearing related injury, nuisance			
Probability of exposure – How likely is this contact?	Low	Low	Low	Low
Consequence – How severe will the consequences be if this occurs?	Medium	Medium	Medium	Medium
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	Medium	Medium
Justification for magnitude	This aspect of operations is not new to the UK. The risks are well understood and readily controllable by operators. Noise from excavation, earth moving, plant and vehicle transport during site preparation has a potential impact on both residents and local wildlife, particularly in sensitive areas, however is not considered to differ greatly in nature from other comparable large-scale construction activity (Broomfield 2012). Noise levels vary during the different stages in the preparation and production cycle. Well drilling is likely the most significant source of noise although faring of gas can also be noisy (Broomfield 2012).			

	Exploration	Appraisal	Operation	Abandonment
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	The Environmental Permitting (England and Wales) Regulations 2010 (as amended)			
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments. Control of Noise (Codes of Practice for Construction and Open Sites) (England) Order 2002 Environmental Noise (England) Regulations 2006 Environmental Noise (England) (Amendment) Regulations 2009 Noise and Statutory Nuisance Act 1993			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Water acquisition

For the purpose of drilling

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Increased water demand from surface waters, groundwater, river or the sea, which may include the use of potable supplies			
Pathway – How might the receptor come into contact with the source?	Potentially reduced water availability for the natural environment and increased competition for limited supplies of water that can be sustainably abstracted			
Receptor – What is at risk?	Environments dependent on water resources (for example, wetlands and aquatic ecosystems) and potentially other industrial water consumers			
Harm – What are the harmful consequences if things go wrong?	Damage to local ecosystems and interruptions either to the supply to other industrial water consumers or the CBM operators themselves			
Probability of exposure – How likely is this contact?	Medium	Low	Medium	Low
Consequence – How severe will the consequences be if this occurs?	Low	Low	Low	Low
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Low	Medium	Low
Justification for magnitude	Low volumes required. AMM technique likely to utilise abandoned mine shaft or adit as conduit to extract gas – though additional boreholes can also be drilled to specific locations in the mine to capture and drain the gas. Consequence may be geographically dependent – some regions in England are already water scarce while others have water available for abstraction.			
Current regulatory	Water Resources Act 1991			

	Exploration	Appraisal	Operation	Abandonment
controls – On what regulatory basis can the Environment Agency impose controls?				
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	Low
Justification for residual risk	Insignificant quantities anticipated and are likely to be imported. The Environment Agency's groundwater guidance states that it will object, through planning or permitting controls, to AMM extraction infrastructure or activity within Source Protection Zone 1 (SPZ1) and/or where the activity would have an unacceptable effect on groundwater (CIWEM 2014).			

Dewatering to access/ release gas

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Increased water demand from surface waters, groundwater, river or the sea, which may include the use of potable supplies			
Pathway – How might the receptor come into contact with the source?	Potentially reduced water availability for the natural environment and increased competition for limited supplies of water that can be sustainably abstracted			
Receptor – What is at risk?	Environments dependent on water resources (for example, wetlands and aquatic ecosystems) and potentially other industrial water consumers			
Harm – What are the harmful consequences if things go wrong?	Damage to local ecosystems and interruptions either to the supply to other industrial water consumers or the AMM operators themselves			
Probability of exposure – How likely is this contact?	N/A	Very Low	Very Low	N/A
Consequence – How severe will the consequences be if this occurs?	N/A	Medium	Medium	N/A
Magnitude of risk – What is the overall magnitude of the risk?	N/A	Low	Low	N/A
Justification for magnitude	Dewatering not relevant to exploration or abandonment phases. AMM preferred sites are where minewater recovery rates are low or where dewatering is being continued (covered by existing minewater management) as useful volumes of gas cannot be recovered from waterlogged workings. The requirement for dewatering is likely to make a scheme economically unviable.			
Current regulatory controls – On what regulatory basis can	Water Resources Act 1991			

	Exploration	Appraisal	Operation	Abandonment
the Environment Agency impose controls?				
Residual risk – What is the magnitude of the risk after management?	N/A	Low	Low	N/A
Justification for residual risk	The likelihood for dewatering to be required for AMM is considered to be low.			

Chemical mixing

Use of proprietary chemicals for borehole drilling

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by the use of proprietary chemicals for drilling purposes – polymers, grouts			
Pathway – How might the receptor come into contact with the source?	Spills at the surface, followed by infiltration into groundwater and surface waters			
Receptor – What is at risk?	Surface waters and groundwater and any user of those waters or habitats relying on them			
Harm – What are the harmful consequences if things go wrong?	Contamination and loss of resources, injury, ill health, loss of or damage to a habitat			
Probability of exposure – How likely is this contact?	Medium	Medium	Medium	Low
Consequence – How severe will the consequences be if this occurs?	Medium	Medium	Medium	Medium
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	Medium	Medium
Justification for magnitude	Potential for spillages at the delivery, storage and mixing stages. AMM techniques are likely to utilise abandoned mine shaft or adit as conduit to extract gas – though additional boreholes can also be drilled to specific locations in the mine to capture and drain the gas. Using information from the drilling operator, the Environment Agency will assess whether an additive is hazardous or a non-hazardous pollutant using a methodology that follows the requirements of the Groundwater Daughter Directive and under the Environment Agency technical guidance WM2. The Environment Agency expects drilling			

	Exploration	Appraisal	Operation	Abandonment
	operators to propose only non-hazardous substances (CIWEM 2014).			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Water Framework Directive (2000/60/EC) Groundwater Daughter Directive (2006/118/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended)			
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments.			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Borehole installation and integrity

Fugitive releases of methane and other gases

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by fugitive releases of methane and other VOCs from the borehole			
Pathway – How might the receptor come into contact with the source?	Vertical migration from the borehole via gaps in the usually cemented annulus between the casing and the drilled borehole wall leading either to emissions to air or to groundwater			
Receptor – What is at risk?	Fluids – groundwater aquifers (both potable and saline), adjacent boreholes and potentially surface waters, with attendant risks to wildlife and water users Gases – the atmosphere, property, wildlife, employees, visitors and the local community			
Harm – What are the harmful consequences if things go wrong?	Contamination and potential loss of any water resources encountered, loss of or damage to a habitat, respiratory illnesses caused by VOCs, asphyxiation, explosion and fire risks from methane Methane is a potent greenhouse gas that contributes to anthropogenic climate change.			
Probability of exposure – How likely is this contact?	Low	Low	Low	Very Low
Consequence – How severe will the consequences be if this occurs?	High	High	High	High
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	Medium	Medium
Justification for magnitude	AMM techniques are likely to utilise abandoned mine shaft or adit as conduit to extract gas – though additional boreholes can also be drilled to specific locations in the mine to capture and drain the gas.			

	Exploration	Appraisal	Operation	Abandonment
	During drilling, the operator must case off the aquifer and pressure test each casing before changing to a non-freshwater mud or on encountering hydrocarbons. Cementing is a critical part of well construction and is a fully designed and engineered process. Operators should use BAT and industry standards for cement to ensure risks are minimised. Cement bond logs can be used to support other evidence to determine if the casing has been successful or not (CIWEM 2014). Probability reduced at abandonment as AMM production is stopped when the productive zones are drowned out by minewater rebound and stop releasing methane. Potential for fugitive releases from headworks or during installation of headworks			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Water Framework Directive (2000/60/EC) Groundwater Daughter Directive (2006/118/EC) Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Notice of intention under Section 199 of the Water Resources Act 1991(as amended by the Water Act 2003)			
Current regulatory controls – On what basis can others impose controls?	Offshore Installations and Wells (Design and Construction, etc) Regulations 1996 Borehole Sites and Operations Regulations 1995			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Disturbance of in situ substances

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by the disturbance of in situ substances, including gases, by the drilling process			
Pathway – How might the receptor come into contact with the source?	Release and migration of pollutants via preferential pathways (such as the well bore and/or fractures) during the drilling process and from there, emissions to atmosphere and/or groundwater			
Receptor – What is at risk?	The atmosphere, groundwater, property, wildlife, employees, visitors and the local community			
Harm – What are the harmful consequences if things go wrong?	Contamination and potential loss of any water resources encountered, loss of or damage to a habitat, respiratory illnesses caused by VOCs, asphyxiation, explosion and fire risks from methane Methane is a potent greenhouse gas that contributes to anthropogenic climate change.			
Probability of exposure – How likely is this contact?	Very Low	Low	Low	N/A
Consequence – How severe will the consequences be if this occurs?	High	High	High	N/A
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	Medium	N/A
Justification for magnitude	Not relevant to abandonment phase. There are no reports of impacts like this being associated with drilling boreholes. AMM techniques are likely to utilise abandoned mine shaft or adit as conduit to extract gas – although additional boreholes can also be drilled to specific locations in the mine to capture and drain the gas.			
Current regulatory controls – On what regulatory basis can	Water Framework Directive (2000/60/EC) Groundwater Daughter Directive (2006/118/EC)			

	Exploration	Appraisal	Operation	Abandonment
the Environment Agency impose controls?	Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Notice of intention under Section 199 of the Water Resources Act 1991(as amended by the Water Act 2003)			
Current regulatory controls – On what basis can others impose controls?	Offshore Installations and Wells (Design and Construction, etc) Regulations 1996 Borehole Sites and Operations Regulations 1995 The Coal Industry Act 1994			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	N/A
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Drill cuttings and spent drilling muds

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by inappropriate management of drill cuttings and spent drilling muds			
Pathway – How might the receptor come into contact with the source?	Surface contamination of the well pad followed by infiltration into groundwater and surface waters Also direct contact with wildlife, employees and visitors			
Receptor – What is at risk?	Groundwater and surface water resources and wildlife that depends on them Health of employees and site visitors			
Harm – What are the harmful consequences if things go wrong?	Contamination and potential loss of any water resources encountered, loss of or damage to a habitat, potential illness as a result of exposure			
Probability of exposure – How likely is this contact?	Low	Very Low	Very Low	N/A
Consequence – How severe will the consequences be if this occurs?	Medium	Medium	Medium	N/A
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Low	Low	N/A
Justification for magnitude	Not relevant at abandonment phase. It is common practice to store drill cuttings and spent drilling muds onsite pending disposal. AMM techniques are likely to utilise abandoned mine shaft or adit as conduit to extract gas – though additional boreholes can also be drilled to specific locations in the mine to capture and drain the gas.			
Current regulatory controls – On what regulatory basis can	Mining Waste Directive (2006/21/EC) Water Framework Directive (2000/60/EC)			

	Exploration	Appraisal	Operation	Abandonment
the Environment Agency impose controls?	Groundwater Daughter Directive (2006/118/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended)			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	N/A
Justification for re4sidual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Build-up of naturally occurring radioactive material (NORM)

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Build-up of NORM in site infrastructure (for example, tanks, pipework, valves)			
Pathway – How might the receptor come into contact with the source?	NORM brought up in flowback fluid can collect in storage tanks and pipework, either as sediment or scale			
Receptor – What is at risk?	Employees and visitors			
Harm – What are the harmful consequences if things go wrong?	Exposure to accumulated NORM			
Probability of exposure – How likely is this contact?	N/A	Low	Medium	Medium
Consequence – How severe will the consequences be if this occurs?	N/A	Medium	Medium	Medium
Magnitude of risk – What is the overall magnitude of the risk?	N/A	Medium	Medium	Medium
Justification for magnitude	Not relevant at exploration phase. This is a recognised issue in the oil and gas industry for both conventional and unconventional developments. The presence of low concentrations of NORM within formation water/ condensate is currently being investigated within the UK. Precipitates may have sufficient NORM to be above the EPR thresholds for permitting. NORM scale and sediment requires conditioning and disposal at landfill sites; there is a small residual exposure pathway at the			

	Exploration	Appraisal	Operation	Abandonment
	conditioning and disposal end of the process. Increased probability at operational and abandonment phases due to potential for multiple sites/ pads, increased infrastructure and build-up over time.			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Basic Safety Standards Directive ((6/29/EURATOM) Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended) [AMM is an EPR NORM industrial activity because it fits at least one of the following categories: - the production of oil and gas - the removal and management of radioactive scales and precipitates from equipment associated with industrial activities - any activity related to coal mine dewatering plants Furthermore, AMM is very likely to be a 'radioactive substances activity', and so an RSR permit will be required for accumulation and disposal of AMM formation water/condensate and solids.]			
Residual risk – What is the magnitude of the risk after management?	N/A	Low	Low	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Accumulation of solids containing NORM

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Accumulation of solids containing NORM after separation from flowback fluids			
Pathway – How might the receptor come into contact with the source?	Exposure to radiation as a result of onsite storage of NORM or movement of the solids to transport them offsite for treatment			
Receptor – What is at risk?	Employees and visitors			
Harm – What are the harmful consequences if things go wrong?	Exposure to accumulated NORM			
Probability of exposure – How likely is this contact?	N/A	Low	Medium	Medium
Consequence – How severe will the consequences be if this occurs?	N/A	Medium	Medium	Medium
Magnitude of risk – What is the overall magnitude of the risk?	N/A	Medium	Medium	Medium
Justification for magnitude	Not relevant at exploration phase. The volume of solids associated with a single exploratory well is likely to be low. The radioactivity associated with this material, while high enough to trigger the need for a permit, is still relatively low. The presence of low concentrations of NORM within produced water is currently being investigated within the UK. Precipitates may have sufficient NORM to be above the EPR thresholds for permitting. NORM scale and sediment requires conditioning and disposal at landfill sites; there is a small residual exposure pathway at the conditioning and disposal end of the process. Increased probability at operational phase due to potential for build-			

	Exploration	Appraisal	Operation	Abandonment
	up over time.			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Basic Safety Standards Directive (96/29/EURATOM) Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended) [AMM is an EPR NORM industrial activity because it fits at least one of the following categories: - the production of oil and gas - the removal and management of radioactive scales and precipitates from equipment associated with industrial activities - any activity related to coal mine dewatering plants Furthermore, AMM is very likely to be a 'radioactive substances activity', and so an RSR permit will be required for accumulation and disposal of AMM produced water and solids.]			
Residual risk – What is the magnitude of the risk after management?	N/A	Low	Low	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Gas management

Controlled venting of gases

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Controlled venting of methane and trace components (for example, other VOCs and gaseous NORM hydrogen sulphide) In emergency only.			
Pathway – How might the receptor come into contact with the source?	Emissions to atmosphere			
Receptor – What is at risk?	The atmosphere, wildlife, employees and visitors			
Harm – What are the harmful consequences if things go wrong?	Odour, exposure to low levels of radioactivity Methane is a potent greenhouse gas that contributes to anthropogenic climate change.			
Probability of exposure – How likely is this contact?	Low	Low	Low	Low
Consequence – How severe will the consequences be if this occurs?	Medium	Medium	Medium	Medium
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	Medium	Medium
Justification for magnitude	The main risk is to the atmosphere. Venting would be a last option for waste gases and mainly a safety feature. Components of green completion systems avoid the need to cold vent or excessively flare the natural gas. USEPA data indicate emissions of methane from oil and gas production account for 63% of the total sector emissions, with the production emissions dominated by venting and flaring (Environment			

	Agency 2012b). There are strong safety, environmental and economic pressures for operators to control and reduce natural gas losses. For specific production equipment, understanding the rate of leakage will form part of the regular measurement regime and part of any equipment performance acceptance test. Further away from the local production equipment, it is important to know that methane is not significantly above the background level at or beyond the plant boundary. This is often tested using fenceline monitoring (Environment Agency 2012b).			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended)			
Current regulatory controls – On what basis can others impose controls?	The Hydrocarbons Licensing Directive Regulations 1995 The Petroleum Act 1998			
Residual risk – What is the magnitude of the risk after management?	Medium	Medium	Medium	Medium
Justification for residual risk	Venting is a last resort. The need for venting can be reduced with the use of green completions.			

Controlled flaring of gases

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Controlled flaring of methane and trace components (for example, other VOCs and gaseous NORM hydrogen sulphide)			
Pathway – How might the receptor come into contact with the source?	Emissions to atmosphere			
Receptor – What is at risk?	The atmosphere, wildlife, employees and visitors			
Harm – What are the harmful consequences if things go wrong?	Odour, exposure to low levels of radioactivity Methane is a potent greenhouse gas that contributes to anthropogenic climate change.			
Probability of exposure – How likely is this contact?	N/A	Medium	Medium	N/A
Consequence – How severe will the consequences be if this occurs?	N/A	Medium	Medium	N/A
Magnitude of risk – What is the overall magnitude of the risk?	N/A	Medium	Medium	N/A
Justification for magnitude	Not relevant at exploration and abandonment phases. The main risk is to the atmosphere. Flaring (as opposed to cold venting) reduces fire hazard onsite and, in transforming methane and other volatile organics to carbon dioxide, reduces the climate change impact of the operation. However, flaring has been associated with local environmental impacts including air quality (NO_x, SO_2, VOCs), light and noise intrusion, and there are efforts to reduce its use in the oil industry (Broderick et al. 2011, after Sanchez et al. 2008, Christen 2004).			

	Exploration	Appraisal	Operation	Abandonment
	Components of green completion systems avoid the need to cold vent or excessively flare the natural gas. Incorporated separators may be used to retain gas for processing and sale. USEPA data indicate emissions of methane from oil and gas production account for 63% of the total sector emissions, with the production emissions dominated by venting and flaring (Environment Agency 2012b). There are strong safety, environmental and economic pressures for operators to control and reduce natural gas losses. For specific production equipment, understanding the rate of leakage will form part of the regular measurement regime and part of any equipment performance acceptance test. Further away from the local production equipment, it is important to know that methane is not significantly above the background level at or beyond the plant boundary. This is often tested using fenceline monitoring (Environment Agency 2012a).			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Mining Waste Directive (2006/21/EC) Industrial Emissions Directive (2010/75/EU) The Environmental Permitting (England and Wales) Regulations 2010 (as amended)			
Current regulatory controls – On what basis can others impose controls?	The Hydrocarbons Licensing Directive Regulations 1995 The Petroleum Act 1998			
Residual risk – What is the magnitude of the risk after management?	N/A	Medium	Medium	N/A
Justification for residual risk	The incorporation of green completions would reduce the need to excessively flare at the production phase reducing the risk to medium.			

Exhaust emissions from onsite equipment

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by gases released from onsite equipment			
Pathway – How might the receptor come into contact with the source?	Exhausts from engines, generators and similar combustion equipment			
Receptor – What is at risk?	The atmosphere, wildlife, the local community, employees and visitors			
Harm – What are the harmful consequences if things go wrong?	Reduction in local air quality and increased photochemical pollution			
Probability of exposure – How likely is this contact?	Low	Low	Low	Low
Consequence – How severe will the consequences be if this occurs?	Low	Low	Medium	Low
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	Medium	Medium
Justification for magnitude	The risks depend on the type of fuel used for onsite generation (diesel, electricity or liquefied petroleum gas) and the sensitivity of the local environment. Emissions from compressor plant may potentially be significant at operational phase and require careful attention from operators and regulators (Environment Agency 2012b).			
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011			

	Exploration	Appraisal	Operation	Abandonment
	The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments. Industrial Emissions Directive (this would be for Environment Agency to apply)			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Explosion and fire (at surface)

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Uncontrolled air/gas mixtures at surface arising from fugitive emissions			
Pathway – How might the receptor come into contact with the source?	Emissions to atmosphere			
Receptor – What is at risk?	Local community, employees and visitors Site infrastructure			
Harm – What are the harmful consequences if things go wrong?	Damage to property, death			
Probability of exposure – How likely is this contact?	Low	Low	Low	Very Low
Consequence – How severe will the consequences be if this occurs?	High	High	High	High
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	Medium	Medium
Justification for magnitude	Reduced emissions completions to capture the gas. Controlled flaring and venting or green completions carried out to reduce potential for uncontrolled emissions. Probability reduced at abandonment phase as AMM production is stopped when the productive zones are drowned out by minewater rebound and stop releasing methane. There are strong safety, environmental and economic pressures for operators to control and reduce natural gas losses. For specific production equipment, understanding the rate of leakage will form			

	Exploration	Appraisal	Operation	Abandonment
	part of the regular measurement regime and part of any equipment performance acceptance test. Further away from the local production equipment, it is important to know that methane is not significantly above the background level at or beyond the plant boundary. This is often tested using fenceline monitoring (Environment Agency 2012b).			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended)			
Current regulatory controls – On what basis can others impose controls?	ATEX regulations Gas Safety (Management) Regulations 1996			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Explosion and fire (coal seams/mine workings)

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Uncontrolled entry of air into coal seams/mine workings			
Pathway – How might the receptor come into contact with the source?	Air drawn into coal seams via suction for gas capture			
Receptor – What is at risk?	Local community, employees and visitors Site infrastructure			
Harm – What are the harmful consequences if things go wrong?	Damage to property, death			
Probability of exposure – How likely is this contact?	N/A	Low	Low	N/A
Consequence – How severe will the consequences be if this occurs?	N/A	High	High	N/A
Magnitude of risk – What is the overall magnitude of the risk?	N/A	Medium	Medium	N/A
Justification for magnitude	Not relevant at exploration or abandonment phase. Risk associated with suction when capturing gas.			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended)			
Current regulatory controls – On what	ATEX regulations			

	Exploration	Appraisal	Operation	Abandonment
basis can others impose controls?	Gas Safety (Management) Regulations 1996			
Residual risk – What is the magnitude of the risk after management?	N/A	Low	Low	N/A
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Gas processing and treatment

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by the use of proprietary chemicals associated with gas treatment (nitrogen, glycol)			
Pathway – How might the receptor come into contact with the source?	Fugitive emissions			
Receptor – What is at risk?	The atmosphere, wildlife, local community, employees and visitors			
Harm – What are the harmful consequences if things go wrong?	Contamination, asphyxiation, odour, fire or explosion Contamination and loss of resources, injury, ill health, loss of or damage to a habitat			
Probability of exposure – How likely is this contact?	N/A	Very Low	Low	N/A
Consequence – How severe will the consequences be if this occurs?	N/A	Medium	Medium	N/A
Magnitude of risk – What is the overall magnitude of the risk?	N/A	Medium	Medium	N/A
Justification for magnitude	Not relevant at exploration or abandonment phases. Increased probability at operational phase due to greater potential volumes of gas for treatment. At the processing facility, the raw natural gas will go through a number of stages to remove the following components: acid gases (specifically hydrogen sulphide), water vapour, mercury and nitrogen. Each stage in the natural gas production process has the potential for fugitive emissions (Environment Agency 2012b). The chemicals used for gas treatment need to be stored and handled appropriately. There is the potential for leakage at the delivery, storage			

	Exploration	Appraisal	Operation	Abandonment
	and mixing stages.			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Mining Waste Directive (2006/21/EC) Water Framework Directive (2000/60/EC) Groundwater Daughter Directive (2006/118/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended)			
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments. Gas Safety (Management) Regulations 1996			
Residual risk – What is the magnitude of the risk after management?	N/A	Low	Low	N/A
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Gas processing and treatment

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Fugitive releases of methane and VOCs from site processing and transportation infrastructure			
Pathway – How might the receptor come into contact with the source?	Leaks from infrastructure like valves, pipework and flares			
Receptor – What is at risk?	The atmosphere, wildlife, employees and visitors			
Harm – What are the harmful consequences if things go wrong?	Contamination, asphyxiation, odour, fire or explosion Methane is a potent greenhouse gas that contributes to anthropogenic climate change.			
Probability of exposure – How likely is this contact?	N/A	Very Low	Low	N/A
Consequence – How severe will the consequences be if this occurs?	N/A	High	High	N/A
Magnitude of risk – What is the overall magnitude of the risk?	N/A	Medium	Medium	N/A
Justification for magnitude	Not relevant at exploration or abandonment phases. Increased probability at operational phase due to greater potential volumes of gas for treatment. The main risk is to the atmosphere. Likely lower scale of gas treatment infrastructure than for CBM. Each stage in the natural gas production process has the potential for fugitive emissions (Environment Agency 2012b). There are strong safety, environmental and economic pressures for operators to control and reduce natural gas losses. For specific production equipment, understanding the rate of leakage will form part of the regular measurement regime and part of any equipment			

	Exploration	Appraisal	Operation	Abandonment
	performance acceptance test. Further away from the local production equipment, it is important to know that methane is not significantly above the background level at or beyond the plant boundary. This is often tested using fenceline monitoring (Environment Agency 2012b).			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended)			
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments. Gas Safety (Management) Regulations 1996			
Residual risk – What is the magnitude of the risk after management?	N/A	Low	Low	N/A
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Offsite disposal

Drill cuttings and drilling muds

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused through the inappropriate disposal of waste drill cuttings and drilling muds			
Pathway – How might the receptor come into contact with the source?	Direct and indirect contact following land spreading			
Receptor – What is at risk?	People, property and wildlife in or near the site of land spreading			
Harm – What are the harmful consequences if things go wrong?	Local contamination of habitats and resources and exposure of people to that contamination			
Probability of exposure – How likely is this contact?	Low	Medium	Medium	N/A
Consequence – How severe will the consequences be if this occurs?	Medium	Medium	Medium	N/A
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	Medium	N/A
Justification for magnitude	Not relevant at abandonment phase. The likely content of the drilling muds and drill cuttings and their potential impact on the environment is well known. AMM techniques are likely to utilise abandoned mine shaft or adit as conduit to extract gas– though additional boreholes can also be drilled to specific locations in the mine to capture and drain the gas.			
Current regulatory controls – On what	Water Framework Directive (2000/60/EC)			

	Exploration	Appraisal	Operation	Abandonment
regulatory basis can the Environment Agency impose controls?	Groundwater Daughter Directive (2006/118/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Control of Pollution (Amendment) Act 1989 The Waste (England and Wales) Regulations 2011 – registration of waste carrier and brokers			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	N/A
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Transport, storage, treatment and disposal of wastes

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by the transport, storage, treatment and disposal of wastes produced by high volume hydraulic fracturing operations			
Pathway – How might the receptor come into contact with the source?	Release of pollutants to air, land and water from transport accidents, storage at transfer stations and treatment plants, discharges to water and land disposal sites			
Receptor – What is at risk?	People, property, wildlife and the wider environment along transport routes and near to storage, treatment and disposal facilities			
Harm – What are the harmful consequences if things go wrong?	Local contamination of habitats and resources and exposure of people to that contamination			
Probability of exposure – How likely is this contact?	Low	Low	Medium	Low
Consequence – How severe will the consequences be if this occurs?	Medium	Medium	Medium	Medium
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	Medium	Medium
Justification for magnitude	The likely content of the wastes and their potential impact on the environment is well known; the risks will depend on the sensitivity of the local environment. Waste carriers and treatment, storage and disposal sites will already be permitted by the Environment Agency. Increased risk due to potential for multiple sites/pads, increased infrastructure and cumulative impacts.			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Control of Pollution (Amendment) Act 1989 The Waste (England and Wales) Regulations 2011 – registration of			

	Exploration	Appraisal	Operation	Abandonment
	waste carrier and brokers Water Resources Act 1991			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.			

Well closure and abandonment

Long-term integrity of borehole

	Exploration	Appraisal	Operation	Abandonment
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by a substance released during the exploration process continues to have an environmental impact beyond the operational phase			
Pathway – How might the receptor come into contact with the source?	Exposure to releases into air or water			
Receptor – What is at risk?	The local population and surrounding environment			
Harm – What are the harmful consequences if things go wrong?	Exposure to released gases and harmful substances brought to the surface, air pollution, surface or subsurface contamination, ill health, loss or damage to a habitat or resource			
Probability of exposure – How likely is this contact?	Low	Low	Low	Low
Consequence – How severe will the consequences be if this occurs?	High	High	High	High
Magnitude of risk – What is the overall magnitude of the risk?	Medium	Medium	Medium	Medium
Justification for magnitude	This process is well established both onshore and offshore requiring notification to HSE, and in accordance with HSE, industry and DECC well abandonment best practice.			
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Water Resources Act 1991 Mining Waste Directive (2006/21/EC)			

	Exploration	Appraisal	Operation	Abandonment
	Water Framework Directive (2000/60/EC) Groundwater Daughter Directive (2006/118/EC)			
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments. Offshore Installations and Wells (Design and Construction, etc) Regulations 1996 Borehole Sites and Operations Regulations 1995			
Residual risk – What is the magnitude of the risk after management?	Low	Low	Low	Low
Justification for residual risk	The Environment Agency expects that, where a AMM development does proceed, there will be established good practice in groundwater protection applied where any associated drilling or operation of the boreholes or shafts passes through a groundwater resource. Groundwater including any local aquifers should be carefully delineated by the operator as part of the well design and fracturing risk assessment process (CIWEM 2014). During drilling, the operator must case off the aquifer and pressure test each casing before changing to a non-freshwater mud or on encountering hydrocarbons. Operators should use BAT and industry standards for cement to ensure risks are minimised. Cement bond logs can be used to support other evidence to determine if the casing has been successful or not (CIWEM 2014).			

Coal mine methane (CMM)

Groundworks

Materials released during site preparation

	Operation
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by materials released during site preparation
Pathway – How might the receptor come into contact with the source?	Exposure to releases to air, land and water
Receptor – What is at risk?	Surface waters, aquifers, wildlife and their habitats, contractors and staff, local community
Harm – What are the harmful consequences if things go wrong?	Contamination and loss of resource, injury, ill health, death, loss of habitat
Probability of exposure – How likely is this contact?	Very Low
Consequence – How severe will the consequences be if this occurs?	High
Magnitude of risk – What is the overall magnitude of the risk?	Medium
Justification for magnitude	Groundworks associated with CMM over existing coal mining operations are likely to be minimal. This aspect of operations is not new to the UK. The risks are well understood and readily controllable by operators.
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Water Framework Directive (2000/60/EC) Groundwater Daughter Directive (2006/118/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Water Resources Act 1991

	Operation
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments.
Residual risk – What is the magnitude of the risk after management?	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.

Surface spills from onsite equipment

	Operation
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by materials (fuels, oils) released from onsite equipment
Pathway – How might the receptor come into contact with the source?	Accidental releases through defective equipment
Receptor – What is at risk?	Groundwater and surface waters
Harm – What are the harmful consequences if things go wrong?	Contamination and loss of resource, injury, ill health, loss of habitat
Probability of exposure – How likely is this contact?	Low
Consequence – How severe will the consequences be if this occurs?	Medium
Magnitude of risk – What is the overall magnitude of the risk?	Medium
Justification for magnitude	Groundworks associated with CMM over existing coal mining operations are likely to be minimal. This aspect of operations is not new to the UK. The risks are well understood and readily controllable by operators.
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Water Framework Directive (2000/60/EC) Groundwater Daughter Directive (2006/118/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Notice of intention under Section 199 of the Water Resources Act 1991(as amended by the Water Act 2003).
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011

	Operation
	The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments.
Residual risk – What is the magnitude of the risk after management?	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.

Noise/ acoustics

	Operation
Source (hazard) – What is the agent or process with the potential to cause harm?	Uncontrolled noise
Pathway – How might the receptor come into contact with the source?	Uncontrolled noise associated with site plant and operations
Receptor – What is at risk?	Employees, visitors, contractors and staff, local community
Harm – What are the harmful consequences if things go wrong?	Risk of hearing related injury, nuisance
Probability of exposure – How likely is this contact?	Low
Consequence – How severe will the consequences be if this occurs?	Medium
Magnitude of risk – What is the overall magnitude of the risk?	Medium
Justification for magnitude	This aspect of operations is not new to the UK. The risks are well understood and readily controllable by operators. Noise from excavation, earth moving, plant and vehicle transport during site preparation has a potential impact on both residents and local wildlife, particularly in sensitive areas. However it is not considered to differ greatly in nature from other comparable large-scale construction activity (Broomfield 2012). Noise levels vary during the different stages in the preparation and production cycle. Flaring of gas can also be noisy (Broomfield 2012).
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	The Environmental Permitting (England and Wales) Regulations 2010 (as amended)

	Operation
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments. Control of Noise (Codes of Practice for Construction and Open Sites) (England) Order 2002 SI 461 Environmental Noise (England) Regulations 2006 Environmental Noise (England) (Amendment) Regulations 2009 Noise and Statutory Nuisance Act 1993
Residual risk – What is the magnitude of the risk after management?	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.

Water acquisition

For the purpose of drilling

	Operation
Source (hazard) – What is the agent or process with the potential to cause harm?	Increased water demand from surface waters, groundwater, river or the sea, which may include the use of potable supplies
Pathway – How might the receptor come into contact with the source?	Potentially reduced water availability for the natural environment and increased competition for limited supplies of water that can be sustainably abstracted
Receptor – What is at risk?	Environments dependent on water resources (for example, wetlands and aquatic ecosystems) and potentially other industrial water consumers
Harm – What are the harmful consequences if things go wrong?	Damage to local ecosystems and interruptions either to the supply to other industrial water consumers or the CMM operators themselves
Probability of exposure – How likely is this contact?	Very Low
Consequence – How severe will the consequences be if this occurs?	Medium
Magnitude of risk – What is the overall magnitude of the risk?	Low
Justification for magnitude	Cross measures boreholes are likely to require little or no water. Small diameter, shallow depth boreholes into disturbed strata. Covered by existing minewater management.
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Water Resources Act 1991

	Operation
Residual risk – What is the magnitude of the risk after management?	Low
Justification for residual risk	Water acquisition for drilling likely to be limited if at all. Supply arrangements will be part of overall minewater management. Insignificant quantities would be anticipated and are likely to be imported.

Chemical mixing

Use of proprietary chemicals for borehole drilling

	Operation
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by the use of proprietary chemicals for drilling purposes – polymers, grouts
Pathway – How might the receptor come into contact with the source?	Spills at the surface, followed by infiltration into groundwater and surface waters
Receptor – What is at risk?	Surface waters and groundwater and any user of those waters or habitats relying on them
Harm – What are the harmful consequences if things go wrong?	Contamination and loss of resources, injury, ill health, loss of or damage to a habitat
Probability of exposure – How likely is this contact?	Low
Consequence – How severe will the consequences be if this occurs?	Medium
Magnitude of risk – What is the overall magnitude of the risk?	Medium
Justification for magnitude	Potential for spillages at the delivery, storage and mixing stages. Most common gas capture method in UK is post(gas)-drainage using cross-measure technique – using inclined boreholes drilled into the overlying and underlying gas sources. Associated chemical volumes likely to be limited. Conditions not favourable to pre(gas)-drainage techniques. Drilling from surface unlikely (pre(gas)drainage surface holes or post(gas)-drainage surface goaf holes).

	Operation
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Water Framework Directive (2000/60/EC) Groundwater Daughter Directive (2006/118/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended)
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments.
Residual risk – What is the magnitude of the risk after management?	Low
Justification for residual risk	Chemical volumes likely to be limited if at all. The identified risks can be mitigated given proper enforcement of regulatory controls.

Management of fluids

Build-up of naturally occurring radioactive material (NORM)

	Operation
Source (hazard) – What is the agent or process with the potential to cause harm?	Build-up of NORM in site infrastructure (for example, tanks, pipework and valves)
Pathway – How might the receptor come into contact with the source?	NORM brought up in flowback fluid can collect in storage tanks and pipework, either as sediment or scale
Receptor – What is at risk?	Employees and visitors
Harm – What are the harmful consequences if things go wrong?	Exposure to accumulated NORM
Probability of exposure – How likely is this contact?	Low
Consequence – How severe will the consequences be if this occurs?	Medium
Magnitude of risk – What is the overall magnitude of the risk?	Medium
Justification for magnitude	Dewatering of seam required for mine working covered by existing minewater management. Drawdown not required in gas capture techniques, so quantity of produced water will be low and limited to condensate. This is a recognised issue in the oil and gas industry for both conventional and unconventional developments. The presence of low concentrations of NORM within produced water

	Operation
	is currently being investigated within the UK. Precipitates may have sufficient NORM to be above the EPR thresholds for permitting. NORM scale and sediment requires conditioning and disposal at landfill sites; there is a small residual exposure pathway at the conditioning and disposal end of the process.
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Basic Safety Standards Directive (96/29/EURATOM) Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended) [CMM is an EPR NORM industrial activity because it fits at least one of the following categories: - the production of oil and gas - the removal and management of radioactive scales and precipitates from equipment associated with industrial activities - any activity related to coal mine dewatering plants Furthermore, CMM is very likely to be a 'radioactive substances activity', and so an RSR permit will be required for accumulation and disposal of CMM precipitates and solids.]
Residual risk – What is the magnitude of the risk after management?	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.

Accumulation of solids containing NORM

	Operation
Source (hazard) – What is the agent or process with the potential to cause harm?	Accumulation of solids containing NORM after separation from flowback fluids
Pathway – How might the receptor come into contact with the source?	Exposure to radiation as a result of onsite storage of NORM or movement of the solids to transport them offsite for treatment
Receptor – What is at risk?	Employees and visitors
Harm – What are the harmful consequences if things go wrong?	Exposure to accumulated NORM
Probability of exposure – How likely is this contact?	Low
Consequence – How severe will the consequences be if this occurs?	Medium
Magnitude of risk – What is the overall magnitude of the risk?	Medium
Justification for magnitude	The volume of solids associated with a single exploratory well is likely to be low. The radioactivity associated with this material, though high enough to trigger the need for a permit, is still relatively low. The presence of low concentrations of NORM within produced water is currently being investigated within the UK. Precipitates may have sufficient NORM to be above the EPR thresholds for permitting. NORM scale and sediment requires conditioning and disposal at landfill sites; there is a small residual exposure pathway at the conditioning and disposal end of the process.
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Basic Safety Standards Directive (96/29/EURATOM) Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended)

	Operation
	[CMM is an EPR NORM industrial activity because it fits at least one of the following categories: - the production of oil and gas - the removal and management of radioactive scales and precipitates from equipment associated with industrial activities - any activity related to coal mine dewatering plants Furthermore, CMM is very likely to be a 'radioactive substances activity', and so an RSR permit will be required for accumulation and disposal of CMM precipitates and solids.]
Residual risk – What is the magnitude of the risk after management?	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.

Controlled venting of gases

	Operation
Source (hazard) – What is the agent or process with the potential to cause harm?	Controlled venting of methane, VOCs, gaseous NORM and hydrogen sulphide Only likely to be used in emergency or if better forms of waste gas management are not viable.
Pathway – How might the receptor come into contact with the source?	Emissions to atmosphere
Receptor – What is at risk?	The atmosphere, wildlife, employees and visitors
Harm – What are the harmful consequences if things go wrong?	Odour, exposure to low levels of radioactivity Methane is a potent greenhouse gas that contributes to anthropogenic climate change.
Probability of exposure – How likely is this contact?	Low
Consequence – How severe will the consequences be if this occurs?	High
Magnitude of risk – What is the overall magnitude of the risk?	Medium
Justification for magnitude	The main risk is to the atmosphere. Venting would be a last option for waste gases and mainly a safety feature. Components of green completion systems avoid the need to cold vent or excessively flare the natural gas. USEPA data indicate emissions of methane from oil and gas production account for 63% of the total sector emissions, with the production emissions dominated by venting and flaring (Environment Agency 2012b). There are strong safety, environmental and economic pressures for operators to control and reduce natural gas losses. For

	Operation
	specific production equipment, understanding the rate of leakage will form part of the regular measurement regime and part of any equipment performance acceptance test. Further away from the local production equipment, it is important to know that methane is not significantly above the background level at or beyond the plant boundary (Environment Agency 2012b).
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended)
Current regulatory controls – On what basis can others impose controls?	The Hydrocarbons Licensing Directive Regulations 1995 The Petroleum Act 1998
Residual risk – What is the magnitude of the risk after management?	Medium
Justification for residual risk	Venting is a last resort. The need for venting can be reduced with the use of green completions.

Controlled flaring of gases

	Operation
Source (hazard) – What is the agent or process with the potential to cause harm?	Controlled flaring of methane, VOCs, gaseous NORM and hydrogen sulphide
Pathway – How might the receptor come into contact with the source?	Emissions to atmosphere
Receptor – What is at risk?	The atmosphere, wildlife, employees and visitors
Harm – What are the harmful consequences if things go wrong?	Odour, exposure to low levels of radioactivity Methane is a potent greenhouse gas that contributes to anthropogenic climate change.
Probability of exposure – How likely is this contact?	Medium
Consequence – How severe will the consequences be if this occurs?	High
Magnitude of risk – What is the overall magnitude of the risk?	High
Justification for magnitude	The main risk is to the atmosphere. Components of green completion systems avoid the need to cold vent or excessively flare the natural gas. Flaring (as opposed to cold venting) reduces fire hazard onsite and, in transforming methane and other volatile organics to carbon dioxide, reduces the climate change impact of the operation. However, flaring has been associated with local environmental impacts including air quality (NO_x, SO_2, VOCs), light and noise intrusion and there are efforts to reduce its use in the oil industry (Broderick et al. 2011, after Sanchez et al. 2008, Christen 2004). USEPA data indicate emissions of methane from oil and gas production account for 63% of the total sector emissions, with

	the production emissions dominated by venting and flaring (Environment Agency 2012b). There are strong safety, environmental and economic pressures for operators to control and reduce natural gas losses. For specific production equipment, understanding the rate of leakage will form part of the regular measurement regime and part of any equipment performance acceptance test. Further away from the local production equipment, it is important to know that methane is not significantly above the background level at or beyond the plant boundary (Environment Agency 2012a).
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended) Industrial Emissions Directive (2010/75/EU)
Current regulatory controls – On what basis can others impose controls?	The Hydrocarbons Licensing Directive Regulations 1995 The Petroleum Act 1998
Residual risk – What is the magnitude of the risk after management?	Medium
Justification for residual risk	The incorporation of green completions would reduce the need to excessively flare reducing the risk to medium.

Exhaust emissions from onsite equipment

	Operation
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by gases released from onsite equipment
Pathway – How might the receptor come into contact with the source?	Exhausts from engines, generators and similar combustion equipment
Receptor – What is at risk?	The atmosphere, wildlife, the local community, employees and visitors
Harm – What are the harmful consequences if things go wrong?	Reduction in local air quality and increased photochemical pollution
Probability of exposure – How likely is this contact?	Low
Consequence – How severe will the consequences be if this occurs?	Low
Magnitude of risk – What is the overall magnitude of the risk?	Low
Justification for magnitude	The risks depend on the type of fuel used for onsite generation (diesel, electricity or liquefied petroleum gas) and the sensitivity of the local environment. Emissions from compressor plant may potentially be significant at operational phase and require careful attention from operators and regulators (Environment Agency 2012b).
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011

	Operation
	The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments. Industrial Emissions Directive (Environment Agency to administer)
Residual risk – What is the magnitude of the risk after management?	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.

Explosion and fire (coal seams/ mine workings)

	Operation
Source (hazard) – What is the agent or process with the potential to cause harm?	Uncontrolled entry of air into coal seams/mine workings
Pathway – How might the receptor come into contact with the source?	Air drawn into coal seams via suction for gas capture
Receptor – What is at risk?	Local community, employees and visitors Site infrastructure
Harm – What are the harmful consequences if things go wrong?	Damage to property, death
Probability of exposure – How likely is this contact?	Medium
Consequence – How severe will the consequences be if this occurs?	High
Magnitude of risk – What is the overall magnitude of the risk?	High
Justification for magnitude	Risk associated with suction when capturing gas
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended)
Current regulatory controls – On what basis can others	ATEX regulations

	Operation
impose controls?	Gas Safety (Management) Regulations 1996
Residual risk – What is the magnitude of the risk after management?	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.

Gas processing and treatment

	Operation
Source (hazard) – What is the agent or process with the potential to cause harm?	Pollution caused by the use of proprietary chemicals associated with gas treatment (nitrogen, glycol)
Pathway – How might the receptor come into contact with the source?	Fugitive emissions
Receptor – What is at risk?	The atmosphere, wildlife, local community, employees and visitors
Harm – What are the harmful consequences if things go wrong?	Contamination, asphyxiation, odour, fire or explosion Contamination and loss of resources, injury, ill health, loss of or damage to a habitat
Probability of exposure – How likely is this contact?	Medium
Consequence – How severe will the consequences be if this occurs?	Medium
Magnitude of risk – What is the overall magnitude of the risk?	Medium
Justification for magnitude	At the processing facility, the raw natural gas will go through a number of stages to remove the following products: acid gases (specifically hydrogen sulphide), water vapour, mercury and nitrogen. Each stage in the natural gas production process has the potential for fugitive emissions (Environment Agency 2012b). The chemicals used for gas treatment need to be stored and handled appropriately. There is the potential for leakage at the delivery, storage and mixing stages.
Current regulatory controls – On what regulatory basis can the Environment	Mining Waste Directive (2006/21/EC) Water Framework Directive (2000/60/EC)

	Operation
Agency impose controls?	Groundwater Daughter Directive (2006/118/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended)
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments. Gas Safety (Management) Regulations 1996
Residual risk – What is the magnitude of the risk after management?	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.

Gas processing and treatment

	Operation
Source (hazard) – What is the agent or process with the potential to cause harm?	Fugitive releases of methane and VOCs from site processing and transportation infrastructure
Pathway – How might the receptor come into contact with the source?	Leaks from infrastructure like valves, pipework and flares
Receptor – What is at risk?	The atmosphere, wildlife, employees and visitors
Harm – What are the harmful consequences if things go wrong?	Contamination, asphyxiation, odour, fire or explosion Methane is a potent greenhouse gas that contributes to anthropogenic climate change.
Probability of exposure – How likely is this contact?	Medium
Consequence – How severe will the consequences be if this occurs?	Medium
Magnitude of risk – What is the overall magnitude of the risk?	Medium
Justification for magnitude	The main risk is to the atmosphere. Each stage in the natural gas production process has the potential for fugitive emissions (Environment Agency 2012b). There are strong safety, environmental and economic pressures for operators to control and reduce natural gas losses. For specific production equipment, understanding the rate of leakage will form part of the regular measurement regime and part of any equipment performance acceptance test. Further away from the local production equipment, it is important to know that methane is not significantly above the background level at or beyond the plant boundary (Environment Agency 2012b).
Current regulatory controls – On what regulatory basis can the Environment Agency impose controls?	Mining Waste Directive (2006/21/EC) The Environmental Permitting (England and Wales) Regulations 2010 (as amended)

	Operation
Current regulatory controls – On what basis can others impose controls?	Town and Country Planning (Development Management Procedure) (England) Order 2010 Town and Country Planning (Environmental Impact Assessment) Regulations 2011 The Environment Agency is a statutory adviser to the Minerals Planning Authority on planning applications and Environmental Impact Assessments. Gas Safety (Management) Regulations 1996
Residual risk – What is the magnitude of the risk after management?	Low
Justification for residual risk	The identified risks can be mitigated given proper enforcement of regulatory controls.

References

Broomfield, M., 2012. *Support to the Identification of Potential Risks for the Environment and Human Health arising from Hydrocarbons Operations involving Hydraulic Fracturing in Europe*. Report ref. AEA/R/ED57281 prepared by AEA Technology. Brussels: European Commission DG Environment.

Broderick J., Anderson, K., Wood, R., Gilbert, P., Sharmina, M., Footitt, A., Glynn, S. and Nicholls, F., 2011. *Shale Gas: An Updated Assessment of Environmental and Climate Change Impacts.* A report commissioned by The Co-operative and undertaken by researchers at the Tyndall Centre, University of Manchester. Available from: http://www.tyndall.ac.uk/shalegasreport [Accessed May 2014].

Christen, K., 2004. Environmental Impacts of Gas Flaring, Venting Add Up. *Environmental Science and Technology*, 38 (24), 480A [cited in Broderick et al. 2011].

CIWEM, 2014. *Shale Gas and Water: An Independent Review of Shale Gas Exploration and Exploitation in the UK with a particular focus on the Implications for the Water Environment.* London: Chartered Institute of Water and Environment Management.

DECC, 2012. *The Unconventional Hydrocarbon Resources of Britain's Onshore Basins – Coalbed Methane (CBM).* London: Department of Energy and Climate Change. Available from: https://www.og.decc.gov.uk/UKpromote/onshore_paper/Promote_UK_CBM.pdf. [Accessed June 2014]

Defra, 2011. Guidelines for Environmental Risk Assessment and Management. London: Department for Environment, Food and Rural Affairs.

DTI, 2001a. *UK Capability: Coalbed Methane Extraction and Utilisation.* CB012. London: Department of Trade and Industry.

DTI, 2001b. *Technical Status Report: Coalbed Methane Extraction and Utilisation*. CB016. London: Department of Trade and Industry.

Environment Agency, 2012a. *Review of Assessment Procedures for Oil and Gas Well Casing Installation.* Bristol: Environment Agency.

Environment Agency, 2012b. *Monitoring and Control of Fugitive Methane from Unconventional Gas Operations.* Bristol: Environment Agency.

Environment Agency, 2013a. *An Environmental Risk Assessment for Shale Gas Exploratory Operations in England.* Bristol: Environment Agency.

Environment Agency, 2013b. *Onshore Oil and Gas Exploratory Operations: Technical Guidance. Consultation draft.* Bristol: Environment Agency.

Gale, J., and Freund, P., 2001, Coal-bed methane enhancement with CO_2 sequestration worldwide potential: Environmental Geosciences, v. 8, no. 3, p. 210–217.

Green, C.A., Styles, P. and Baptie, B.J., 2012. *Preese Hall Shale Gas Fracturing. Reviews and Recommendations for Induced Seismic Mitigation*. London: Department of Energy and Climate Change.

Groat, C.G. and Grimshaw, T., 2012. *Fact-Based Regulation for Environmental Protection in Shale Gas Development*. Austin, TX: The Energy Institute, University of Texas.

NYSDEC, 2011. *Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program. Well permit issuance for horizontal drilling and high-volume hydraulic fracturing to develop the Marcellus Shale and other low-permeability gas reservoirs.* Revised draft. Albany, NY: New York State Department of Environmental Conservation. Available

from: http://www.dec.ny.gov/energy/75370.html [Accessed May 2014] [cited in Environment Agency 2012b].

Reznik, A., Singh, P. K., and Foley, W. L., 1982, An analysis of the effect of carbon dioxide injection on the recovery of in-situ methane from bituminous coal: An experimental simulation: Society of Petroleum Engineers/U.S. Department of Energy 10822

Schroeder, K., Ozdemir, E., and Morsi, B.I., 2002, Sequestration of carbon dioxide in coal seams: Journal of Energy and Environmental Research, v. 2, no. 1. p. 54–63. (from U.S. Department of Energy, National Energy Technology Laboratory, First National Conference on Carbon Sequestration, 2001).

USEPA, 2004. *Evaluation of Impacts to Underground Sources of Drinking Water by Hydraulic Fracturing of Coalbed Methane Reservoirs.* EPA 816-R-04-003. Washington DC: US Environmental Protection Agency, Office of Water, Office of Ground Water and Drinking Water.

Bibliography

Arthur, J.D., Bohm, B. and Layne, M., 2008. *Hydraulic fracturing considerations for natural gas wells of the Marcellus Shale*. Presented at The Ground Water Protection Council 2008 Annual Forum, Cincinnati, OH, 21–24 September 2008.

COGCC, 2000. *Summary Report of Bradenhead Testing, Gas Well Remediation, and Groundwater Investigations San Juan Basin, La Plata County, Colorado*. Denver, CO: State of Colorado Oil and Gas Conservation Commission.

COGCC, 2009a. *Casing Head Test Report. OGCC Operator Number 26420, API Number 123-11848*. Denver, CO: State of Colorado Oil and Gas Conservation Commission.

COGCC, 2009b. *Sundry Notice. OGCC Operator Number 26420, API Number 05-123-11848.* Denver, CO: State of Colorado Oil and Gas Conservation Commission.

COGCC, 2009c. *Colorado Oil and Gas Conservation Commission approved Wattenberg Casing head testing and staff policy. Letter sent to all oil and gas operators active in the Denver Basin.* Denver, CO: State of Colorado Oil and Gas Conservation Commission.

Considine, T., Watson, R., Considine, N. and Martin. J., 2012. *Environmental Impacts during Marcellus Shale Gas Drilling: Causes, Impacts, and Remedies*. Buffalo, NY: Shale Resources and Society Institute, University of Buffalo.

Davies, R.J., Mathias, S.A., Moss, J., Hustoft, S. and Newport, L., 2012. Hydraulic fractures: how far can they go?, *Marine and Petroleum Geology*, 37 (1), 1-6.

ICF Incorporated, 2009. *Technical Assistance for the draft Supplemental Generic Environmental Impact Statement (SGEIS) on the Oil, Gas and Solution Mining Regulatory Program. Well permit issuance for horizontal drilling and high-volume hydraulic fracturing to develop the Marcellus Shale and other low permeability gas reservoirs—Task 1*. Albany, NY: New York State Energy Research and Development Authority.

Michaels, C., Simpson, J.L. and Wegner, W., 2010. *Fractured Communities: Case Studies of the Environmental Impacts of Industrial Gas Drilling.* Ossining, NY: New York Riverkeeper.

McMahon, P.B., Thomas, J.C. and Hunt, A.G., 2011. *Use of Diverse Geochemical Data Sets to Determine Sources and Sinks of nitrate and Methane in Groundwater, Garfield County, Colorado, 2009.* US Geological Survey Scientific Investigations Report 2010–5215. Reston, VA: United States Geological Survey.

Myers, T., 2009. *Technical Memorandum: Review and Analysis of Draft Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program. Well*

Permit Issuance for Horizontal Drilling and High-volume Hydraulic Fracturing to Develop the Marcellus Shale and other Low-permeability Gas Reservoirs. New York, NY: Natural Resources Defense Council.

OGS, 2005. *Petroleum Technology Transfer Council – South Midcontinent Region Regional Update*, Fourth Publication, 2005. Norman, OK: Oklahoma Geological Survey. Available from: http://www.ogs.ou.edu/pttcnewsarchive.php [Accessed May 2014].

Ohio DNR, 2008. *Report on the Investigation of the Natural Gas Invasion of Aquifers in Bainbridge Township of Geauga County, Ohio*. Columbus, OH: Ohio Department of Natural Resources, Division of Mineral Resources Management.

Pashin, J.C., Groshong, R.H. and Caroll, R.E., 2001. *Enhanced Coalbed Methane Recovery Through Sequestration of Carbon Dioxide: Potential for a Market-Based Environmental Solution in the Black Warrior Basin of Alabama*. US Department of Energy, National Energy Technology Laboratory, First National Conference on Carbon Sequestration Proceedings, DOE/NETL-2001/1144. Available from: http://www.netl.doe.gov/publications/proceedings/01/carbon_seq/3a2.pdf [Accessed May 2014].

PADEP, 2010. *Consent Order and Settlement Agreement (Commonwealth of Pennsylvania Department of Environmental Protection and Cabot Oil & Gas Corporation).* Harrisburg, PA: Pennsylvania Department of Environmental Protection.

PEQB (Pennsylvania Environmental Quality Board), 2009. Proposed Rulemaking [25 PA. CODE CH. 95] wastewater treatment requirements [39 Pa.B. 6467] [Saturday, November 7, 2009]. *The Pennsylvania Bulletin*, 39 (45), Doc. No. 09-2065.

Royal Society and Royal Academy of Engineering, 2012. *Shale Gas Extraction in the UK: A Review of Hydraulic Fracturing*. London: The Royal Society and The Royal Academy of Engineering. Available from: http://royalsociety.org/policy/projects/shale-gas-extraction/report/ [accessed May 2014].

Sanchez, M. Karnae, S. and John, K., 2008. Source Characterization of Volatile Organic Compounds Affecting the Air Quality in a Coastal Urban Area of South Texas. *International Journal of Environmental Research and Public Health*, 5 (3), 130-138 [cited in Broderick et al. 2011].

SEPA, 2012. *Regulatory Guidance: Coal Bed Methane and Shale Gas.* Stirling: Scottish Environmental Protection Agency.

Stearns, M., Tindall, J., Cronin, G., Friedel, M. and Bergquist, E., 2005. Effects of Coal-bed Methane Discharge Waters on the Vegetation and Soil Ecosystem in Powder River Basin, Wyoming. *Water, Air, and Soil Pollution*, 168 (1-4), 33-57.

UNEP, 2012. *Gas Fracking: Can we safely squeeze the rocks?* UNEP Global Environmental Alert Service, November 2012. Sioux Falls, SD: United Nations Environment Programme Earth Resources Observation and Science (EROS) Center.

Urbina, I., 2011. Regulation lax as gas wells' tainted water hits rivers. *The New York Times*, 26 February 2011. Available from: http://www.nytimes.com/2011/02/27/us/27gas.html?pagewanted=1&_r=2&hpw [Accessed May 2104].

USEPA, 2010. *Trip report (EXCO Resources' gas well drilling site, Norris Ferry Road, southern Caddo Parish (Shreveport), LA).* Dallas, TX: U.S. Environmental Protection Agency Region 6.

USEPA, 2011. *Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources.* Report EPA/600/D-11/001. Washington DC: US Environmental Protection Agency, Office of Research and Development.

Working Group (Coal Authority, Health and Safety Executive, British Drilling Association, Federation of Piling Specialists, Association of Geotechnical and Geoenvironmental Specialists), 2012. *Guidance on Managing the Risk of Hazardous Gases when Drilling or Piling Near Coal.*

List of abbreviations

AMM	abandoned mine methane
BAT	Best Available Techniques
CBM	coal bed methane
CMM	coal mine methane
ECBM	enhanced coal bed methane (CBM recovery using carbon dioxide or nitrogen injection)
EPR	Environmental Permitting Regulations
ERA	Environmental Risk Assessment
HSE	Health and Safety Executive
NORM	naturally occurring radioactive material
RSR	Radioactive Substances Regulation
UKOOG	United Kingdom Onshore Operators Group
VOC	volatile organic compound

Glossary

Drilling fluid

Mud, water or air pumped down the drill string which acts as a lubricant for the bit and is used to carry rock cuttings back up the wellbore. It is also used for pressure control in the wellbore.

Flaring

The burning of unwanted gas through a pipe.

Flowback fluids

Fracturing fluid contaminated with minerals and NORM returned to the surface during and following high volume hydraulic fracturing.

Fracking or fracing

(pronounced ‘fracking’) Informal abbreviation for ‘hydraulic fracturing’.

Fracturing fluids

Water and additives used at pressure in the high volume hydraulic fracturing of shale beds.

Green completions

Also known as ‘reduced emission completions’ (RECs). Involves the installation of portable equipment specially designed to handle the high initial flow of water, sand and gas. A sand trap is used to remove the solids and is followed by a three-phase separator which separates the water from the condensate (liquid hydrocarbons) and gas

High volume hydraulic fracturing

The injection of 1,000 m^3 of fluid or more at high pressure to fracture a shale bed and release the methane contained within it

Hydraulic fracturing fluid

Fluid used to perform hydraulic fracturing. Includes the primary carrier fluid, proppant material and all applicable additives (see Appendix).

Hydraulic fracturing

Act of pumping hydraulic fracturing fluid into a formation to increase its permeability.

Methane

Methane (CH_4) is a greenhouse gas that remains in the atmosphere for approximately 9–15 years. Methane is also a primary constituent of natural gas and an important energy source.

NORM

Naturally occurring radioactive material. Low-level radioactivity that can exist naturally in native materials, like some shales, and may be present in drill cuttings and other wastes from a well.

Produced water

Liquids co-produced during oil and gas wells production.

Proppant or propping agent

A granular substance (sand grains, aluminium pellets, or other material) that is carried in suspension by the fracturing fluid and that serves to keep the cracks open when fracturing fluid is withdrawn after a fracture treatment.

Stimulation

The act of increasing a well's productivity by artificial means such as hydraulic fracturing or acidising.

Unconventional gas

Gas contained in rocks (which may or may not contain natural fractures) which exhibit in situ gas permeability of less than 1 millidarcy. The term 'unconventional gas' is not always used in accordance with this technical definition, particularly in the USA where a different definition is commonly used, and care must be exercised in the use and interpretation of this term.

Venting

Controlled release of gases into the atmosphere in the course of gas production operations. These gases might be natural gas or other hydrocarbon vapours, water vapour, and other gases such as carbon dioxide.

Well pad

A site constructed, prepared, levelled and/or cleared to perform the activities and to stage the equipment and other infrastructure necessary to drill one or more natural gas exploratory or production wells. The area directly disturbed during drilling and operation of a gas well.

Well site

Includes the well pad and access roads, equipment storage and staging areas, vehicle turnarounds, and any other areas directly or indirectly impacted by activities involving a well.

Well bore

A borehole – the hole drilled by the bit. A well bore may have casing in it or it may be open (uncased); or part of it may be cased, and part of it may be open.

Wellhead

The equipment installed at the surface of the well bore. A wellhead includes such equipment as the casing head and tubing head.

Appendix: Example fracture fluid additives

Additive type	Description of purpose	Examples of chemicals
Proppant	'Props' open fractures and allows gas/ fluids to flow more freely to the well bore.	Sand (sintered bauxite; zirconium oxide; ceramic beads)
Acid	Removes cement and drilling mud from casing perforations prior to fracturing fluid injection and provides accessible path to formation.	Hydrochloric acid (3–28%) Muriatic acid
Breaker	Reduces the viscosity of the fluid so as to release proppant into fractures and to enhance the recovery of the fracturing fluid.	Peroxydisulfates
Bactericide/ biocide/ antibacterial agent	Inhibits growth of organisms that could produce gases (particularly hydrogen sulphide) which could contaminate methane gas. Also prevents the growth of bacteria, which can reduce the ability of the fluid to carry proppant into the fractures.	Gluteraldehyde 2,2-Dibromo-3-nitrilopropionamide
Buffer/ pH adjusting agent	Adjusts and controls the pH of the fluid to maximise the effectiveness of other additives such as crosslinkers.	Sodium or potassium carbonate Acetic acid
Clay stabiliser/ control/ KCl	Prevents swelling and migration of formation clays which could block pore spaces, thereby reducing permeability.	Salts (for example, tetramethyl ammonium chloride) Potassium chloride (KCl)
Corrosion inhibitor (including oxygen scavengers)	Reduces rust formation on steel tubing, well casings, tools, and tanks (used only in fracturing fluids that contain acid).	Methanol Ammonium bisulfate for oxygen scavengers
Crosslinker	Increases fluid viscosity using phosphate esters combined with metals. The metals are referred to as crosslinking agents. The increased fracturing fluid viscosity allows the fluid to carry more proppant into the fractures.	Potassium hydroxide Borate salts
Friction reducer	Allows fracture fluids to be injected at optimum rates and pressures by minimising friction.	Sodium acrylate – acrylamide copolymer Polyacrylamide (PAM)
Petroleum distillates	Gelling agent Increases fracturing fluid viscosity, allowing the fluid to carry more proppant into the fractures.	Guar gum Petroleum distillates
Iron control	Prevents the precipitation of metal oxides which could plug off the formation.	Citric acid
Scale inhibitor	Prevents the precipitation of carbonates and sulphates (calcium carbonate, calcium sulphate, barium sulphate), which could plug off the formation.	Ammonium chloride Ethylene glycol
Solvent	Additive that is soluble in oil, water and acid-based treatment fluids which is used to control the wettability of contact surfaces or to	Various aromatic hydrocarbons

Additive type	Description of purpose	Examples of chemicals
	prevent or break emulsions.	
Surfactant	Reduces fracturing fluid surface tension thereby aiding fluid recovery.	Methanol Isopropanol Ethoxylated alcohol

Source: Environment Agency (2012b, Table 1.4), after NYSDEC (2011, Table 5.6)

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