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Foreign and Commonwealth Office

# Shale Gas Study

Final Report



April 2015

Amec Foster Wheeler Environment  
& Infrastructure UK Limited



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## Report for

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# Executive summary

## Purpose

The exploration and production of shale gas represents a significant opportunity for many countries. It could help address energy security, energy costs and the need for transitional energy sources in moving towards a low carbon future. Brazil, as one of 10 countries that have collectively been estimated to contain nearly 80% of the world's estimated technically recoverable shale gas resources<sup>1</sup>, is actively considering the potential for shale gas. However, in common with many other nations<sup>2</sup> considering the potential for unconventional oil and gas, the proposed development of shale gas in Brazil has also raised concerns regarding the potential effects on the environment<sup>3</sup>.

At present, Brazil does not have specific procedures or recommendations from the environmental agencies concerning shale gas or oil exploration and development although there is a resolution from ANP, the oil and gas licensing agency, for the management of risks to human health and the environment. Following an initiative of the Ministries of Mines and Energy and the Environment, a project has been established to analyse the key issues concerning the development and production of unconventional oil and gas resources under a federal Program known as PROMINP (Mobilization Program of Industry in the Oil and Natural Gas).

As a contribution to research under PROMINP and in order to support the Brazilian government develop a strong regulation for the safe exploration of shale gas by drawing on international research, Amec Foster Wheeler Environment and Infrastructure UK Ltd has completed a review of the risks to the environment and human health of shale gas exploration and production and the approaches to managing these risks through regulatory frameworks in the UK and Europe.

## Environmental Risks

The key risks identified through this work are summarised in the following table. It indicates that the majority of risks and impacts associated with unconventional oil and gas exploration and development are common to those associated with conventional oil and gas development. Differences however do occur when considering the technologies and requirements of the hydraulic fracturing process itself. These are likely to include: induced seismic events; the local sourcing of water, creating additional demand during periods of water stress; the management of chemicals and the mixing, storage and use of the fracture fluid, the management of flowback water and fugitive greenhouse gas emissions.

Theme	Risk/Impact	Conventional	Un-conventional
<b>Biodiversity</b>	Direct loss and/or fragmentation of habitat from construction and operation of well site and well pad activities.	✓	✓
	Indirect impacts on habitats/species due to, for example, disturbance from noise, human presence and light pollution and the introduction of invasive species and the exposure to pollution through causal pathways.	✓	✓
<b>Land Use and Geology</b>	Land requirements for pad and pipelines, disruption to soil layers and compaction and resulting impacts on removal of land for alternative uses (natural or anthropogenic) and ecology/ environment impacts.	✓	✓

<sup>1</sup> *US Energy Information Administration*, Technically Recoverable Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41 Countries Outside the United States, 2013

<sup>2</sup> *BIO Intelligence Service* (2013), Presentation of the results of the public consultation "Unconventional fossil fuels (e.g. shale gas) in Europe" Brussels – 7<sup>th</sup> June 2013, for the European Commission and DG Environment, [http://ec.europa.eu/environment/integration/energy/pdf/Presentation\\_07062013.pdf](http://ec.europa.eu/environment/integration/energy/pdf/Presentation_07062013.pdf)

<sup>3</sup> *Brazilian Academy of Sciences Letter to President Rouseff*, 5<sup>th</sup> August 2013, <http://jonathandeblog.com/2013/08/29/fracking-not-welcomed-with-open-arms-in-brazil/>

Theme	Risk/Impact	Conventional	Un-conventional
	Induced seismicity from hydraulic fracturing activities and the potential impact on well integrity, creation of geological pathways for pollutants and possible minor earth tremors.	✓ (in limited circumstance <sup>4</sup> )	✓
<b>Water Resources</b>	Surface spillage of pollutants such as diesel and drilling fluids and silt-laden run-off resulting in surface water pollution.	✓	✓
	Surface spillage of hydraulic fracturing fluids and wastewaters resulting in surface water pollution.		✓
	Well failure resulting in pollutants released from the well to groundwaters.	✓	✓
	Introduction of pollutants due to induced fractures providing pathways to groundwater resources through either pre-existing man-made or natural structures.		✓
	Inappropriate selection of chemicals in hydraulic fracturing and/ or unsuitable assessment leading to unacceptable risks to the environment from releases.		✓
	Water consumption associated with hydraulic fracturing activities affecting the availability of water resources, aquatic habitats and ecosystems and water quality.		✓
	Well pad development at risk of flooding and/or resulting in increased flood risk off site due to increase in impermeable area and/or location of facilities in areas of flood risk.	✓	✓
<b>Air Quality</b>	Emissions to air from well pad construction and drilling resulting in adverse local air quality impacts.	✓	✓
	Emissions associated with hydraulic fracturing activities resulting in adverse local air quality impacts.		✓
<b>Climate Change</b>	Greenhouse gas (GHG) emissions from well pad construction and drilling.	✓	✓
	GHG emissions associated with hydraulic fracturing activities.		✓
	GHG emissions arising from well completion.	✓	✓
	Fugitive GHG emissions.	✓	✓
	Combustion of extracted hydrocarbons generating GHG emissions.	✓	✓
<b>Waste Arisings</b>	Generation of construction and drilling wastes.	✓	✓
	Generation of flowback water following hydraulic fracturing activities.		✓
<b>Cultural Heritage</b>	Direct loss of or damage to cultural heritage features and landscapes from construction of well pad and associated infrastructure.	✓	✓
	Indirect effects on the setting of cultural heritage assets as a result of the well pad construction and operation.	✓	✓
<b>Landscape</b>	Impacts and landscape character and visual amenity due to well pad construction and operation activities.	✓	✓
<b>Human Health</b>	Emissions to air, dust and noise associated with construction and drilling activities resulting in adverse impacts on nearby receptors.	✓	✓

<sup>4</sup> *Davies et al (2012) Induced Seismicity and Hydraulic Fracturing for the Recovery of Hydrocarbons, Marine and Petroleum Geology Manuscript, <https://www.dur.ac.uk/resources/refine/InducedSeismicityfull.pdf>*

Theme	Risk/Impact	Conventional	Un-conventional
	Contamination of drinking water supply due to hydraulic fracturing activities.		✓
	Risks associated with the health and safety of workers onsite.	✓	✓
	Disturbance and nuisance issues	✓	✓

## Measures to Avoid, Minimise and Mitigate Risks

Given the commonality between the effects arising from unconventional oil and gas and conventional oil and gas exploration, there is a considerable body of practice available to address the issues concerning site selection, technology, construction practice, operation and decommissioning. These measures to avoid, minimise and mitigate risks are contained in **Section 3** of this report which itself summarises details contained in **Appendix B**. Within the UK there is a long track record of undertaking conventional oil and gas exploration and production in an environmentally and socially acceptable manner, which suggests that such measures are effective in managing those effects that are common between unconventional and conventional oil and gas exploration and production<sup>5</sup>.

The remaining mitigation measures identified for the effects associated with hydraulic fracturing (induced seismic events; the local sourcing of water, creating additional demand during periods of water stress; the management of chemicals and the mixing, storage and use of the fracture fluid, the management of flowback water and fugitive greenhouse gas emissions) are, within the UK context, unproven; however, reflect expert judgment on what is most effective:

- ▶ **Management of induced seismicity:** recommendations from the Royal Society and Royal Academy of Engineering in their 2012 report, 'Shale gas extraction in the UK: a review of hydraulic fracturing'<sup>6</sup>.
- ▶ **Management of chemicals used in fracture fluids:** requirements of the Environment Agency<sup>7</sup>, and the assessment of effects against the requirements of the Joint Agencies Groundwater Directive Advisory Group.
- ▶ **Management of water demand and flowback water:** recommendations from Water UK research<sup>8</sup> and recommendations from CIWEM report on Shale Gas and Water<sup>9</sup>.
- ▶ **Management of fugitive greenhouse gas emissions:** recommendations from Mackay and Stone report<sup>10</sup> into potential greenhouse gas emissions associated with shale gas extraction and use.

## European Regulatory Framework

The European regulatory framework to manage the risks to the environment and human health of shale gas exploration and production has been reviewed. The European Commission adopted Recommendation

<sup>5</sup> House of Commons Energy and Climate Change Committee (2011), Shale Gas Fifth Report of Session 2010–12, HC 795, May 2011

<sup>6</sup> Royal Society and Royal Academy of Engineering (2012), Shale gas extraction in the UK: a review of hydraulic fracturing (Terms of Reference, pp 8) June 2012

<sup>7</sup> Environment Agency (2013), Onshore oil and gas exploratory operations: technical guidance, Consultation Draft, August 2013

<sup>8</sup> Amec Foster Wheeler (2013), Understanding The Potential Impacts Of Shale Gas Fracking On The UK Water Industry-Stage 1, Report Ref. No. WR09C301

<sup>9</sup> 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

<sup>10</sup> MacKay, D.J.C. and Stone, T.J. (2013) *Potential Greenhouse Gas Emissions Associated with Shale Gas Extraction and Use*. Report on behalf of DECC. London: DECC

2014/70/EU<sup>11</sup> provides a set of coherent minimum principles that may be used for Member States that are looking to develop the exploration and production of hydrocarbons using high volume hydraulic fracturing (HVHF). The Recommendation provides a common framework for competent authorities, operators and the civil society to work within. It reflects a considerable body of work, including an assessment of risks, Member State practice and the scope of existing legislation and potential policy options<sup>12</sup>. It is however, not a Directive and so the extent to which it will be implemented across Member States remains uncertain, although its effectiveness will be reviewed 18 months after its publication.

The Recommendation attempts to address the gaps identified within the existing suite of Directives and Regulations. These include:

- ▶ Insufficient requirement for site characterisation and setting of baseline conditions for air, water and soil;
- ▶ Insufficient requirement for subsurface site characterisation, including baseline conditions for deep ground/geology/seismicity;
- ▶ No criteria or common principles available against which to perform a geological risk assessment;
- ▶ No monitoring of injection tests/'mini-fractures' required;
- ▶ Requirement for cumulative effects may be inconsistently implemented (e.g. of environmental impacts, traffic related impacts and land take);
- ▶ Public participation not always required as it generally occurs upon the performance of an EIA, which, at exploration stage, is not required if the screening procedure concludes that the project is not likely to have significant effect on the environment.
- ▶ Post closure monitoring requirements insufficiently specified.

At the European Member State level:

- ▶ None of the Member States examined have a regulatory regime specifically for unconventional gas;
- ▶ There are legal uncertainties which are prompting Member States to review legislation and draft new law leaving to potential divergence, although this may be addressed by the Recommendation.
- ▶ Whilst the completion of guidance by Member States is still in its early stages, under the Recommendation, the Commission will be reviewing current reference documents to ensure that they covers the management of waste from hydrocarbon exploration and production involving High Volume Hydraulic Fracturing (HVHF). Such information will be publicly available and so could help inform emerging guidance in Brazil.

## Brazilian Regulatory Framework

In considering the environmental implications of shale gas exploration and production, both Brazil and the EU have recognised the importance of undertaking a high level assessment of areas to be licensed. Within the EU, this is through the implementation of the Strategic Environmental Assessment Directive (2001/42/EC), whilst in Brazil, it is under the Interministerial Ordinance 198/2012 ("environmental assessment of sedimentary area"). Both require the licensing body to set out its proposed areas, identify the nature of any effects and identify where development will not be "suitable" due to likely significant adverse environmental effects. There is potential for the Ordinance 198/2012 to go further in the consideration of the

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<sup>11</sup> Commission recommendation on 22<sup>nd</sup> January 2014 on minimum principles for the exploration and production of hydrocarbons (such as shales gas) using high-volume hydraulic fracturing (2014/70/EU), <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014H0070&from=EN>

<sup>12</sup> [http://ec.europa.eu/environment/integration/energy/uff\\_studies\\_en.htm](http://ec.europa.eu/environment/integration/energy/uff_studies_en.htm)



scope of the effects considered (to ensure that they anticipate those considered at the project stage) and to issue guidance to operators on matters to consider at the project stage. At the project level, Environmental Impact Assessment (EIA) is a common assessment tool across both Brazil and Europe, with appropriate matters identified through scoping.

The ANP Resolution 21/2014 provides the first specific basis for a regulatory framework for managing operational safety issues, as well as possible effects on the environment and human health, related with unconventional gas in Brazil. In this approach it is analogous to the role played by the European Commission adopted Recommendation 2014/70/EU which provided a set of minimum principles that may to be used when looking to develop the exploration and production of hydrocarbons using HVHF.

Drawing on the contents of Recommendation 2014/70/EU and the research findings completed as part of this study, there is an opportunity to refine the ANP Resolution further to clarify certain aspects of the Resolution in order to improve its effectiveness. These include:

- ▶ Reviewing the definition of hydraulic fracturing.
- ▶ Extending the information required to be provided from operators to include: the availability and capacity of existing water resources; the quantities, quality and management of waste water; and the monitoring of any induced seismicity.
- ▶ Ensuring any separation distances between wells and aquifers is supported by the most recent research and international practice.
- ▶ Requiring surface casing and cementation to extend to a specified depth below any aquifer used for domestic consumption/public water supply.
- ▶ Providing a traffic light system approach to the control of hydraulic fracturing and any induced seismicity.
- ▶ Requiring further detail from the operator regarding monitoring post well decommissioning and abandonment.

The Resolution also states that the approval of hydraulic fracturing in unconventional reservoirs by ANP will depend on, among other requirements, the "*presentation by the operator of the environmental permit issued by the competent agency, with specific authorization for operations of hydraulic fracturing in unconventional reservoir, when applicable*". The Brazilian environmental legislation does not define what should be included within the environmental permit, and what supporting studies would be necessary. A recent amendment to UK law (the Infrastructure Act 2015) introduced the requirement for a hydraulic fracturing consent, to be issued by Department of Energy and Climate Change (DECC) to the operator, where hydraulic fracturing is proposed at a depth below 1,000m (see **Section 4.6.1**) and in applying for this consent, the operator needs to demonstrate that it has met the following conditions:

- ▶ The environmental impact of the development has been taken into account by the local planning authority.
- ▶ Appropriate arrangements have been made for the independent inspection of the integrity of the relevant well.
- ▶ The level of methane in groundwater has, or will have, been monitored in the period of 12 months before the associated hydraulic fracturing begins.
- ▶ Appropriate arrangements have been made for the monitoring of emissions of methane into the air.
- ▶ The associated hydraulic fracturing will not take place within protected groundwater source areas.
- ▶ The associated hydraulic fracturing will not take place within other protected areas.
- ▶ Cumulative effects have been taken into account.
- ▶ Regulator approval has been given to the substances to be used.



- ▶ Appropriate arrangements are made for restoration of the site, once exploration and/or production activity has concluded.
- ▶ Relevant consultations have been completed.

In the absence of a current definition of what to include within an environmental permit for hydraulic fracturing within Brazil, the current UK hydraulic fracturing consent information provides a useful starting point and it is recommended that the PROMINP project considers the application of these requirements (or similar) in more detail.

The PROMINP project provides a basis to address a number of additional issues, to facilitate the safe and effective regulation of unconventional gas. As, part of this project, and aligned with developments in Europe we would encourage the consideration of the following issues.

- ▶ Capacity Building;
- ▶ Zoning and Minimum Distances;
- ▶ Baseline conditions;
- ▶ Monitoring;
- ▶ Disclosure of Information;
- ▶ Hydraulic Fracturing
- ▶ Induced Seismicity;
- ▶ Carbon Emissions;
- ▶ Well Closure.

It is recommended that an evaluation is undertaken of the proposed mitigation and management measures for each of the above areas to test and aid their refinement and to ensure their applicability to Brazil. This could be undertaken by members of the PROMINP project team as part of the current PROMINP project.





# Contents

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<b>1.</b>	<b>Shale Gas</b>	<b>13</b>
1.1	Overview	13
1.2	Purpose of this Report	14
1.3	Scope of the Study	14
1.3.1	Methodology	15
1.3.2	Limitations	16
1.4	Shale Gas Resources and Reserves	17
1.4.1	Definitions	17
1.4.2	Global Context	17
1.4.3	The Shale Gas Opportunity in Brazil	20
1.4.4	Concerns of Brazilian Society	22
1.4.5	Need for Regulation	23
1.5	Report Contents	23
<b>2.</b>	<b>Shale Exploration and Production</b>	<b>25</b>
2.1	Introduction	25
2.2	Shale and Shale Gas	25
2.2.1	Shale Gas Extraction	25
2.3	Stages of Shale Gas Extraction	26
2.3.1	Stage 1: Non-Intrusive Exploration	27
2.3.2	Stage 2: Exploration Drilling and Hydraulic Fracturing	27
2.3.3	Stage 3: Production Development	32
2.3.4	Stage 4: Production, Operation and Maintenance	33
2.3.5	Stage 5: Decommissioning of Wells	33
2.3.6	Stage 6: Site Restoration and Relinquishment	34
2.4	Summary	34
<b>3.</b>	<b>What are the Risks and the Effects?</b>	<b>35</b>
3.1	Overview	35
3.2	Biodiversity and Nature Conservation	37
3.2.1	Effects on Biodiversity and Nature Conservation	37
3.2.2	Summary of Risks and Avoidance, Minimisation and Mitigation Measures	39
3.3	Land Use and Geology	42
3.3.1	Effects on Land Use and Geology	42
3.3.2	Summary of Risks and Avoidance, Minimisation and Mitigation Measures	44
3.4	Water Resources	47
3.4.1	Effects on Water Resources	47
3.4.2	Summary of Risks and Avoidance, Minimisation and Mitigation Measures	51
3.5	Air quality	58
3.5.1	Effects on Air Quality	58
3.5.2	Key Risk and Avoidance, Minimisation and Mitigation Measures	59
3.6	Climate Change	61
3.6.1	Effects on Climate Change	61
3.6.2	Key Risk and Avoidance, Minimisation and Mitigation Measures	63
3.7	Waste Arisings	65

3.7.1	Effects on Waste Arising	66
3.7.2	Summary of Risks and Avoidance, Minimisation and Mitigation Measures	66
<b>3.8</b>	<b>Cultural Heritage</b>	<b>69</b>
3.8.1	Effects on Cultural Heritage	69
3.8.2	Summary of Risks and Avoidance, Minimisation and Mitigation Measures	70
<b>3.9</b>	<b>Landscape</b>	<b>71</b>
3.9.1	Effects on Landscape	71
3.9.2	Summary of Risks and Avoidance, Minimisation and Mitigation Measures	71
<b>3.10</b>	<b>Human Health</b>	<b>72</b>
3.10.1	Effects on Human Health	72
3.10.2	Summary of Risks and Avoidance, Minimisation and Mitigation Measures	73
<b>3.11</b>	<b>Collective Measures for Avoidance, Minimisation and Mitigation</b>	<b>77</b>
<b>3.12</b>	<b>Summary</b>	<b>80</b>
<b>4.</b>	<b>European Regulatory Framework for the Environmental Effects of Shale Gas</b>	<b>83</b>
4.1	Introduction	83
4.2	European Community Recommendation	83
4.3	Recommendation Commitments and Review	87
4.3.1	Relevant European Community Directives and Regulations	87
4.4	Strategic Environmental Assessment	88
4.5	Environmental Impact Assessment	90
4.5.1	Habitats Directives	93
4.5.2	Mining Waste Directive	93
4.5.3	Water Framework Directive	93
4.5.4	SEVESO II/SEVESO III	94
4.5.5	REACH	94
4.5.6	ELD	94
4.5.7	GD and GWD	95
4.6	European Member State Regulations	95
4.6.1	Advances in the UK	97
4.7	Moratoria	98
4.7.1	France	98
4.7.2	Bulgaria	99
4.8	Voluntary Measures	99
4.9	Summary	100
<b>5.</b>	<b>Brazilian Regulatory Framework for the Environmental Effects of Oil and Gas</b>	<b>103</b>
5.1	Introduction	103
5.2	Environmental Regulatory Requirements for the Oil and Natural Gas industry	103
5.2.1	Environmental Permitting and EIA	103
5.3	Other Activities	106
5.4	Strategic Environmental Assessment	108
5.5	Unconventional Resources and Resolution ANP 21/2014	108

5.6	Conclusion	111
6.	Potential Implication for Brazilian Regulatory Framework for Shale Gas	113
6.1.1	Capacity Building	119
6.1.2	Zoning and Minimum Distances	119
6.1.3	Baseline conditions	119
6.1.4	Monitoring	120
6.1.5	Disclosure of Information	121
6.1.6	Hydraulic Fracturing	121
6.1.7	Induced Seismicity	122
6.1.8	Carbon Emissions	122
6.1.9	Well Closure	123
7.	Glossary and Abbreviations	125

---

Table 1.1:	Top 10 Countries with Technically Recoverable Shale Gas Resources (TRR)	18
Table 2.1:	Unconventional Oil and Gas Exploration and Production Lifecycle and Key Activities	34
Table 3.1	Potential Causes of Principal Environmental Risks Specific to Unconventional Gas Exploration and Production	35
Table 3.2	Summary of Risks to Biodiversity and Mitigation Measures	39
Table 3.3	Summary of Risks to Land Use and Mitigation Measures	44
Table 3.4	Summary of Risks from Induced Seismicity and Mitigation Measures	45
Table 3.5	Summary of Risks to Surface Water and Mitigation Measures	52
Table 3.6	Summary of Risks to Ground Water and Mitigation Measures	55
Table 3.7	Summary of Risks to Water Resource Risks and Mitigation Measures	58
Table 3.8	Summary of Risks to Air Quality and Mitigation Measures	60
Table 3.9	Summary of Climate Change Risks and Mitigation Measures	64
Table 3.10	Summary of Waste Risks and Mitigation Measures	67
Table 3.11	Summary of Risks to Cultural Heritage and Mitigation Measures	70
Table 3.12	Summary of Risks to Landscape and Mitigation Measures	72
Table 3.13	Summary of Risks to Human Health and Mitigation Measures	74
Table 3.14	Summary of High Level Risks and Mitigation Measures	77
Table 4.1	Regulatory and non-regulatory measures included in the Recommendation	85
Table 4.2	Summary of Relevant Directives and Regulations	87
Table 4.3	SEA Topics	89
Table 4.4	EIA and screening status in selected Member States	90

---

Figure 1.1:	Global Shale Resource Estimates	18
Figure 1.2	Onshore Sedimentary Basins with Prospectivity in Brazil	21
Figure 2.1:	Shale Gas Exploration and Production	26

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Appendix A	Terms of Reference	
Appendix B	Environmental Topic Chapters	
Appendix C	EU "Acquis Communautaire" Relating to Shale Gas	



# 1. Shale Gas

## 1.1 Overview

The exploration and production of shale gas represents a significant opportunity for many countries. It could help address energy security, reduce energy costs and meet the need for transitional energy sources in moving towards a low carbon future.<sup>13</sup> The United States (US) stands as an example of the huge economic impact that shale gas and oil can have and the transformational economic effects in the US have been influential in the energy policy thinking of many countries.<sup>14,15</sup>

Brazil has been ranked by the US Energy Information Administration as one of the top 10 countries that have collectively been estimated to contain nearly 80% of the world's estimated technically recoverable shale gas resource<sup>16</sup> is actively considering the potential for shale gas. The scale of the resource is potentially significant: its shale deposits could exceed its pre-salt gas reserves<sup>17</sup>. In consequence, shale gas could provide an alternative indigenous energy resource to supplement the current sources (which are reliant on hydro-electricity) and could help seek to cut dependency on liquefied natural gas (LNG) imports.

"*Discovering shale gas and other unconventional would be ideal*" for Brazil, Mauricio Tolmasquim, head of the government's energy policy agency (EPE) has been quoted as saying.<sup>18</sup>

Whilst hydraulic fracturing has been a drilling techniques used for many years as part of enhanced oil and gas recovery and for geothermal exploitation, its application to shale gas and oil has increased the potential volumes of water and chemicals used. In common with many other nations<sup>19</sup> considering the potential for unconventional oil and gas, the proposed development of shale gas in Brazil has also raised concerns regarding the potential effects on the environment<sup>20</sup>. These concerns centre on a number of factors:

- ▶ The risk of water contamination from hydraulic fracturing fluids, gas migration and surface wastewater;
- ▶ The risks to water resources from the use of water required for hydraulic fracturing, particularly in water scarce locations;
- ▶ Intensive development (in the manner of the extensive networks of well pads in the western US) could fragment sensitive ecologies;
- ▶ Methane emissions from wells and pipelines specifically, and increased fossil fuel consumption generally threaten to accelerate climate change;
- ▶ Induced seismic events arising from hydraulic fracturing could cause surface damage to property and people; and
- ▶ The combination of local impacts from development in less disturbed environments.

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<sup>13</sup> *Intergovernmental Panel on Climate Change (IPCC) Working Group 3, 5th Assessment Report, 2014*

<sup>14</sup> *House of Lords Economic Affairs Committee (2014), 3rd Report of Session 2013–14, The Economic Impact on UK Energy Policy of Shale Gas and Oil, 2014*

<sup>15</sup> *International Energy Agency (2013), World Energy Outlook 2013, page 115*

<sup>16</sup> *US Energy Information Administration (2013), Technically Recoverable Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41 Countries Outside the United States, 2013*

<sup>17</sup> *Peak Oil (2013), Brazil Advances in the Shale Game, 23<sup>rd</sup> December 2013* <http://peakoil.com/production/brazil-advances-in-the-shale-game>

<sup>18</sup> *Bloomberg Business, Brazil Prepares to Surprise Drillers This Time With Gas, 8<sup>th</sup> February 2013*

<http://www.bloomberg.com/news/2013-02-08/brazil-prepares-to-surprise-drillers-this-time-with-gas.html>

<sup>19</sup> *BIO Intelligence Service (2013), Presentation of the results of the public consultation "Unconventional fossil fuels (e.g. shale gas) in Europe" Brussels – 7<sup>th</sup> June 2013, for the European Commission and DG Environment,* [http://ec.europa.eu/environment/integration/energy/pdf/Presentation\\_07062013.pdf](http://ec.europa.eu/environment/integration/energy/pdf/Presentation_07062013.pdf)

<sup>20</sup> *Brazilian Academy of Sciences Letter to President Rouseff, 5<sup>th</sup> August 2013,* <http://jonathandeblog.com/2013/08/29/fracking-not-welcomed-with-open-arms-in-brazil/>

Concerns and opposition have been raised in a number of quarters. For example, in 2013 the Brazilian Academy of Sciences appealed in a public letter to Brazilian President Dilma Rousseff to suspend the 12th onshore licensing auction “*in light of the Brazilian government’s intention to pursue shale gas exploration*”. In December 2013, prosecutors in Piauí state requested a court injunction to ban the practice of hydraulic fracturing and in June 2014, a court upheld a ban in Paraná state, affecting existing licence holders.

At present, Brazil does not have specific regulations concerning shale gas or oil exploration and development although there is a resolution from ANP, the oil and gas licensing agency, for the management of risks to human health and the environment. Following an initiative of the Ministries of Mines and Energy (MME) and the Environment (MfE), a project aiming at “*analysing critical issues concerning the development and production of unconventional oil and gas resources and the definition of public policies for its environmentally safe exploitation*” has been set up under a federal program known as PROMINP (Mobilization Program of Industry in the Oil and Natural Gas). The expected result is likely to be a “white paper” summarizing the critical issues and the actions needed for solution/mitigation of the impacts related to the use of unconventional hydrocarbons; the proposition of normative and regulatory acts to the promotion of the activity; and the adoption of measures for communication and clarification of the main stakeholders (public prosecutors, scientific community, non-governmental organisations (NGOs)) and of society at large.

As a contribution to the PROMINP study, and in order to support the Brazilian government develop a strong regulation for the safe exploration of shale gas by drawing on international research, Amec Foster Wheeler Environment and Infrastructure UK Ltd (Amec Foster Wheeler) was appointed by the FCO under the 2014/15 Prosperity Fund to provide a review of the risks to the environment and human health of shale gas exploration and production and the approaches to managing these risks through regulatory frameworks in the UK and Europe.

## 1.2 Purpose of this Report

The purpose of this report is to:

- ▶ Provide an outline of the likely significant effects and principal risks associated with hydraulic fracturing as a means to extract shale gas, including geological risks, such as induced seismicity, environmental risks, such as groundwater contamination, and climate change risks, such as from fugitive methane emissions
- ▶ Provide a summary of the measures to avoid, minimise or mitigate the likely effects to ensure that the risks to the environment and human health can be effectively managed
- ▶ Provide a review of the regulations that are used in the UK and Europe to address the specific risks to the environment and human health from hydraulic fracturing.
- ▶ Outline what lessons can be learned from the regulatory frameworks employed in UK and Europe to the management of risks associated with hydraulic fracturing that could be relevant to the Brazilian context.

## 1.3 Scope of the Study

The study focuses on the likely significant effects and associated risks to the environment and human health arising from onshore extraction of shale gas from hydraulic fracturing only.

Offshore shale gas extraction and the subsequent use of shale gas will not be addressed.

The effects and risks of other types of unconventional oil and gas, such as virgin coalbed methane, have not been considered in the study; although may become important for future considerations of resources in Brazil.

The study does not consider the effects from conventional oil and gas extraction and production.



The focus on the effects and associated risks from onshore extraction of shale gas from hydraulic fracturing mirrors the focus of the Royal Society and Royal Academy of Engineering report on shale gas extraction in the UK, whose scope was an important influence on this study<sup>21</sup>.

### 1.3.1 Methodology

To undertake this work, the following activities have been completed:

- i. Terms of Reference were drafted and agreed with the FCO and ANP, to ensure that the subsequent project aims addressed the principal needs of the Brazilian government stakeholders and the PROMINP project.
- ii. Publicly accessible information and peer reviewed research was used as the basis to identify and assess likely significant effects and principal risks to the environment and human health associated with hydraulic fracturing for shale gas. This included:
  - ▶ Studies for the European Commission used as part of the evidence base as part of an evolving policy and regulatory position to managing the effects of hydraulic fracturing on human health and the environment.
  - ▶ Studies for the UK government, regulators and agencies related to the effects arising from unconventional oil and gas.
  - ▶ Written evidence, transcripts of committee meetings and reports from the UK House of Lords and the House of Commons committees of inquiry into the effects of shale gas.
  - ▶ Academic reports and peer reviewed publications on the effects from shale gas and hydraulic fracturing.
  - ▶ Studies produced by unconventional oil and gas developers, used as part of planning applications for exploration sites within the UK.
  - ▶ Other studies produced by NGOs, or single interest groups highlighting the potential effects of shale gas and hydraulic fracturing.
  - ▶ Other sources of information (such as online newspapers and journals).

Studies for the EC, government and academic reports were given greater weight than the other sources, although steps were taken, if such other information were used, to ensure any views could be corroborated. For the avoidance of doubt, no primary research was undertaken.

- iii. A synthesis of the information gathered was presented by environmental and human health topic, summarising the effects and associated risks. This included:
  - ▶ Effects on biodiversity and nature conservation;
  - ▶ Effects on land use and geology (including induced seismicity);
  - ▶ Effects on water resources (included increased demand, and potential contamination of surface and groundwater);
  - ▶ Effects on air quality;
  - ▶ Effects on climate change (included fugitive methane emissions);
  - ▶ Effects on waste arisings (including consideration of solid and liquid wastes, such as drill cuttings and flowback water);
  - ▶ Effects on cultural heritage (included archaeology);

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<sup>21</sup> *Royal Society and Royal Academy of Engineering* (2012), Shale gas extraction in the UK: a review of hydraulic fracturing (Terms of Reference, pp 8) June 2012

- ▶ Effects on landscapes;
  - ▶ Effects on human health of workers and potentially affected communities.
- iv. Drawing on the literature and information sourced, and for each of the topics considered, measures to manage the effects and associated risks of shale gas have been identified and assessed.
  - v. Drawing on the literature and information sourced, regulations and proposals used to address the specific risks to the environment and human health within Europe were reviewed and summarised highlighting lessons that could be learned that could be relevant to the Brazilian context.
  - vi. Provisional findings of the study were presented at PROMNIP (Project MA-09) technical workshop on 25th and 26th November at MME auditorium in Brasilia. Copies of the presentations were also provided to ANP, MME and FCO for comment.
  - vii. A draft report was completed and provided to FCO and ANP to circulate to key stakeholders. Comments were received from ANA, ANP, the Brazilian Geological Survey, EPE, Ibama and Shell. Whilst given the opportunity to comment, no response was received from MME, IBP or Petrobras.
  - viii. The report was then revised following receipt of stakeholder comment. The revised report was then subject to an independent peer review by Durham University.
  - ix. Following receipt of comments from Durham University, the report was revised and finalised for submission to the FCO, ANP and other participants in the PROMINP project.

### 1.3.2 Limitations

This study has the following limitations:

- ▶ The focus of the study is unconventional gas exploration and production that uses hydraulic fracturing and horizontal drilling (such as shale gas), referred to as 'unconventional gas' in this report. Other unconventional fossil fuels (such as tight gas, tight oil and coal bed methane) are not within the scope of the study;
- ▶ There are currently few active unconventional gas projects involving the use of hydraulic fracturing combined with horizontal drilling (such as shale gas) in the European Union (EU) so current evidence of European experience is limited. A number of studies for either the European Commission (EC) or member states have reflected this limited evidence base, and so have drawn more widely using studies from North America in particular, where experience of unconventional oil and gas exploration is extensive. However, whilst care has been taken to caveat such studies or draw attention to such limitations, caution needs to be applied when considering research which in part relates to historical practices that would not be relevant to the Brazilian regulatory and administrative setting;
- ▶ A number of technical (and other) measures to address the potential environmental and health risks have been identified. These have been drawn from a variety of studies for the EU, but which themselves are yet to be applied in the EU, and so their effectiveness remains, to some extent uncertain.
- ▶ The focus of the study was on water-based fracturing. Non-water-based and new technologies would require a separate assessment of risks and technical measures if these were to be considered as part of a risk management framework.

## 1.4 Shale Gas Resources and Reserves

### 1.4.1 Definitions

Natural gas produced from shale is often referred to as “unconventional”. What has qualified as “unconventional” at any particular time is a complex interactive function of resource characteristics, the available exploration and production technologies, the current economic environment, and the scale, frequency, and duration of production from the resource<sup>22</sup>. Unconventional gas can be considered to be gas trapped in formations that are atypical in terms of their geological location and characteristics.

The term “unconventional gas” actually covers three main types of natural gas resources: shale gas, tight gas and coalbed methane (also known as coal seam gas). Shale gas and tight gas are reservoir rocks with low permeability (<0.1 mD in shales versus >1 mD in conventional reservoir sandstones) which means that hydrocarbons are effectively trapped and unable to flow at rates to be commercial without additional engineering intervention. A combination of horizontal drilling and fracture stimulation technology is required to enable economic extraction of oil or gas from shale and other rocks with low permeability. Coalbed methane reflects the fact that virtually all coals contain some methane as the result of coal formation which either adsorbs into coal micropores (<2nm) or is dispersed in pore spaces. When pressure is reduced, methane gas is released from the coal, which diffuses through the coal matrix and flows through the fracture system of the coal bed.

“Conventional” oil and natural gas production refers to crude oil and natural gas that is produced by a well drilled into a geologic formation in which the reservoir and fluid characteristics permit the oil and natural gas to readily flow to the wellbore.

Hydraulic fracturing is the technique used to fracture rocks of low permeability which contain hydrocarbons (such as shale) by the injection of water at high pressure. Small particles (usually sand) are pumped into the fractures to keep them open when the pressure is released. This enables gas, previously trapped within the rock matrix to flow into the well. High-volume hydraulic fracturing (HVHF) is defined by the EC<sup>23</sup> as “*injecting 1,000 m<sup>3</sup> or more of water per fracturing stage or 10 000 m<sup>3</sup> or more of water during the entire fracturing process into a well*”.

### 1.4.2 Global Context

**Figure 1.1** is a map of basins with assessed oil and shale gas formations, taken from the US Energy Information Administration (US EIA)<sup>24</sup>. As can be noted, the distribution of shale gas and oil resources is spread throughout the world, with substantial resources in each continent.

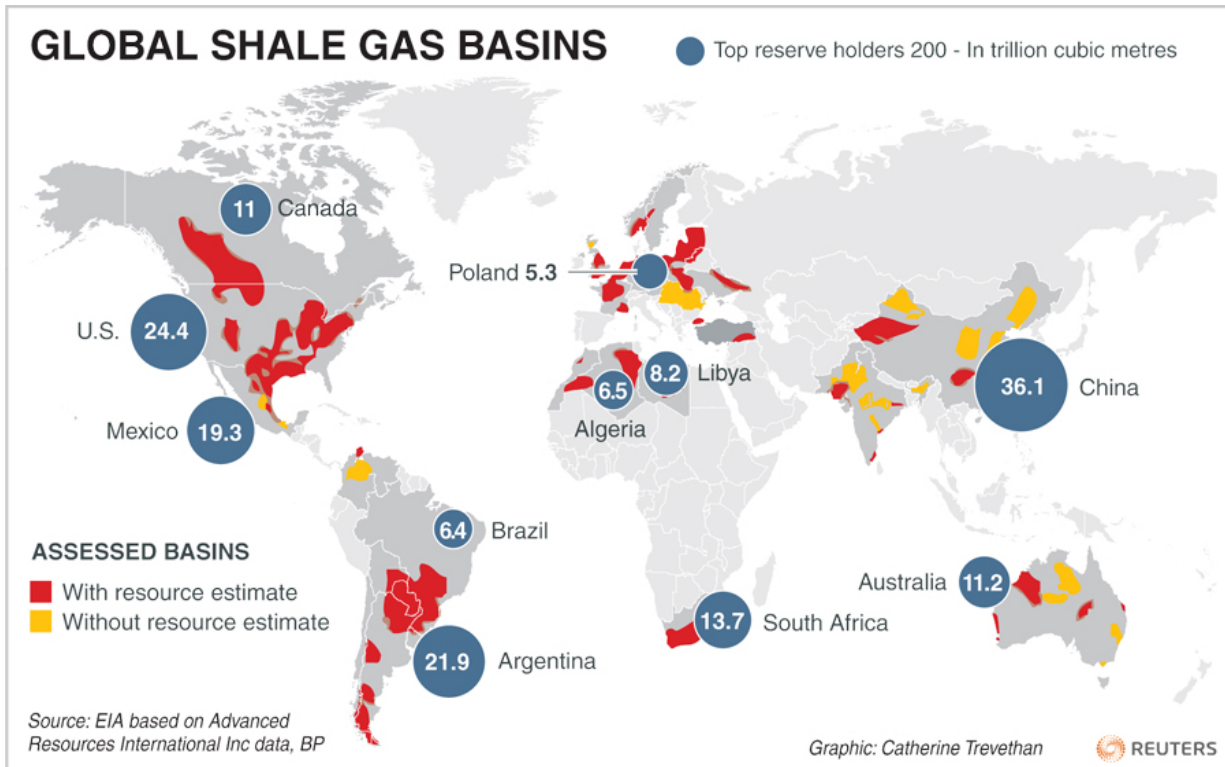
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<sup>22</sup> US Energy Information Administration Glossary, <http://www.eia.gov/tools/glossary/index.cfm?id=u>

<sup>23</sup> European Union (2014), Commission Recommendation of 22 January 2014 on minimum principles for the exploration and production of hydrocarbons (such as shale gas) using high-volume hydraulic fracturing (2014/70/EU), <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014H0070&from=EN>

<sup>24</sup> US Energy Information Administration (2013), Technically Recoverable Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41 Countries Outside the United States, 2013, <http://www.eia.gov/analysis/studies/worldshalegas/>

Figure 1.1: Global Shale Resource Estimates



In 2013, based on an assessment of 137 shale formations in 41 countries outside the US, the US EIA estimated<sup>25</sup> the technically recoverable shale oil and gas resources for the world as follows:

- ▶ 345 billion barrels (bbls) of world shale oil resources; and
- ▶ 7,299 trillion cubic feet (tcf) (207 trillion cubic metres (tcm)) of world shale gas resources.

By comparison, the globally technically recoverable resource of conventional gas has been estimated at 15,256 tcf (432 tcm)<sup>26</sup> so current estimates of shale gas represent some 32% of all Technically Recoverable Resources (TRRs) of gas.

Nearly 80% of the world’s estimated technically recoverable shale gas resources are found in 10 countries, listed in **Table 1.1**.

Table 1.1: Top 10 Countries with Technically Recoverable Shale Gas Resources (TRR)

Rank	Country	Shale gas (tcf)	Shale (tcm)
1	China	1,115	31.6
2	Argentina	802	22.7
3	Algeria	707	20.0
4	U.S.	665	18.8

<sup>25</sup> US Energy Information Administration (2013), Technically Recoverable Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41 Countries Outside the United States, 2013, <http://www.eia.gov/analysis/studies/worldshalegas/>

<sup>26</sup> House of Commons Energy and Climate Change Committee (2013), The Impact of Shale Gas on Energy Markets Seventh Report of Session 2012–13, para22, 2013

**Table 1.1 (continued): Top 10 Countries with Technically Recoverable Shale Gas Resources (TRR)**

Rank	Country	Shale gas (tcf)	Shale (tcm)
5	Canada	573	16.2
6	Mexico	545	15.4
7	Australia	437	12.4
8	South Africa	390	11.0
9	Russia	285	8.1
10	Brazil	245	6.9
	World Total	7,299	206.6

Based on U.S. shale production experience, the recovery factors used ranged from 20 percent to 30 percent, with values as low as 15 percent and as high as 35 percent being applied in exceptional cases.

The UK Energy Research Centre (UKERC) conducted a comprehensive review of 62 studies that provided original estimates of regional and global shale gas resources<sup>27</sup>. This suggested that the US holds around 10% of the global TRR of shale gas, while Europe holds around 8%. Shale gas resources could however be much more important at the regional level. For example, shale gas may represent 34% of the remaining TRR of natural gas in China, 36% in Canada, 48% in Europe and 31% in the US. For Europe currently, 89% of annual gas demand is imported and one estimate suggests shale gas could reduce European import dependency by up to 27% by 2035<sup>28</sup>. If such estimates are borne out, shale gas would represent a significant alternative to importing gas from other regions and provide a degree of energy independence, security and autonomy.

Rapid growth in the production of shale gas in the US since 2008 has occurred following advances in horizontal drilling and hydraulic fracturing. The International Energy Agency (IEA) announced in 2009 that unconventional gas had "changed the game" in North America and elsewhere<sup>29</sup>. In 2012, shale gas constituted 35% of total US gas production and it is forecast that it will account for 50% of total US gas production by 2040<sup>30</sup>.

Recent experience<sup>31</sup> with shale gas in the US and other countries suggests that economic recoverability can be significantly influenced by above-the-ground factors as well as by geology. Key positive above-the-ground advantages in the US and Canada that may not apply in other locations include:

- ▶ Private ownership of subsurface rights that provide a strong incentive for development;
- ▶ Availability of many independent operators and supporting contractors with critical expertise and suitable drilling rigs and, pre-existing pipeline infrastructure; and
- ▶ The availability of water resources for use in hydraulic fracturing.

<sup>27</sup> *McGlade, C, J Speirs, and S Sorrell (2012), A review of regional and global estimates of unconventional gas resources: A report to the Energy Security Unit of the Joint Research Centre of the European Union. 2012*

<sup>28</sup> *Poyry (2013), Macroeconomic effects of European Shale Gas Production, November 2013*

<sup>29</sup> *IEA (2009), World Energy Outlook 2009, Executive Summary*

<sup>30</sup> *US Energy Information Administration (2013), Annual Energy Outlook 2013, 2013*

<sup>31</sup> *House of Lords Economic Affairs Committee (2013), 3rd Report of Session 2013–14, The Economic Impact on UK Energy Policy of Shale Gas and Oil; UKERC, A review of regional and global estimates of unconventional gas resources, A report to the Energy Security Unit of the Joint Research Centre of the European commission, September 2012; US Energy Information Administration, Annual Energy Outlook 2013, 2013*

In consequence, the extent to which the current technically recoverable global estimates of shale gas will be realised and the pace with which they will be extracted remains uncertain; however, the North American experience suggests that shale gas could be a significant factor in meeting future global energy needs.

There is currently no reported offshore exploration activity for unconventional gas anywhere in the world. Offshore shale gas resources are excluded from global estimates. This is unlikely to change in the near future because there are a number of logistical and operational hurdles which make the cost of exploration and development uneconomic<sup>32</sup>.

#### 1.4.3 The Shale Gas Opportunity in Brazil

Brazil is thought to have considerable potential for unconventional gas production. The US Energy Information Administration 2013 assessment estimates the shale gas TRR as being 6.9 trillion cubic metres<sup>33</sup>. Brazil's shale and tight gas potential exists primarily in three prospective basins: Parnaíba, Parnaíba, and Recôncavo. These are three of 18 known onshore sedimentary basins, of which, 14 basins may have petroleum source rocks. Another potentially significant resource, the São Francisco Basin, exists in Minas Gerais State. Consultants at Wood Mackenzie have estimated that the basin could hold up to 17 trillion cubic metres of gas<sup>34</sup>; however, estimates of TRR of this basin are uncertain.

**Figure 1.2** presents the onshore sedimentary basins with prospectivity for shale gas in Brazil.

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<sup>32</sup> *House of Commons Energy and Climate Change Committee* (2013), *The Impact of Shale Gas on Energy Markets Seventh Report of Session 2012–13*, para22, 2013

<sup>33</sup> *US Energy Information Administration* (2013), *Technically Recoverable Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41 Countries Outside the United States*, 2013, <http://www.eia.gov/analysis/studies/worldshalegas/>

<sup>34</sup> *IM*, *Shale Gas Prospects in Brazil*, August 23, 2013



Figure 1.2 Onshore Sedimentary Basins with Prospectivity in Brazil



Image courtesy of CARBMAP, Brazil

### Oil and Gas Licensing in Brazil

According to Article 176 of the Brazilian Federal Constitution, oilfields and other mineral resources belong to the state. Article 3 of Law No. 9.478 (the Petroleum Law) guarantees ownership of oil deposits, natural gas and other fluid hydrocarbons to the Federal Republic of Brazil while Article 21 states that the Federal Republic owns exploration and production rights on Brazilian territory. Concession holders are however granted ownership of extracted oil and gas (Article 26, Petroleum Law), with the proviso that they must pay an equivalent share of 0.5 - 1 % of the production to the landowner (Article 52, Petroleum Law). Under the Petroleum Law concession contracts allow both exploration and exploitation (Article 24, Petroleum Law). During the exploration phase, the company can evaluate and conduct test drilling in order to assess the economic value of the hydrocarbons (Article 24, Petroleum Law). Once the production phase has started, further development can take place (Article 24 Paragraph 2 Petroleum Law). Concession contracts are awarded by the Brazilian National Agency of Petroleum, Natural Gas and Biofuels (ANP) via licensing

rounds. Companies can participate in the bidding procedure as operators or non-operators. Multinational companies must form a partnership with a company registered/based in Brazil to sign a concession contract.

The 12th licensing round offered onshore exploration that included unconventional oil and gas opportunities and comprised of 240 blocks in seven basins: 110 blocks covering 164,477 km<sup>2</sup> located in the Acre, Parana, Parecis, Parnaíba, and Sao Francisco Basins; and 130 blocks covering 3,870 km<sup>2</sup> in the mature Reconcavo and Sergipe-Alagoas Basins. Subsequently, ANP granted 72 onshore blocks totalling 47,430 km<sup>2</sup>, in five sedimentary basins (Acre, Parana, Parnaíba, Reconcavo and Sergipe-Alagoas) with some concessions signed by June 5th 2014<sup>35</sup>. Analysis and assessment is still needed to determine if the economics makes drilling feasible.<sup>36</sup> It is also noted that the majority (but not all) of the licensed blocks are in more remote areas of the country. In consequence, in addition to considering whether the areas are geologically suitable, infrastructure, such as roads and pipelines would need to be built or substantially improved. There may also be a lack of local equipment and services for hydraulic fracturing, besides a trained workforce which could affect the pace of any future development. Whilst acknowledging the challenges, the IEA World Energy Outlook projections have anticipated that unconventional gas production will start to gather pace in the early 2020s, adding some 6 billion cubic metres to Brazilian's annual supply of gas by 2035.

#### 1.4.4 Concerns of Brazilian Society

The Brazilian Academy of Sciences has argued that: *"although the USA International Energy Agency suggest that the occurrence of shale gas reserves is 7.35 trillion cubic metres in the geological basins of Paraná, Parnaíba, Solimões and Amazonas, Reconcavo and São Francisco .... it should be noted, that these forecasts are totally preliminary, especially due to the petrographic, structural and geomechanical characteristics of the geology considered in this calculation, which can decisively influence the economy of their exploitation"*<sup>37</sup>.

The Parána shale basin overlaps a large section of the Guarani Aquifer, one of the world's largest aquifers. This natural resource, which extends into Argentina, Paraguay and Uruguay is governed by the Guarani Aquifer Agreement (GAS), signed by the four countries in August 2010, with all four parties undertaking to protect its sustainable common use and respect the obligation of not *"causing significant harm to the other Parties or the environment."* In their letter requesting that shale gas exploitation be set aside from the licensing process, the Brazilian Academy of Sciences highlighted that: *"A great part of the reserves of gas/shale oil of the Parana Basin in Brazil and part of the reserves in the north of Argentina are just below the Guarani Aquifer, the major source of high quality potable water of the South America..... In this sense it is not reasonable that areas of exploitation are immediately offered to companies, excluding the scientific community and the other regulatory agencies of the country from the access and discussion of all information available through studies by Universities and research institutes. Such studies give a better knowledge of the intrinsic properties of the ores and their exploration conditions, as well as the environmental consequences of this activity that may largely overcome its possible social gains"*.

The concessions awarded for the development of unconventional fossil fuels in Acre in the Amazon basin are situated in the middle of indigenous lands. Large parts of the Amazon basin are classified as a conservation area, including areas adjacent to the areas licensed for shale development. There are concerns that shale exploration in the Amazon will add to existing pressures on the forests, in an area that has already suffered from high levels of deforestation as a result of ever-growing demand for land<sup>38</sup>.

It is also noted that the final declaration of the World Indigenous Peoples Conference on Territories, Rights and Sustainable Development, which took place in Rio in 2012, called on the UN, governments and corporations to abandon *"false solutions to climate change"* such as *"hydraulic fracturing"* which *"endanger the future of life as we know it"*<sup>39</sup>.

<sup>35</sup> <http://www.brasil-rounds-data.anp.gov.br/relatoriosbid/Bacia/ConsolidadoBaciaDesktop> and *IMI*, Outlook for Brazil's Oil and Gas Onshore Segment, May 16, 2014

<sup>36</sup> *IMI*, Shale Gas Prospects in Brazil, August 23, 2013

<sup>37</sup> *Brazilian Academy of Sciences Letter to President Rouseff*, August 5 2013, <http://jonathandeaiblog.com/2013/08/29/fracking-not-welcomed-with-open-arms-in-brazil/>

<sup>38</sup> *Leydimere J C Oliveira et al* (2013), Large-scale expansion of agriculture in Amazonia may be a no-win scenario, *Environ. Res. Lett.* 8 02402, <http://iopscience.iop.org/1748-9326/8/2/024021/article>

<sup>39</sup> <http://www.ienearth.org/kari-oca-2-declaration/>

The Federal Prosecution Office (MPF) in states of Maranhão, Bahia and Paraná filed suits (with preliminary injunction granted) to prohibit the practice of hydraulic fracturing, affecting existing licence holders. These prohibitions were implemented in response to concerns about water and ground contamination. ANP and MME have appealed against this decision but the suspension is still currently valid. It is understood that the MPF is requiring further evidence and also requesting an environmental assessment of the sedimentary area (an AAAS), as defined in Ordinance 198/2012<sup>40</sup>, before any unconventional exploration activities may go ahead.

#### 1.4.5 Need for Regulation

Following consultation on a draft version before the 12<sup>th</sup> licensing round, ANP published a specific resolution (Resolution ANP 21/2014) on 11<sup>th</sup> April 2014, aiming to regulate “*well drilling followed by the employment of the technique of hydraulic fracturing for the production of unconventional resources*”. The Resolution takes into account both operational safety issues, as well as procedures to mitigate environmental impacts. The resolution defined “*hydraulic fracturing in unconventional reservoir*” as the “*injection technique of pressurized fluids in a well, in volumes above 3,000 m<sup>3</sup>, with the objective of creating fractures in a particular rocky formation whose permeability is less than 0.1 mD, enabling the recovery of hydrocarbons contained in this formation*”.

The Resolution establishes mandatory adoption of an environmental management system that contains a plan for the control, treatment and disposal of the generated effluents. Additionally, the Resolution requires the performance of preliminary studies, which are necessary for the approval of the operations by ANP, such as fracturing simulations and risk analysis. In relation to the performance of the activity itself, the Resolution provides standards to be complied with and determines the preparation of an emergency response plan. The Resolution also states that the approval of hydraulic fracturing in unconventional reservoirs by ANP will depend on, among other requirements, the “*presentation by the operator of the environmental permit issued by the competent agency, with specific authorization for operations of hydraulic fracturing in unconventional reservoir, when applicable*”.

The environmental legislation so far does not include any requirement of specific studies or procedures relating to hydraulic fracturing at the federal or state level. In both cases, such studies and procedures might be required as a condition for approval and issuing of environmental permits previous of drilling and production. It is also possible that such studies and procedures will be defined in the scope of a set of new types of permitting specifically related to drilling and production of unconventional. It is possible that these requirements or new types of permits will be set down by a new resolution, or by an ordinance or other specific rule, in the case of federal competence.

## 1.5 Report Contents

The remainder of this report contains:

- ▶ **Section 2:** Provides a brief outline of what shale and shale gas is, and a description of the likely activities involved in the stages of shale gas exploration and production.
- ▶ **Section 3:** Provides a summary of the potential effects arising from the stages of exploration, production and decommissioning associated with shale gas. Likely risks and possible avoidance, minimisation and mitigation measures are identified for each topic area considered. The background research used to compile each of these topic summaries is contained in **Appendix B**.
- ▶ **Section 4:** Provides an overview of the regulatory framework for shale gas exploration and development in Europe.
- ▶ **Section 5:** Provides an outline of the policy and regulatory framework for oil and gas in Brazil

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<sup>40</sup> The ordinance requires the adoption of prior environmental evaluation (“environmental assessment of sedimentary area”), similar to Strategic Environmental Assessment leading to the identification of areas within the sedimentary basin that are either suitable, not suitable areas or under moratorium (because the lack of information) for exploration and production.



- ▶ **Section 6:** Provides an outline of the potential implications for Brazilian regulations regarding the environmental and health effects of shale gas.

## 2. Shale Exploration and Production

### 2.1 Introduction

This section describes briefly what shale and shale gas is, and then provides a description of the likely activities involved in the stages of shale gas exploration and production. The effects arising from the activities involved in each stage are then summarised in Section 3, with substantially more detail provided in **Appendix B** of this report.

### 2.2 Shale and Shale Gas

In conventional oil and gas accumulations, shales comprise the source rock from which hydrocarbons are generated following burial. Through geological time, these hydrocarbons migrate from the source rock, through carrier beds and ultimately accumulate in porous reservoirs (typically sandstone or carbonate) in discrete traps, typically located in structural highs on the margins of the basin centres. In the case of unconventional hydrocarbon accumulations (such as shale gas), shale acts as both source and reservoir rock, with the extensive basin centres becoming the exploration targets.

Shale<sup>41</sup> is predominantly comprised of very fine-grained clay particles deposited in a thinly laminated texture, but shale gas production may also come from layers of limestone or thin clastic beds within the gross shale sequence. The clay particles fall out of suspension and become interspersed with organic matter, which is measured as the rock's total organic carbon content (TOC). Through deep burial, these muddy strata are compacted and the pore water is expelled resulting in a low-permeability, potentially layered rock called 'shale', which "*describes the very fine-grained and laminar nature of the sediment, not the rock composition (which is layered). Each of these layers creates a barrier to fluid migration, and this stacked system, called 'composite layering', is an effective vertical seal*"<sup>42</sup>.

Matrix permeabilities (the ability of fluids to pass through them) of typical shale are very low compared with conventional oil and gas reservoirs ( $<<0.1$  mD in shales versus  $>0.1$  mD in conventional reservoir sandstones, with shale gas reservoirs usually measured in nanodarcies) which means that, in shale, hydrocarbons are effectively trapped and unable to flow or be extracted under normal circumstances, and they are usually only able to migrate to conventional traps over geological time.

#### 2.2.1 Shale Gas Extraction

Additional stimulation by hydraulic fracturing (often termed 'fracking') is required to increase permeability locally around the well (see **Figure 2.1**). Once a well has been drilled and cased ('completed'), explosive charges fired by an electric current perforate holes along selected intervals of the well within the shale formation from which shale gas is produced ('production zone'). Pumps are used to inject fracturing fluids, consisting of water, sand ('proppant') and chemicals, under high pressure into the well. The injection pressure generates stresses in the shale that exceed its tensional strength, opening up existing fractures or creating new ones. The fractures typically extend a few hundred metres into the rock<sup>43</sup> and the newly created fractures are propped open by the sand. Additional fluids are pumped into the well to maintain the pressure in the well so that fracture development can continue and proppant can be carried deeper into the formation<sup>44</sup>. A well may be too long to maintain sufficient pressure to stimulate fractures across its entire length. Plugs may be inserted to divide the well into smaller sections ('stages'). Stages are fractured sequentially, beginning with the stage furthest away and moving towards the start of the well. After

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<sup>41</sup> 'Shales' targeted by the shale gas industry in the USA are more likely to be siliceous oozes (now chert) or marls (fine grained carbonate clay mixtures)

<sup>42</sup> *British Geological Survey* (2013), The Carboniferous Bowland Shale gas study: geology and resource estimation, 2013

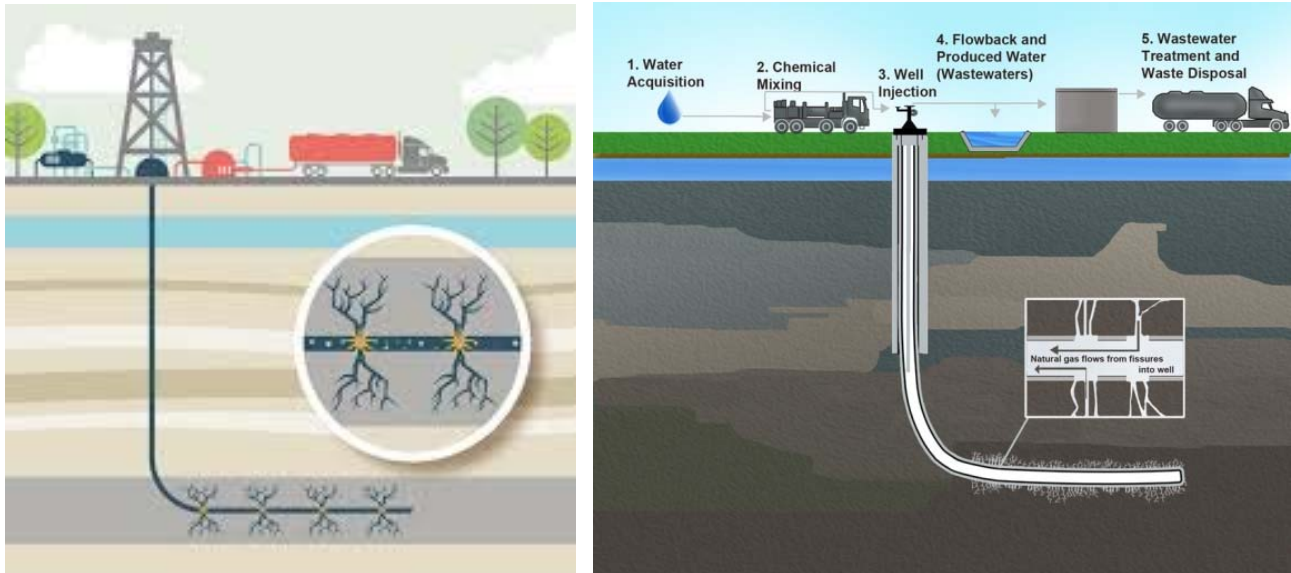
<sup>43</sup> *Davies et al* (2012), Hydraulic fractures: how far can they go?, *Marine and Petroleum Geology* (in press). [http://www.dur.ac.uk/resources/dei/JMPG\\_1575.pdf](http://www.dur.ac.uk/resources/dei/JMPG_1575.pdf)

<sup>44</sup> *American Petroleum Institute* (2009), "Hydraulic Fracturing Operations – Well Construction and Integrity Guidelines (HF1) – Upstream Segment". October 2009. Available via <http://www.api.org>



fracturing, the plugs are drilled through and the well is depressurised. This creates a pressure gradient so that gas flows out of the shale into the well.

**Figure 2.1: Shale Gas Exploration and Production**



(Source: Public Health Watch and U.S. Environmental Protection Agency), NB: figures are illustrative and not to scale.

Fracturing fluid flows back to the surface ('flowback water') also containing saline water with dissolved minerals from the shale formation ('formation or produced water'). Fracturing fluid and formation/produced water returns to the surface over the lifetime of the well as it continues to produce shale gas. Although definitions vary, flowback water and produced water collectively constitute 'wastewaters'.

## 2.3 Stages of Shale Gas Extraction

The project life cycle for shale gas extraction consists of differing stages. Each stage contains a variety of activities, many of which are common to both conventional and unconventional exploration and development. Whilst the number of stages described in the literature<sup>45</sup> varies, to permit a fuller description of activities and subsequently of the effects, the following six stages have been used (based on the stages used in the SEA of onshore oil and gas licensing<sup>46</sup>):

- ▶ Non-intrusive exploration;
- ▶ Exploration drilling and hydraulic fracturing;
- ▶ Production development;
- ▶ Production/operation/maintenance;
- ▶ Decommissioning of wells;
- ▶ Site restoration and relinquishment.

The stages are described in more detail in the following subsections.

<sup>45</sup> Ricardo AEA (2014), Unconventional Gas in England: Description of infrastructure and future scenarios, Report for Environment Agency, Ricardo-AEA/R/ED58661 February 2014, Amec et al (2014), Technical support for assessing the need for a risk management framework for unconventional gas extraction: final report to European Commission and DG Environment, August 2014; AEA et al (2012) Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing. a report for the European Commission AEA/R/ED57281; Tyndall Centre for Climate Change (2011), Shale gas: a provisional assessment of climate change and environmental impacts, January 2011

<sup>46</sup> Amec (2013), Strategic Environmental Assessment for Further Onshore Oil and Gas Licensing: Environmental Report, report for DECC, December 2013



### 2.3.1 Stage 1: Non-Intrusive Exploration

Stage 1 of the unconventional oil and gas exploration and production lifecycle comprises of non-intrusive activities including site identification, site selection and the securing of regulatory consent. These activities would be largely desk-based but could include the completion of geological mapping and sampling of exposures if available followed by geochemical, petrographic and geomechanical testing; ambient monitoring (noise and air pollution) as well as mapping of the hydrological connectivity of the proposed site and transport surveys to inform the modelling of any effects from vehicle movements as part of any planning application. Ecological surveys are also likely to be required to establish a baseline from which to measure any potential effects and to identify any species that require specific management and care.

Seismic testing would be undertaken during this stage. Seismic exploration uses artificially-generated sound ('seismic') waves to image sub-surface geological conditions. A vibration source is used to generate seismic waves at or near the surface (typically dynamite charges arranged in an array or a large vibrating plate attached to the base of a heavy duty vehicle, see below). Receiving devices called 'geophones' are placed in a geometric array on the surface to detect the seismic signal that is partially reflected back from subsurface geological features, such as changes in rock type or faults. 2D seismic exploration involves acquiring seismic data along a single line of geophones to detect the reflected seismic energy generated by the vibration source. It gives you data through a two-dimensional, or 2D, vertical cross-section. 3D surveys use a grid of geophones and vibration source points to gather seismic data over an area rather than a single cross-section, and from a range of different angles. This essentially provides a 3D picture of subsurface conditions resulting in much more detailed information for building into the geological model.

Vibroseis is a commonly used method of seismic survey and involves the employment of large truck mounted vibrator units as well as support vehicles for data recording. The truck moves along slowly stopping every 6 to 20 metres to lower the plate and produce a vibration. Geophones are placed along the same alignment on the surface to receive the seismic data.

Construction of temporary tracks/roads may be required to facilitate site access for vibrator unit vehicles (should vibroseis be undertaken); however, temporary access routes can also be made from materials such as high density polyethylene panels.

### 2.3.2 Stage 2: Exploration Drilling and Hydraulic Fracturing

#### Well Site and Pad Development

Once a site has been identified, site preparation activities will take place. Physical works will include the removal of vegetation and levelling an area of adequate size and preparing the surface to support movement of heavy equipment and heavy goods vehicles (HGVs) delivering drilling equipment and delivering/removing fracturing fluids. Ground surface preparation would typically involve staking, grading, stripping and stockpiling of topsoil reserves. A well pad would then be constructed on the levelled site using compacted aggregate laid on an impermeable membrane and geotextile layer. Erosion and sediment control structures would be constructed around the site, along with bunds for screening and noise attenuation and pits as needed for retention of drilling fluid and, possibly, freshwater. Surface water runoff would be collected and attenuated via perimeter ditches.

The size of well pads at this stage vary but occupy approximately 1 - 2 hectares. For example, Cuadrilla, a UK independent oil and gas exploration company is currently proposing to develop a number of unconventional wells in Lancashire (UK). For one exploration site, the proposals include a 1.55 hectare well pad plus a further hectare of surrounding surface works. The remainder of the Cuadrilla site is to comprise a further 5.5 hectares for surface water collection ditches, landscaped bunds, fencing and pipelines<sup>47</sup>.

Well pad equipment includes pits, impoundments, tanks, hydraulic fracturing equipment, reduced emission completion equipment, dehydrators and production equipment such as separators, brine tanks. Additionally, construction of access roads and pipelines would be required. Pipelines may be buried. In the US, these

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<sup>47</sup> See: *Cuadrilla Bowland Ltd (2014), Temporary Shale Gas Exploration, Preston New Road, Lancashire: Environmental Statement p.25* at: [http://www.cuadrillaresources.com/wp-content/uploads/2014/07/PNR\\_ES\\_Vol1\\_Environmental\\_Statement.pdf](http://www.cuadrillaresources.com/wp-content/uploads/2014/07/PNR_ES_Vol1_Environmental_Statement.pdf)

associated roads and facilities are estimated<sup>48</sup> to account for on average about 1.6 hectares of the land area associated with each well pad for the life of the wells.

### Seismic Arrays

Surface seismic monitoring arrays, comprising of passive seismic monitoring devices, would be installed to collect seismic data to provide a baseline and to monitor the induced seismic effects from fluid injection. For the proposed Cuadrilla exploratory drilling site in Lancashire, this has included eight surface arrays and 80 buried arrays spread over a 25km<sup>2</sup> area. Surface arrays require shallow pits some 0.8m deep covered by a manhole cover, each with a small junction box (occupying 1m<sup>2</sup> and 0.5m deep) with an estimated time of construction 1-2 days. Buried arrays will be drilled boreholes, approximately 100m deep drilled by a truck mounted rig, capped with a concrete pad and an inspection collar, requiring around 4 days to install. The arrays will be used to measure the induced seismicity that could arise from the hydraulic fracturing with results compared, in the UK, to a “traffic light” system<sup>49</sup>. The UK uses the following thresholds:

- ▶ ‘Green’ would mean magnitude of 0 M<sub>L</sub> which would mean injection could proceed as planned;
- ▶ ‘Amber’ would mean a magnitude of between 0 to 0.5 M<sub>L</sub> would mean that injection could proceed with caution, possibly at reduced rates and that monitoring is intensified; and
- ▶ ‘Red’ is defined as a magnitude 0.5 M<sub>L</sub> or higher, where injection is suspended immediately and the pressure of fluid in the well is also reduced immediately.

The level of 0.5 M<sub>L</sub> is well below what could be felt at the surface.

### Drilling

Wells for shale gas development using hydraulic fracturing in the US are drilled by rotary rigs - these are typically either 12 to 14 metre “singles” or 21 to 24 metre high “doubles”. These rigs can hold either one or two joined lengths of drill pipe. “Triple” rigs are over 30 metres high and may see increasing use for shale gas development. Within the UK, recent proposals have included drill rigs in the range of 30-50m high.<sup>50</sup>

Operators may use a single drilling rig for the entire wellbore or alternatively may make use of two or three rigs in sequence- but only one rig will drill at any one time. Typically, the rig used for the vertical portion of the well bore is smaller than that used to drill the horizontal section- a triple rig may be used for this purpose. Auxiliary equipment includes tanks for water, fuel and drilling mud, generators, compressors, solids control equipment, choke manifold, accumulator, pipe racks, and an office space. Fuel storage tanks associated with larger rigs would need to be able to accommodate about 45,000 to 54,000 litres.

A series of holes (‘wellbores’) of decreasing diameter and increasing depth are drilled and lined with steel casing joined together to form continuous ‘strings’ of casing:

- ▶ **Conductor casing.** Set into the ground to a depth of approximately 30 metres, the conductor casing serves as a foundation for the well and prevents caving in of surface soils.
- ▶ **Surface casing.** The next wellbore is drilled and sealed with a casing that runs past the bottom of any freshwater bearing zones (including but not limited to drinking water aquifers) and extends all the way back to the surface. Cement is pumped down the wellbore and up between the casing and the rock until it reaches the surface.

<sup>48</sup> *New York State Department of Environmental Conservation* (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, September 2011

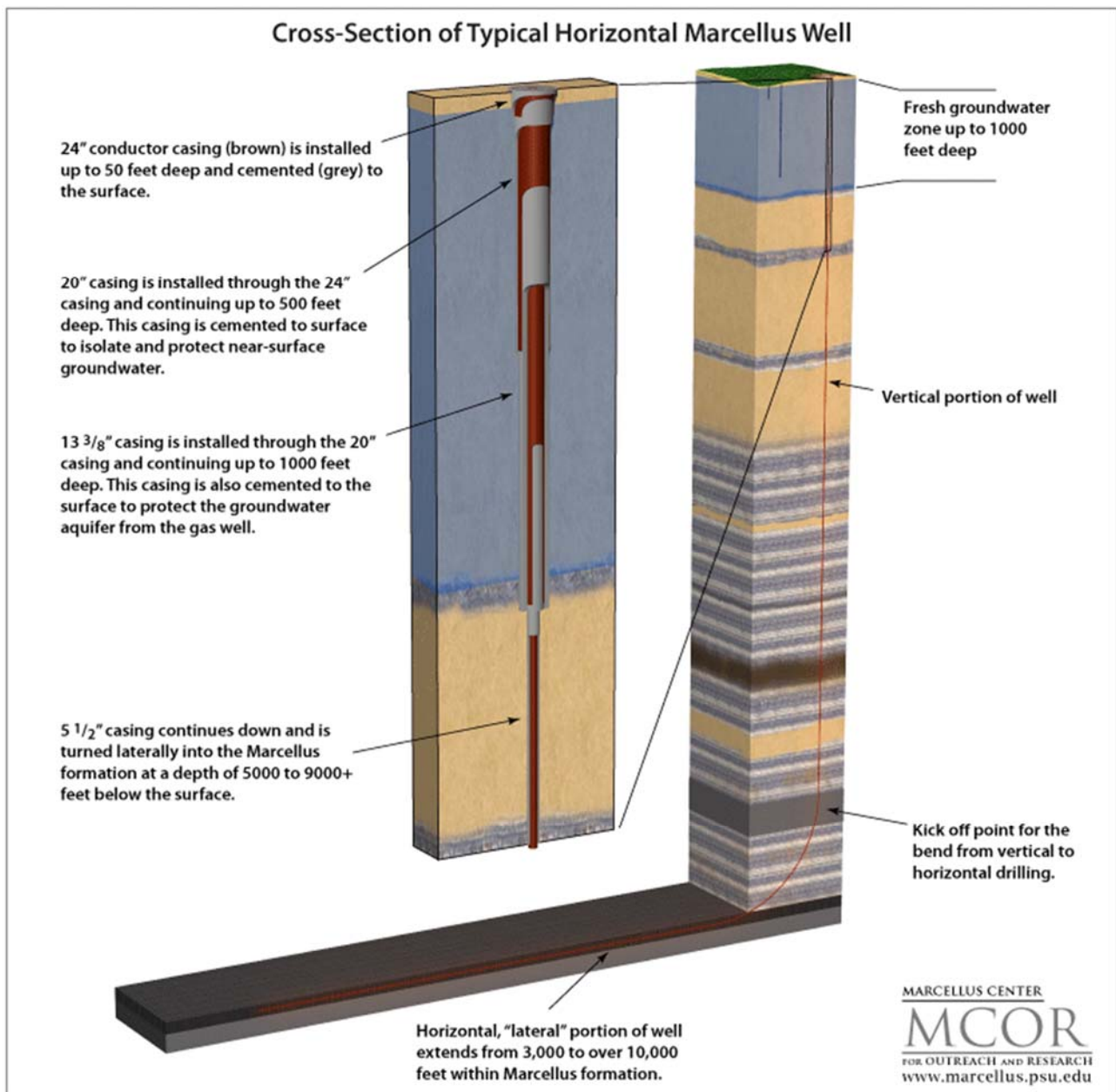
<sup>49</sup> DECC (2012), Ministerial Statement by Edward Davey: Exploration for shale gas, 13 December 2012, <https://www.gov.uk/government/news/written-ministerial-statement-by-edward-davey-exploration-for-shale-gas> and <https://www.gov.uk/government/publications/traffic-light-monitoring-system-shale-gas-and-fracking>

<sup>50</sup> See: *Cuadrilla Bowland Ltd* (2014), Temporary Shale Gas Exploration, Preston New Road, Lancashire: Environmental Statement p.39 at: [http://www.cuadrillaresources.com/wp-content/uploads/2014/07/PNR\\_ES\\_Vol1\\_Environmental\\_Statement.pdf](http://www.cuadrillaresources.com/wp-content/uploads/2014/07/PNR_ES_Vol1_Environmental_Statement.pdf)

- ▶ **Intermediate casing.** Another wellbore is drilled and lined by an intermediate casing to isolate the well from non-freshwater zones that may cause instability or be abnormally pressurised. The casing may be sealed with cement typically either up to the base of the surface casing or all the way to the surface.
- ▶ **Production casing.** A final wellbore is drilled into the target rock formation or zone containing shale gas. Once fractured, the shale gas produces into the well. This wellbore is lined with a production casing that may be sealed with cement either to a safe height above the target formation up to the base of the intermediate casing; or all the way to the surface, depending on well depths and local geological conditions.

**Figure 2.1** shows the completed casing string for a completed horizontal well, highlighting the importance of overlap and cementation to the surface.

**Figure 2.1: Cross Section of Typical Horizontal Well, Detailing Casing**



Section 4.4 of the Oil and Gas UK Well Integrity Guidelines outlines the detailed requirements for casing design<sup>51</sup> and the API requirements note the specific casing and cementing requirements for hydraulic fracturing.

In order to control where fracturing occurs within the horizontal component of the wellbore, the well case must be perforated at target locations. These perforations can be set into the casing using 'frac sleeves' which can be mechanically opened. In the event that these sleeves fail to open, the casing can be perforated using abrasive jetting techniques or through the use of small shaped explosive charges.

The last steps prior to fracturing are the installation of a wellhead which is designed and pressure-rated for the fracturing operation. The system is then pressure tested.

### Hydraulic Fracturing

Once the casing has been perforated and tested, fracturing fluid can be pumped into the well at high pressure causing fractures in the rock. Hydraulic fracturing will be performed over multiple stages over lengths of casing (for example, Cuadrilla proposed to perform between 30-45 hydraulic fractures, each over approximately 50m of casing length). Pressure testing and monitoring will take place in advance of and during each fracture stage (including):

- ▶ Equipment rig up and testing, including testing the integrity of all high pressure equipment (fracturing wellhead, flowlines, manifolds, piping and pump equipment).
- ▶ Monitoring pressure on the production string and all well annuli during rig up and testing.
- ▶ Continuously monitor and recording the pressures in the annulus between the intermediate casing and the production casing and records are maintained.
- ▶ Monitoring any adjacent or offset wells for pressure on the production string and other well annuli, as required.

The range of fluid pressures used in high volume hydraulic fracturing is typically 10,000 to 15,000 psi (700 – 1000 bar), and exceptionally up to 20,000 psi (1400 bar). This compares to a pressure of up to 10,000 psi (700 bar) for a conventional well.

For hydraulic fracturing, JRC (2013) suggests that a horizontal well would require 15,000 m<sup>3</sup> of fracture fluid and the well would be fractured twice during its lifetime (initial fracturing and one refracture)<sup>52</sup>. However, AEA (2012) note that horizontal shale gas wells typically use 10,000 to 25,000 m<sup>3</sup> water per well, based largely on US analysis<sup>53</sup>. The AEA report also summarised the limited evidence from activity in Europe, which gave a range: 9000 – 29,000 m<sup>3</sup>/well (from Cuadrilla in Holland); 1,600m<sup>3</sup> (Halliburton at Lubocino-1 well in Poland); 7,000m<sup>3</sup> – 8,000m<sup>3</sup> (the Danish Energy Agency). Industry estimates<sup>54</sup> suggest ranges of 10,000m<sup>3</sup> to 20,000m<sup>3</sup>. Cuadrilla indicate that it is likely they could use between 22,375m<sup>3</sup> and 28,000m<sup>3</sup> per well in their planning application<sup>55</sup> for the exploratory drilling site in Lancashire.

In order to induce and maintain permeability, and generate productive fractures, chemicals are added to the water to create hydraulic fracturing fluid, the composition of which is dependent on site specific conditions including the underlying geology. Evidence suggests that up to 750 chemicals were used between 2005 and 2009 in shale gas drilling throughout the US. Typically, fracturing fluid includes<sup>56</sup>:

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<sup>51</sup> <http://www.oilandgasuk.co.uk/publications/publications.cfm>. See also API HF1 – Hydraulic Fracturing Operations – Well Construction and Integrity Guidelines (<http://api.org/publications-standards-and-statistics.aspx>).

<sup>52</sup> Gandosi, L (2013) An overview of hydraulic fracturing and other formation stimulation technologies for shale gas production, A Joint Research Centre report (EUR 26347 EN)

<sup>53</sup> AEA et al (2012), Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe, report for the European Commission AEA/R/ED57281

<sup>54</sup> <http://www.total.com/en/energies-savoir-faire/petrole-gaz/exploration-production/secteurs-strategiques/gaz-non-conventionnels/focus-gaz-de-schiste/environmental-challenges>

<sup>55</sup> See: *Cuadrilla Bowland Ltd* (2014), Temporary Shale Gas Exploration, Preston New Road, Lancashire: Environmental Statement Appendix B – Scheme Parameters, page B8

<sup>56</sup> King (2012) Hydraulic Fracturing 101. *Journal of Petroleum Technology*, April 2012 p34-42

- ▶ Water: about 98-99% of total volume;
- ▶ Proppant: about 1-1.9% of total volume, usually sand or ceramic particles. The proppant is forced into the fractures by the pressured water, and holds the fractures open once the water pressure is released.;
- ▶ Friction reducer: about 0.025% of total volume, usually polyacrylamide;
- ▶ Disinfectant: about 0.005% to 0.05%, usually glutaraldehyde, quaternary amine or tetrakis hydroxymethyl phosphonium sulphate;
- ▶ Surfactants: 0.05-0.2%;
- ▶ Gelation chemicals (thickeners): usually guar gum or cellulose polymers;
- ▶ Scale inhibitors: phosphate esters or phosphonates;
- ▶ Hydrochloric acid may be used in some cases to reduce fracture initiation pressure;
- ▶ Corrosion inhibitor, used at 0.2% to 0.5% of acid volumes, and only used if acid is used.

In the UK, Cuadrilla has released details of the composition of fracturing fluid used in hydraulic fracturing at Preese Hall, Lancashire<sup>57</sup>. Results from the Preese Hall-1 Well show that over six fracturing episodes, the following volumes of substances were used as fracturing fluid:

- ▶ 8,399m<sup>3</sup> of fresh water (sourced from the region's water supply company, United Utilities);
- ▶ 462 tonnes of sand (sourced from Sibelo UK);
- ▶ 3.7m<sup>3</sup> of friction reducer (polyacrylamide emulsion in hydrocarbon oil); and
- ▶ 4.25 kg of chemical tracer (consisting of water and sodium salt).

In the UK, the environmental regulator (the Environment Agency in England, the Scottish Environmental Protection Agency in Scotland and Natural Resources Wales in Wales) will assess whether a substance proposed for use in well stimulation is hazardous or a non-hazardous pollutant using a methodology that follows the requirements of the Groundwater Daughter Directive<sup>58</sup> as part of the environmental permitting process.

In an initiative proposed by the UK Onshore Oil and Gas, as part of best practice guidance<sup>59</sup>, operators will be required to disclose the chemical additives of fracturing fluids on a well-by-well basis.

## Well Completion

Following the release of pressure, some of the liquid that is injected returns to the surface through the drilled well. This fluid is known as 'flowback water' and is typically very saline and contains minerals dissolved from the rocks. The proportion of fracturing fluid that returns as flowback water varies between wells, with some US studies reporting flowback of between 10 – 40% of the fracturing fluid<sup>60</sup>, although other studies report that flowback can be as high as 75%.<sup>61</sup> The volume of flowback water returned depends on the properties of the rock formation (such as the geology of the host formation and mobility of naturally occurring compounds), fracturing design and the type of fracturing fluid used.<sup>62</sup>

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<sup>57</sup> *Cuadrilla* (2013) Composition of Components in Bowland Shale Fracturing Fluid for Preese Hall-1 Well

<sup>58</sup> [www.wfduk.org/legislative-background-and-classification-results](http://www.wfduk.org/legislative-background-and-classification-results)

<sup>59</sup> UKOOG (2015), UK Onshore Shale Gas Well Guidelines Issue 2 January 2015

<sup>60</sup> *Halliburton* (2014) Produced and Flowback Water Recycling and Reuse Economics, Limitations, and Technology, Oil and Gas Facilities

<sup>61</sup> *AEA et al* (2012) Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing. a report for the European Commission AEA/R/ED57281

<sup>62</sup> *King GE* (2012) Hydraulic Fracturing 101, *Journal of Petroleum Technology*, April 2012 p34 – 42, as cited in AEA (2012) Support to the Identification of Potential Risks for the Environment and Human Health arising from Hydrocarbons Operations involving Hydraulic Fracturing in Europe



Some of the water that flows to the surface may also include produced water (water coming to the surface, under pressure, 'produced' from saturation of the host formation); however, due to the low permeabilities of shale, produced water is generated in very low volumes when compared with the volumes of flow back fluid or in contrast to the produced water that can be found in conventional oil and gas wells. Whilst flowback water typically returns to the surface within the first few days or weeks following injection of fracturing fluid, produced water, where it occurs, is generated from the rocks across the lifetime of the well.

Flowback water requires storage prior to any treatment or disposal. In the US, holding ponds are used to store flowback water to allow the settlement of its contents. Open storage and settlement is not permitted in the UK, with storage of flowback water in tanks on site as part of a closed system prior to treatment or disposal<sup>63</sup>.

Recovered fracturing fluid and produced waters from wet shale formations are collected and sent for treatment and disposal or re-use, after treatment, where possible.

Any natural gas that may arise from drilling and flowback fluid may be disposed of by flaring in the earlier exploration stages. As an alternative to flaring, 'green completion' or 'reduced emissions completions' (REC) can be used which involve the capture of methane from the fracturing process for use or export off site.

### 2.3.3 Stage 3: Production Development

The range and type of activities associated with Stage 3 of the unconventional oil and gas exploration and production lifecycle would be similar to those identified under Stage 2. The area of land take required per well pad would be greater than that associated with the exploratory drilling stage reflecting the need for additional infrastructure such as storage tanks and on-site pipelines. Where initial exploration drilling has been successful, multi-well pads are now widely used, where 6-10 wells are accommodated on a single pad enabling a single multistage horizontal well pad to access approximately 250 hectares of shale gas play, compared to approximately 15 hectares for a vertical well pad. Further, King<sup>64</sup> reports that a single 2.4 hectare well pad is used to collect shale gas from a 2,400 hectare area, although the construction of well pads with only 1 to 2 wells is still a widespread practice at present in some states in the USA<sup>65</sup>.

Assuming 3.6 hectares per multi-well pad, this suggests that approximately 1.4% of the land above a productive shale gas reservoir may need to be used to fully exploit the reservoir, or more if other indirect land-uses (e.g. central storage facilities, compressors and connecting pipelines) are taken into account<sup>66</sup>. For this ancillary infrastructure, works are likely to include further clearance of vegetation, soil loss and soil compaction which may have negative effects in terms of soil function and processes.

Before gas production can commence, pipeline infrastructure must be developed to collect natural gas for transfer to the existing natural gas pipeline infrastructure.

Changes will also be required at the wellhead. In addition to the assembly of pressure-controlled devices and valves at the top of the wellhead, production tree or "Christmas tree" equipment at the wellpad during the production phase is likely to include:

- ▶ A two-phase gas/water separator;
- ▶ Gas metering devices (each well or shared);
- ▶ Water metering devices (each well or shared);
- ▶ Brine storage tanks (shared by all wells).

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<sup>63</sup> DECC (2014) Fracking UK Shale: Water

<sup>64</sup> King GE (2012) Hydraulic Fracturing 101, Journal of Petroleum Technology, April 2012 p34 – 42, as cited in AEA (2012) Support to the Identification of Potential Risks for the Environment and Human Health arising from Hydrocarbons Operations involving Hydraulic Fracturing in Europe

<sup>65</sup> Ricardo-AEA (2014), Unconventional Gas in England: Description of infrastructure and future scenarios, a Report for the Environment Agency, Ricardo-AEA/R/ED58661, February 2014

<sup>66</sup> AEA et al (2012) Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing. a report for the European Commission AEA/R/ED57281, p.31

<http://ec.europa.eu/environment/integration/energy/pdf/fracking%20study.pdf>



A well head compressor may also be added during later years and a dehydrator may be present at some sites.

#### 2.3.4 Stage 4: Production, Operation and Maintenance

Produced gas flows from the wellhead to the separator through a flow line a few inches in diameter. At the separator, water will be removed from the gas stream via a valve and sent to the brine storage tanks. The gas then continues through a meter and then to the departing gathering line which will likely follow the route of the wellpad access road. From there, it is transported to a centralised compression facility.

The necessary compression to allow gas to flow into a large transmission line for sale would typically occur at a centralised site. Dehydration units would also be located at the centralised compression facilities. Based on experience in the US, it is estimated that a centralised compression facility would service well pads within a 4 to 6 mile radius. The gathering system from the well to the facility would comprise PVC or steel pipes, with the buried lines leaving the compression facility being made of coated steel.

During production, re-fracturing may be required in order to stimulate the flow of shale gas. In the US, the frequency of re-fracturing is not certain and is estimated to be once per 5 – 10 years on average, if at all. For the purposes of their report, AEA (2012) assumed that a well would be re-fractured between 0 and 4 times over a well lifetime of up to 40 years. However, a recent study from the US<sup>67</sup> suggests that refracturing periods could be shortening: “Operators are increasingly refracturing two to four years later [after initial well completion] to stimulate oil and gas production. Refracturing of 15 oil wells in the Bakken Shale yielded a 30% increase in estimated ultimate recovery. In the Barnett Shale, where natural gas production declines 3- to 5-fold within a few years, refracturing increased estimated ultimate recovery by 20%. As the price for oil or natural gas rises, refracturing will become increasingly common.”

The accumulation of liquids in mature wells can impede and sometimes halt gas production. When the accumulation of liquid results in the slowing or cessation of gas production, the removal of fluids is required in order to maintain production. This is known as ‘liquid unloading’.

Monitoring of the site could include ambient air monitoring, hydrostatic pressure testing of pipework and equipment used to transport gas, regular seismic monitoring and monitoring of fracture propagation to: (1) ensure early warning of unexpected leakages; and (2) obtain emissions estimates for regulators and government.

#### 2.3.5 Stage 5: Decommissioning of Wells

When the well is no longer economic to operate, it is taken out of service, either temporarily or permanently. Decommissioning takes place in accordance with established procedures in the oil and gas production industry.<sup>68</sup> Wells must be properly closed to eliminate pathways to the surface or to freshwater sources. Procedures include the installation of a surface plug to stop surface water seepage into wellbore. A cement plug is installed at the base of the lowest underground source of drinking water to isolate water resources from potential contamination by hydrocarbons or other substances migrating via the well bore. A cement plug would also be installed at the top of the shale gas formation. Historically, wells in the US were often poorly plugged with various unsuitable materials from the site, leading to poor containment and potential releases of gas or fluids from the well<sup>69</sup>. Cement plugging is now most common for sealing wells.

Decommissioning will require additional machinery, and potentially, construction compounds to facilitate the completion of well plugging and the subsequent removal of site equipment. Associated works may require some site clearance.

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<sup>67</sup> Jackson R. et al (2014) *The Environmental Costs and Benefits of Fracking* p.332 in: Annual Review of Environmental Resources 2014 39:327–62 <http://sites.biology.duke.edu/jackson/arer2014.pdf>

<sup>68</sup> *Oil and Gas UK* (2012), “OP071 - Guidelines for the suspension and abandonment of wells” (Issue 4), and “Guidelines on qualification of materials for the suspension and abandonment of wells” (Issue 1), July 2012, available via: <http://www.oilandgasuk.co.uk>

<sup>69</sup> *Technology Subgroup of the Operations & Environment Task Group* (2011) Paper #2-25: Plugging and Abandonment of Oil and Gas Wells [http://www.npc.org/Prudent\\_Development-Topic\\_Papers/2-25\\_Well\\_Plugging\\_and\\_Abandonment\\_Paper.pdf](http://www.npc.org/Prudent_Development-Topic_Papers/2-25_Well_Plugging_and_Abandonment_Paper.pdf)

### 2.3.6 Stage 6: Site Restoration and Relinquishment

Following completion, some of the land used for a well pad and associated infrastructure can be returned to the prior use, or to other uses. However, well established natural habitats cannot necessarily be fully restored following use of the land for shale gas extraction. Consequently, it may not be possible to fully restore a site, or to return the land to its previous status.

## 2.4 Summary

**Table 2.1** summarises the activities that could occur at each stage of the lifecycle of unconventional oil and gas exploration and production.

**Table 2.1: Unconventional Oil and Gas Exploration and Production Lifecycle and Key Activities**

Stage	Activities: Unconventional Oil and Gas
1.	Non-intrusive exploration, including: <ul style="list-style-type: none"> <li>• Site identification, selection, characterisation;</li> <li>• Seismic surveys;</li> <li>• Securing of necessary development and operation permits.</li> </ul>
2.	Exploration drilling and hydraulic fracturing, including: <ul style="list-style-type: none"> <li>• Pad preparation road connections and baseline monitoring;</li> <li>• Well design and construction and completion;</li> <li>• Hydraulic fracturing;</li> <li>• Well testing including flaring.</li> </ul>
3.	Production development, including : <ul style="list-style-type: none"> <li>• Pad preparation and baseline monitoring;</li> <li>• Facility construction and installation;</li> <li>• Well design construction and completion;</li> <li>• Hydraulic fracturing;</li> <li>• Well testing, possibly including flaring</li> <li>• Provision of pipeline connections</li> <li>• (Possibly) re-fracturing.</li> </ul>
4.	Production/operation/maintenance, including: <ul style="list-style-type: none"> <li>• Gas/oil production;</li> <li>• (Possibly) re-fracturing.</li> <li>• Production and disposal of wastes/emissions;</li> <li>• Power generation, chemical use and reservoir monitoring;</li> <li>• Environmental monitoring and well integrity monitoring.</li> </ul>
5.	Decommissioning of wells, including: <ul style="list-style-type: none"> <li>• Well plugging and testing;</li> <li>• Site equipment removal;</li> <li>• Environmental monitoring and well integrity monitoring.</li> </ul>
6.	Site restoration and relinquishment, including: <ul style="list-style-type: none"> <li>• Pre-relinquishment survey and inspection;</li> <li>• Site restoration and reclamation.</li> </ul>

Note: Exploration wells most usually move from Stage 2 to Stage 4, though some may be used for long-term production testing and some may be retained and their sites redeveloped as a production project. For the purposes of this review, the appraisal stage (a term commonly used in industry) spans Stages 2 and 3.

## 3. What are the Risks and the Effects?

### 3.1 Overview

This section provides a summary of the potential effects arising from the stages of exploration, production and decommissioning associated with shale gas for the following topics:

- ▶ Biodiversity and nature conservation;
- ▶ Land use and geology (including induced seismicity);
- ▶ Water resources;
- ▶ Air quality;
- ▶ Climate change;
- ▶ Waste;
- ▶ Cultural heritage (included archaeology);
- ▶ Landscapes; and
- ▶ Health.

Likely risks and possible mitigation measures are also identified for each topic area considered. The background research used to compile each of these topic summaries is contained in **Appendix B**.

For each of the topics considered, **Table 3.1** provides a summary of the potential environmental risks/impacts associated with unconventional gas exploration and production and, for comparative purposes, conventional oil and gas. It draws on the review of environmental risks presented in the AEA 2012 report prepared for DG Environment<sup>70</sup>, supplemented by more recent studies that have considered risks on biodiversity and human health<sup>71</sup>. It shows that the majority of effects associated with unconventional oil and gas exploration and development are also common to those associated with conventional oil and gas development. Differences however do occur when considering the technologies and requirements of the hydraulic fracturing process itself. With regard to the risks arising from hydraulic fracturing alone, potential risks are likely to include: induced seismic events; the local sourcing of water, creating additional demand during periods of water stress; the management of chemicals and the mixing, storage and use of the fracture fluid, the management of flowback water and fugitive greenhouse gas emissions.

**Table 3.1 Potential Environmental Impacts Associated with Conventional and Unconventional Gas Exploration and Production**

Theme	Risk/Impact	Conventional	Un-conventional
<b>Biodiversity</b>	Direct loss and/or fragmentation of habitat from construction and operation of well site and well pad activities.	✓	✓
	Indirect impacts on habitats/species due to, for example, disturbance from noise, human presence and light pollution and the introduction of invasive species and the exposure to pollution through causal pathways.	✓	✓

<sup>70</sup> AEA *et al* (2012) Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing. a report for the European Commission AEA/R/ED57281

<sup>71</sup> *Public Health England* (2014) Review of the Potential Public Health Impacts of Exposures to Chemical and Radioactive Pollutants as a Result of Shale Gas Extraction: Draft for Comment, available from [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/332837/PHE-CRCE-009\\_3-7-14.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/332837/PHE-CRCE-009_3-7-14.pdf)

**Table 3.1 (continued) Potential Environmental Impacts Associated with Conventional and Unconventional Gas Exploration and Production**

Theme	Risk/Impact	Conventional	Un-conventional
<b>Land Use and Geology</b>	Land requirements for pad and pipelines, disruption to soil layers and compaction and resulting impacts on removal of land for alternative uses (natural or anthropogenic) and ecology/ environment impacts.	✓	✓
	Induced seismicity from hydraulic fracturing activities and the potential impact on well integrity, creation of geological pathways for pollutants and possible minor earth tremors.	✓ (in limited circumstance <sup>72</sup> )	✓
<b>Water Resources</b>	Surface spillage of pollutants such as diesel and drilling fluids and silt-laden run-off resulting in surface water pollution.	✓	✓
	Surface spillage of hydraulic fracturing fluids and wastewaters resulting in surface water pollution.		✓
	Well failure resulting in pollutants released from the well to groundwaters.	✓	✓
	Introduction of pollutants due to induced fractures providing pathways to groundwater resources through either pre-existing man-made or natural structures.		✓
	Inappropriate selection of chemicals in hydraulic fracturing and/ or unsuitable assessment leading to unacceptable risks to the environment from releases.		✓
	Water consumption associated with hydraulic fracturing activities affecting the availability of water resources, aquatic habitats and ecosystems and water quality.		✓
	Well pad development at risk of flooding and/or resulting in increased flood risk off site due to increase in impermeable area and/or location of facilities in areas of flood risk.	✓	✓
<b>Air Quality</b>	Emissions to air from well pad construction and drilling resulting in adverse local air quality impacts.	✓	✓
	Emissions associated with hydraulic fracturing activities resulting in adverse local air quality impacts.		✓
<b>Climate Change</b>	Greenhouse gas (GHG) emissions from well pad construction and drilling.	✓	✓
	GHG emissions associated with hydraulic fracturing activities.		✓
	GHG emissions arising from well completion.	✓	✓
	Fugitive GHG emissions.	✓	✓
	Combustion of extracted hydrocarbons generating GHG emissions.	✓	✓
<b>Waste Arisings</b>	Generation of construction and drilling wastes.	✓	✓
	Generation of flowback water following hydraulic fracturing activities.		✓

<sup>72</sup> Davies et al (2012) Induced Seismicity and Hydraulic Fracturing for the Recovery of Hydrocarbons, Marine and Petroleum Geology Manuscript, <https://www.dur.ac.uk/resources/refine/InducedSeismicityfull.pdf>

**Table 3.1 (continued) Potential Environmental Impacts Associated with Conventional and Unconventional Gas Exploration and Production**

Theme	Risk/Impact	Conventional	Un-conventional
<b>Cultural Heritage</b>	Direct loss of or damage to cultural heritage features and landscapes from construction of well pad and associated infrastructure.	✓	✓
	Indirect effects on the setting of cultural heritage assets as a result of the well pad construction and operation.	✓	✓
<b>Landscape</b>	Impacts and landscape character and visual amenity due to well pad construction and operation activities.	✓	✓
<b>Human Health</b>	Emissions to air, dust and noise associated with construction and drilling activities resulting in adverse impacts on nearby receptors.	✓	✓
	Contamination of drinking water supply due to hydraulic fracturing activities.		✓
	Risks associated with the health and safety of workers onsite.	✓	✓
	Disturbance and nuisance issues	✓	✓

These risks and effects are discussed in more detail in the remainder of this section. For each topic, the risks are identified and the measures to avoid, minimise, reduce and mitigate the effects are summarised in tables at the end of each sub-section.

## 3.2 Biodiversity and Nature Conservation

Biodiversity is the variability among living organisms and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems. Biodiversity is integral to the functioning of ecosystems which in turn, provide 'ecosystem services' which include food, flood management, pollination and the provision of clean air and water. Pressures and risks in respect of biodiversity in respect of unconventional oil and gas exploration and production include: direct impacts on habitats and species (such as through fragmentation, water abstraction and discharge); indirect impacts through air and water contamination; and indirect and cumulative effects such as climate change and the ability of plants and animals to respond.

### 3.2.1 Effects on Biodiversity and Nature Conservation

#### Non-intrusive Exploration

There is potential for disturbance to sensitive species arising from seismic survey work, particularly if this was to occur during the breeding season. Whilst there is a considerable body of research in respect of potential effects arising from seismic surveys in the marine environment<sup>73</sup>, there is no known evidence of onshore surveys resulting in adverse impacts on biodiversity. The literature reviewed as part of this study (see **Appendix B.1**) does not identify seismic surveys themselves as representing a significant risk to ecology, although associated vehicle movements and/or the installation of the arrays may result in short term disturbance/habitat loss.

Should significant new road infrastructure be required to facilitate site access then there may be an increased risk of habitat loss, fragmentation and disturbance.

<sup>73</sup> IAGC (2011), Seismic Surveys and Protecting the Marine Environment, [http://www.iagc.org/media/files/page/ab24210c/IAGC\\_1\\_Pager\\_ProtectingMarineEnv\\_FINAL\\_2014\\_06\\_12.pdf](http://www.iagc.org/media/files/page/ab24210c/IAGC_1_Pager_ProtectingMarineEnv_FINAL_2014_06_12.pdf)

## Exploration drilling and hydraulic fracturing

Impacts on biodiversity from this phase can arise from two separate operations: preparation for, and construction of, the well pad(s) and subsequently exploratory activities involving drilling, fracking, testing and flaring.

Well pad construction could result in the loss and/or fragmentation of habitat, the effects being direct (such as loss to drilling pads and access roads, fencing of compounds and degradation of habitats due to water abstraction) or indirect (such as disturbance from noise, human presence and light pollution and the introduction of invasive species). The effects of habitat loss and fragmentation are in the relatively early stages of research. Typical land-take for a drilling pad and associated compound is approximately 1-2 hectares (ha) during the exploratory drilling and hydraulic fracturing stage (compared to 1ha for conventional oil and gas exploration drilling).

The nature of potential direct and indirect effects on biodiversity associated with well pad construction would be similar to conventional oil and gas construction activity as well as other types of development (particularly where this involves the development of greenfield land) although the magnitude of effect may be greater owing to the differences in the scale of land take and intensity of activity.

Drilling associated with both conventional and unconventional oil and gas exploration and production may cause disturbance to ecological receptors. The impact of noise disturbance on biodiversity associated with unconventional oil and gas drilling activity has been identified<sup>74</sup> as an issue of particular significance, reflecting the fact that the drilling of wells in a well pad may take many months of continuous drilling depending on the number and depth of wells drilled (each well typically taking 1-2 months of 24 hours/day drilling although the wells proposed by Cuadrilla in Lancashire UK would take between 3 and 5 months). Additional identified impacts include the potential introduction of invasive species (plants, animals and micro-organisms) associated with the importation of water and construction materials on to the site, although this risk would be similar to other forms of development and particularly those involving the importation of water (for example, activity involving the transfer of untreated water).

During both conventional and unconventional onshore oil and gas exploration operations, the accidental release of substances such as diesel and drilling fluids, silt-laden run-off and the deposition of pollutants associated with transport movements could also negatively affect biodiversity. With specific regard to unconventional oil and gas exploration, potentially polluting substances will also include hydraulic fracturing fluids. **Section 3.4** considers further the potential sources of pollution in this regard.

## Production Development

There could be a range of direct effects on biodiversity associated with production development activity, including habitat loss (from the land take for the larger production pad<sup>75</sup>), severance (associated with road and pipeline construction, for example) and species disturbance including noise, human activity and light pollution which could affect sensitive species, particularly during the breeding season. Water used during the fracturing process could potentially affect habitats and species especially during times of water stress.

## Production/operation/maintenance

Assuming that all operational activities would take place within the already identified site area, there would be no additional land take and hence direct effects on biodiversity. However, there would be the potential for continued disturbance and/or displacement as a result of operational activities, including noise, traffic movements, human activity and light pollution which could affect sensitive species (such as bats), particularly during the breeding season. The accidental release of pollutants, including untreated flowback water from refracturing could also affect both habitats and species.

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<sup>74</sup> See Moore, V., Beresford, A., & Gove, B. (2014) Hydraulic fracturing for shale gas in the UK: Examining the evidence for potential environmental impacts. UK: RSPB p.27 and p.36 case study on bat behaviour, available via <http://www.rspb.org.uk/forprofessionals/policy/climatechange/action/ukenergy/fit-to-frack.aspx>

<sup>75</sup> A typical well pad and compound would be approximately 3ha (compared to 1.9ha per pad for conventional drilling) during production, extending to an additional 2.4ha for every hectare of well pad area, or an additional 9ha per well pad.



The main risk of groundwater contamination associated with hydraulic fracturing is commonly considered to be the leakage of fracturing fluid and methane as a result of inadequacies in well cementing (well integrity) or due to the movement of contaminants through existing faults or porous rocks to groundwater resources. Any effects on groundwater could impact on water dependent habitats, such as wetlands. An evaluation<sup>76</sup> of operational impacts associated with Marcellus Shale drilling concluded that: “*Water-supply contamination from so-called stray gas occurs more often from failures in well design and construction, breaches in spent hydraulic-fracturing water-containment ponds, and spills of leftover natural gas liquids used in drilling. Where groundwater has been impacted ... the issue stems not from hydraulic fracturing per se, but poorly formulated cement and improperly designed wells.*”

Additional abstraction of water to supply wells could affect wetland ecosystems through the lowering of groundwater levels, particularly in times of water stress.<sup>77</sup>

### Decommissioning and Site Restoration

All activities associated with decommissioning and site restoration would take place within the existing site area and therefore no further effects on biodiversity are anticipated.

#### 3.2.2 Summary of Risks and Avoidance, Minimisation and Mitigation Measures

**Table 3.2** summarises the key biodiversity risks and avoidance, minimisation and mitigation measures. Collectively, the measures can be collated into a Biodiversity Mitigation Strategy (BMS) which is a commonly used method of specifying and monitoring measures which will be used to help lessen impacts associated with construction and operation.

**Table 3.2 Summary of Risks to Biodiversity and Avoidance, Minimisation and Mitigation Measures**

Source	Activity	Summary	Measure
1. Land required for the well pad	Site selection and preparation and all subsequent stages	<p>Potential cumulative risks of impacts on removal of habitat, introduction of invasive species, noise disturbance, emissions to air and water, human activity, traffic, habitat degradation. Impacts on sensitive areas</p> <p>Impact arises from the degrading, fragmentation or removal of habitat and direct loss of species and indirect effects on foraging areas leading to increased stress on species</p>	<p>a) Site selection and avoidance of sites/areas of high conservation/ecological value (e.g. Natura 2000 within Europe, designated conservation sites, water protection areas, reforestation areas).</p> <p>b) Site selection process should include use of buffer zones between proposed wellsite and designated conservation sites, with buffer zone provided at least at 1km separation from the boundary of proposed site and the boundary of the designated area (NB reflects UK experience, and could vary depending on the nature of the designation).</p> <p>c) Potential pollutant pathways between proposed wellpad and exploration activities and sensitive receptors should be identified and documented. Where evidence of pathway which could have direct causal effect, through pollutant spillage, on a designated site, consider alternative siting, based on extended buffer zone and use of pollution prevention measures to minimise risk.</p> <p>d) Prohibit operations within designated conservation sites (e.g. Natura 2000 within Europe, protected sites, water protection areas, reforestation areas) or within certain</p>

<sup>76</sup> *Considine T. et al* (2012) Environmental Impacts during Marcellus Shale Gas Drilling: Causes, Impacts and Remedies. Shale Resources and Society Institute p.8. <http://cce.cornell.edu/EnergyClimateChange/NaturalGasDev/Documents/UBSRSI-Environmental%20Impact%20Report%202012.pdf>

<sup>77</sup> See *Tyndall Centre for Climate Change Research* (2011) Shale gas: a provisional assessment of climate change and environmental impacts p.59



Source	Activity	Summary	Measure
			<p>distances to designated conservation sites (see buffer zone above).</p> <p>e) Restrict operations within designated conservation sites (see above) and within certain distances to designated conservation sites to minimise disturbance from activities (noise from drilling and traffic movements).</p> <p>f) Require optimisation of well pads, i.e. the number of wells, pad density and pad spacing (e.g. one pad per 2.6 km<sup>2</sup> proposed by New York State).</p> <p>g) Pre-construction checks and monitoring for protected species, either resident on the proposed wellsite or making use of the area for foraging or hunting or as part of any migration route.</p> <p>h) Where proposed exploration site important for foraging, consider alternative location including use of buffer zone and/or ensure or establish alternative areas available to key species.</p> <p>i) Programming of site/vegetation clearance to avoid disruption to ground nesting birds.</p> <p>j) Ecological pre-start checks prior to each new phase of the project (e.g. drilling, fracturing, initial flow testing, extended flow testing, decommissioning).</p> <p>k) Briefings and training for all site personnel prior to construction and each phase of the project regarding conduct, awareness of designated sites and species and awareness of any pollutant pathways.</p> <p>l) Regular compliance checks undertaken by the Ecological Clerk of Works.</p> <p>m) Yearly re-assessment of site vegetation to determine species use/presence.</p> <p>n) Ongoing monitoring and survey work through operations to establish if any effects on sensitive receptors.</p>
2.	Noise from plant Drilling and Production	Potential cumulative risks of noise on species populations arising from the disturbance of species, potentially important during breeding seasons	<p>a) Avoid siting of well pad in areas of sites/areas of high conservation/ecological value (e.g. Natura 2000 within Europe, designated conservation sites).</p> <p>b) Site selection process should include use of buffer zones between proposed well pad and designated conservation sites, with buffer zone providing at least at 1km separation from the boundary of proposed site and the boundary of the designated area (NB reflects UK experience regarding noise attenuation and distance).</p> <p>c) Prohibit/restrict operations within designated conservation sites (e.g. Natura 2000 within Europe, protected sites) or within certain distances to designated conservation.</p> <p>d) Prohibit/restrict operations during breeding season if designated conservation areas contain sensitive species and are within buffer zone.</p> <p>e) Application of specific design measures to limit noise disturbance (through bunds and acoustic barriers, enclosed flaring, equipment orientation and controls on timing of operations), as well as measures to minimise</p>

Source	Activity	Summary	Measure
			effects from lighting (orientation, cowling).
3. Vehicle movements	Vehicle movements associated with construction, water, flowback and produced water management	Potential cumulative risks of impacts on removal of habitat (for construction of access roads), introduction of invasive species, noise disturbance, emissions to air and water, human activity, traffic, habitat degradation. Impacts on sensitive areas. Impact arises from the direct loss of species through roadkill and disturbance of species, potentially important during breeding seasons	<ul style="list-style-type: none"> <li>a) Avoid siting of well pad and ancillary infrastructure in areas of sites/areas of high conservation/ecological value (e.g. Natura 2000 within Europe, designated conservation sites).</li> <li>b) Site selection process should include use of buffer zones and once works started, use of buffer zones where the works and access routes are in close proximity to sensitive habitats.</li> <li>c) Require optimisation of well pads, i.e. the number of wells, pad density and pad spacing (e.g. one pad per 2.6 km<sup>2</sup> proposed by New York State)</li> <li>d) Review and implement measures to minimise water use and vehicle movements.</li> <li>e) Prohibit/restrict operations (including vehicle movements) during breeding season if designated conservation areas contain sensitive species and are within buffer zone.</li> </ul>
4. Spillages of chemicals	Chemical transportation, storage and mixing	Accidents and spillages can result in contamination (e.g. through tank ruptures, equipment and impoundment failures, overfills, vandalism, accidents, fires, poor operational practice) Impact arises from the degradation of habitats and potential direct loss of species.	<ul style="list-style-type: none"> <li>a) Require good site practice to prevention of leaks and spills.</li> <li>b) Require tank level alarms.</li> <li>c) Require double skinned closed storage tanks.</li> <li>d) Require spill kits.</li> <li>e) Require berm around site boundary.</li> <li>f) Require impervious site liner under pad with puncture proof underlay.</li> <li>g) Require collection and control of surface runoff.</li> <li>h) Avoid the use of persistent, bio-cumulative and toxic, carcinogenic and mutagenic chemicals.</li> <li>i) Require good site security.</li> <li>j) Require pollution incident emergency response plan.</li> <li>k) Require pollution prevention training.</li> </ul>
5. Spillages of flowback or produced water	Fracturing	Accidents and spillages can result in contamination (e.g. through tank ruptures, equipment and impoundment failures, overfills, vandalism, accidents, fires, poor operational practice, blowouts) Impact arises from the degradation of habitats and potential direct loss of species.	See measures proposed for issue 4.
6. Injection of pollutants into ground arising from injection activities	Hydraulic fracturing	Fluid contaminants transferred to groundwater and then to surface water via induced fractures extending beyond target formation, through bio-geological reactions with chemical additives, via pre-existing fractures / faults, via pre-existing man-made	See measures proposed for issue 22.

Source	Activity	Summary	Measure
		structures, well casing failures Impacts is pollution of aquifers and surface waters with adverse effects on aquatic ecology.	
7.	Pipeline route	Pipeline construction	Linear feature may adversely affect biodiversity, particularly in sensitive area and lead to habitat severance and fragmentation
			<ul style="list-style-type: none"> <li>a) Seek to site well pad close to existing pipeline infrastructure, if available, to minimise need for new pipeline.</li> <li>b) For any new pipeline that is required, preferentially follow routes of existing linear infrastructure to minimise land take and disturbance on undeveloped land.</li> <li>c) During planning application process, require environmental impact assessment (EIA)* for proposed pipeline.</li> <li>d) Use of buffer zones where the works and access routes are in close proximity to sensitive habitats.</li> <li>e) Consider species pathways/crossings of linear feature at key points to avoid severance</li> </ul>
8.	Remaining legacy land use post abandonment	Abandonment	It may not be possible to fully restore sites
			<ul style="list-style-type: none"> <li>a) Require land disturbed during well construction and development to be reclaimed and restored as soon as possible</li> <li>b) Require habitat restoration and/or enhancement using native plantings before site relinquishment.</li> <li>c) Require post abandonment monitoring**.</li> <li>d) Require post abandonment emergency plan.</li> <li>e) Require post abandonment well inspection.</li> <li>f) Note: Transfer of responsibility of site to competent authority only after satisfactory reinstatement of habitat and sufficient monitoring of site to demonstrate no sustained risk to biodiversity.</li> </ul>

\*All activities associated with unconventional gas exploration and production (subject to specific regulatory thresholds) are likely to require EIA.

\*\*In the UK, arrangements for post abandonment monitoring are currently being agreed between operators and the Government.

### 3.3 Land Use and Geology

Land use in this context is concerned with the effective use of land, i.e. by encouraging the reuse of land that has been previously developed (brownfield land) as well promoting sustainable patterns of land use, e.g. in relation to the protection of open spaces and green infrastructure. Geology and soils is concerned with important geological sites, the contamination of soils and high quality agricultural land.

The principal effects are anticipated to be associated with cumulative land-take, compaction of soils, induced seismicity, contamination and waste disposal, although in all cases, appropriate mitigation can be employed to either reduce risks or long term effects.

#### 3.3.1 Effects on Land Use and Geology

##### Non-intrusive Exploration

There may be a requirement for the temporary construction of new roads to facilitate access to sites and this could result in the loss of greenfield land and soils, disruption to soil layers/compaction and may obstruct the

use of land (e.g. for agricultural use). Where soils are high agricultural quality these effects may be more severe.

### Exploration drilling and hydraulic fracturing

Principal effects relate to land-take associated with exploration drilling and hydraulic fracturing, amounting to 1-2 ha pad (which compares to 1 ha per pad for conventional oil and gas exploration drilling). Further land-take would be required for access roads. In the US, these associated roads and facilities are estimated<sup>78</sup> to account for on average about 1.6 hectares of the land area associated with each well pad for the life of the wells. Like other large scale developments, cumulatively there could be significant effects in a locality which could influence farming viability for some landholdings.

In addition to the direct land take, and removal of top soil, well pad construction could lead to disruption of soil layers and compaction which may affect soil function and processes. Economically, such effects would be important, where land take involved activities on high quality agricultural land. However, such impacts are generally shared with other large construction projects (particularly those located on greenfield sites) and soil stripping and storage and land restoration could help to mitigate this impact. Notwithstanding, it is recognised that in areas of intensive agriculture, effects on existing communities/businesses may be more pronounced.

There is potential for induced seismicity associated with fracturing activity. In the UK, in 2011, there were two instances of induced seismicity attributed to hydraulic fracturing<sup>79</sup> with one seismic event of magnitude 2.3 ML and the second of magnitude 1.5 ML. In addition to the UK, induced seismicity associated with hydraulic fracturing has been identified in other shale gas fields located in the USA and Canada. Hydraulic fracturing for shale gas in these fields is known to have induced 79 seismic events with a magnitude >1. The largest of these was an earthquake of magnitude 3.8 ML, which occurred in the Horn River Basin of British Columbia, Canada<sup>80</sup>. It was felt, but caused no recorded damage. In this context, Davies *et al*<sup>81</sup> state that, when compared with other sources of induced seismicity such as mining and reservoir impoundment, “hydraulic fracturing has been, to date, a relatively benign mechanism. It is possible that fault reactivation by hydraulic fracturing might cause induced seismicity larger than that recorded to date, but a fuller understanding of shale geology can mitigate against this risk” and that the likelihood of hydraulic fracturing “causing felt seismicity ( $M > 3$ ) is very small”. Similarly, the AEA (2012)<sup>82</sup> conclude that: “In view of the low frequency of reported incidents, it is judged that the frequency of significant seismic events is “rare” and the potential significance of this impact is “slight.” Multiple development could increase the risk of seismic events due to one operation affecting the well integrity of a separate operation, although in view of the low frequency of the reported events and the established measures for monitoring well integrity, the risks are judged to remain low.” Recent research<sup>83</sup> adds that: “Events of this size (3.6 ML) ... might be sufficient to cause minor damage to property, such as cracked plaster; however, such occurrences, if they ever occur, will be infrequent.” Notwithstanding, in some locations where buildings are of poor construction and slope stability is poor, it is recognised that events of this magnitude could cause minor property damage. Within the UK, any induced seismicity is monitored and compared with a “traffic light” system<sup>84</sup> which depending on a seismic events’ magnitude could lead to temporary suspension of any hydraulic fracturing activity.

<sup>78</sup> New York State Department of Environmental Conservation (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, September 2011

<sup>79</sup> Green C., Styles P.; Baptie B. (2012) Preese Hall Shale Gas Fracturing Review and Recommendations for Induced Seismic Mitigation [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/15745/5075-preese-hall-shale-gas-fracturing-review.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/15745/5075-preese-hall-shale-gas-fracturing-review.pdf)

<sup>80</sup> Davies, J.D. Foulgar, G., Bindley, A., Styles, P. (2013) What size of earthquakes can be caused by fracking? *DEI Briefing Note April 2013*. Durham University: Durham

<sup>81</sup> Davies, J.D. Foulgar, G., Bindley, A., Styles, P. (2013) What size of earthquakes can be caused by fracking? *DEI Briefing Note April 2013*. Durham University: Durham.

<sup>82</sup> AEA (2012) Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe: AEAT, report for the European Commission, 2012, p.54 <http://ec.europa.eu/environment/integration/energy/pdf/fracking%20study.pdf>

<sup>83</sup> Westaway R. & Younger P. (2014) Quantification of potential macroseismic effects of the induced seismicity that might result from hydraulic fracturing for shale gas exploitation in the UK, *Quarterly Journal of Engineering Geology and Hydrogeology* (forthcoming - published online November 11, 2014, doi:10.1144/qjegh2014-011) <http://qjegh.geoscienceworld.org/content/early/2014/10/29/qjegh2014-011.full.pdf+html>

<sup>84</sup> <https://www.gov.uk/government/publications/traffic-light-monitoring-system-shale-gas-and-fracking>

There is the potential for the disturbance of contaminated land through construction and drilling activities and contamination by spillage during exploration production phases, although in both cases appropriate mitigation can be employed to reduce these risks.

### Production development

The range and type of effects associated with Stage 3 of the unconventional oil and gas exploration and production lifecycle would be similar to those identified under exploration drill and hydraulic fracturing. During this stage, land take would equate to around 3ha (which compares to 1.9ha per pad for conventional oil and gas exploration drilling) with potentially further land-take required for pipe lines.

During this stage further hydraulic fracturing could be required but the risk of induced seismicity, providing there are appropriate safeguards, is judged to be small.

### Production/operation/maintenance

Based on the assumption that there would be no additional land take and that the risk of induced seismicity and land contamination from operational activities would be low, this stage has been assessed as having a neutral effect on land use, geology and soils.

### Decommissioning and site restoration

There are anticipated to be no long term effects associated with these phases, in light of employing appropriate mitigation.

## 3.3.2 Summary of Risks and Avoidance, Minimisation and Mitigation Measures

**Table 3.3** summarises the key land use risks and avoidance, minimisation and mitigation measures.

**Table 3.3 Summary of Risks to Land Use and Avoidance, Minimisation and Mitigation Measures**

	Source	Activity	Summary	Measure
9.	Land required for the well pad, include on site storage of flowback water and produced water	Site selection and preparation	<p>Potential cumulative impacts. A typical pad and ancillary infrastructure occupies approximately 3.6ha during exploration and production and well pads containing multiple well could have a density ranging from one pad per 250ha – 2,500 ha (which, depending on location and other land uses could increase competition for land).</p> <p>Potentially isolated impacts can also occur if even only a few small well pads are in direct conflict with nearby or adjacent sensitive land uses such as residences, schools, hospitals, etc. Impact is removal of land from other uses (e.g. natural habitat, agriculture, industry, and housing), lower ecological status, impact on local land use planning and adjacent land usage</p>	<p>a) Appropriate site selection to avoid sensitive areas (high land, agricultural and ecological value locations).</p> <p>b) Require compatibility with current and future potential land use (Natura 2000 sites within Europe, conservation sites, human use, industrial use, appropriate zoning).</p> <p>c) Require use of buffer zones, to minimise effects on other land uses (and effects on sensitive receptors) such as residential areas, schools hospitals and other sensitive areas(e.g. industry good practice requires 1,600m distance where possible).</p> <p>d) Require optimisation of well pads, i.e. the number of wells, pad density and pad spacing (e.g. one pad per 2.6 km<sup>2</sup> proposed by New York State).</p> <p>e) Where necessary, sites should be carefully stripped of topsoils prior to construction works commencing to avoid damage. All soils should be handled in suitable conditions (e.g. dry weather) and the most appropriate method of soil handling should be used. Soils should be stored in allocated heaps and protected from erosion, contamination or degradation.</p>

**Table 3.3 Summary of Risks to Land Use and Avoidance, Minimisation and Mitigation Measures**

Source	Activity	Summary	Measure	
10.	Pipeline construction	Pipeline construction and operation	<p>Pipeline corridors and their right of way and/or maintenance easements may sever properties, preventing or compromising the continuous and unencumbered use of surface property and causing a loss of surface property value</p>	<p>a) Seek to site well pad close to existing pipeline infrastructure, if available, to minimise need for new pipeline.</p> <p>b) For any new pipeline that is required, preferentially follow routes of existing linear infrastructure to minimise land take and disturbance on undeveloped land.</p> <p>c) During planning application process, require environmental impact assessment (EIA)* for proposed pipelines.</p> <p>d) Use of buffer zones where the works and access routes are in close proximity to sensitive habitats.</p> <p>e) Consider pathways/crossings of linear feature at key points to avoid severance</p>
11.	Remaining legacy land use post abandonment	Abandonment	<p>It may not be possible to fully restore sites</p>	<p>a) Require land disturbed during well construction and development to be reclaimed and restored to previous use condition as soon as possible</p> <p>b) Require post abandonment monitoring.</p> <p>c) Require post abandonment emergency plan.</p> <p>d) Require post abandonment well inspection.</p> <p>e) Note: Transfer of responsibility of site to competent authority only after satisfactory reinstatement of habitat and sufficient monitoring of site to demonstrate no sustained risk to biodiversity.</p>

\*All activities associated with unconventional gas exploration and production (subject to specific regulatory thresholds) are likely to require EIA.

**Table 3.4** summarises the key induced seismicity risks and avoidance, minimisation and mitigation measures.

**Table 3.4 Summary of Risks from Induced Seismicity and Avoidance, Minimisation and Mitigation Measures**

Source	Activity	Summary	Measure	
12.	Fracturing	Well injection of hydraulic fracturing fluid	<p>Potential for minor earth tremors (e.g. the largest of the earth tremors at the Preese Hall well in the UK during April and May 2011 had a magnitude of 2.3 following hydraulic fracturing). An event of this size at an expected depth of 2-3 km is unlikely to cause structural damage though it may be felt close to the epicentre</p> <p>Multiple developments could increase the risk of events affecting other operations, e.g. affecting well integrity.</p>	<p>a) Competent authorities compile regional maps of underground resources.</p> <p>b) Operator to review available information on geology, structure (including faults) and in situ stresses in the vicinity of the proposed site to avoid hydraulically fracturing into, or close to, existing critically stressed faults.</p> <p>c) Operator to conduct 2D/3D geophysical (seismic ) surveys to identify faults and fractures.</p> <p>d) Operator to engage with third parties (e.g. regulators, other operators, researchers) to ensure fully aware of any issues / proximity (e.g. to other underground activities). Sharing of information to ensure that all operators in a gas play are aware of risks and can therefore plan.</p> <p>e) Require development of geo-referenced database of the zone before work commences covering geology, groundwater flows,</p>



Source	Activity	Summary	Measure
			<p>pathways, natural microseismicity. Require ongoing development as data is collected through exploration.</p> <p>f) Carry out modelling and risk based geomechanical assessments of proposed hydraulic fracturing with regard to faults (including maximum magnitude estimates).</p> <p>g) Apply ground motion prediction models to assess the potential impact of induced earthquakes.</p> <p>h) Identify potential seismic receptors within a defined radius of the well site (5km) including: wells, infrastructure, special buildings, residential buildings and industrial/commercial buildings. Avoid high seismicity risk areas.</p> <p>i) Require minimum distance between hydraulic fracture pipes and geological strata containing aquifers (e.g. ~literature review has identified range from between 600m -1,000m depending on source and country) and the surface (e.g. any activity closer than the specified depth requires special permit).</p> <p>j) Require appropriate well design, construction, testing and monitoring.</p> <p>k) A Hydraulic Fracturing Programme<sup>85</sup> similar to that in operation in the UK should be prepared by the operator and agreed with the relevant regulator.</p> <p>l) Require smaller preinjection prior to main operations to enable induced seismicity response to be assessed, followed by succession of injections over short duration of casing length.</p> <p>m) Monitor the fracture growth and direction during hydraulic fracturing using buried microseismic arrays to ensure hydraulic fractures / pollutants do not extend beyond the gas-producing formations and do not result in seismic events or damage to buildings/installations that could be the result of fracturing.</p> <p>n) Monitoring background induced and natural seismicity before, during and after hydraulic fracturing.</p> <p>o) Implementation of a Traffic Light System (via the surface seismic monitoring array) and cessation of operation if induced seismic event exceeds agreed threshold e.g. within UK, it is 0.5M<sub>L</sub>.</p> <p>p) Determine the presence and levels of methane in groundwater, including drinking water through sampling of shallow groundwater during wet and dry periods and/or borehole to sample deep groundwater and characterise the hydrological series.</p>

<sup>85</sup> UKOOG (2013) guidelines suggest Hydraulic Fracturing Programmes (HFP) are developed “that describes the control and mitigation measures for fracture containment and for any potential induced seismicity” (See Appendix B.3.10 and <http://www.ukoog.org.uk/images/ukoog/pdfs/ShaleGasWellGuidelinesIssue2.pdf>).



## 3.4 Water Resources

Risks to water quality and resources arising from unconventional oil and gas activities include, in particular: surface water contamination from surface spills; groundwater contamination arising from surface spills, loss of well integrity and fracture propagation; the treatment of wastewater (considered in **Section 3.7**); and the use of water during exploration and production.

Onshore oil and gas exploration and production could both be affected by flooding (for example, where well pads are located in areas prone to flooding) or exacerbate flood risk off site (for example, due to increased surface water runoff).

### 3.4.1 Effects on Water Resources

#### Non-intrusive Exploration

No effects on water resources or flood risk would be expected during this stage.

#### Exploration Drilling and Hydraulic Fracturing

##### Surface Spills

Surface spills/leaks of fracturing and other fluids including, for example, drilling muds/cuttings and flowback water is one of the most common causes of water contamination associated with onshore oil and gas exploration and production<sup>86</sup>. Sources of surface spills/leaks could include: well 'blowouts'; vehicle accidents; or inadequate storage of hydraulic fracturing fluids and flowback water. The Massachusetts Institute of Technology (MIT, 2011<sup>87</sup>) reviewed 43 incidents of environmental pollution related to natural gas operations including shale gas and identified that, alongside groundwater contamination by natural gas or drilling fluid (47% of total incidents), surface spills of stored hydraulic fracturing fluids and flowback water (33% of total incidents) are the most widely reported causes of water contamination. Blowouts, meanwhile, represented only a small proportion (4%) of incidents. Similarly, an analysis of notices of violations (NOVs) from the Pennsylvania Marcellus Shale industry between January 2008 and August 2011 by Considine *et al* (2012)<sup>88</sup> highlights that blowouts (and venting) represented only 0.9% of all NOVs. In this respect, The Royal Academy of Engineering and Royal Society (2012) highlight that blowouts are rare and that whilst some shales can be over-pressurised, blowout is unlikely because shale has very low permeability<sup>89</sup>.

Research<sup>90</sup> indicates that surface spills arising from oil and gas exploration and production activities generally do not have major environmental impacts as they are often small, take place on the well pad and are contained within the boundaries of well pad sites through the implementation of control measures and best practice. Where there are major environmental events, the impacts are often mitigated. Notwithstanding, the significance of any effect is dependent on the amount and type of fluids spilled and the sensitivity of the receiving environment.

##### Hydraulic Fracturing

During hydraulic fracturing, water is injected into the well at high pressures causing fractures in the rock. In order to induce and maintain permeability, and generate productive fractures, chemicals are added to the water to create hydraulic fracturing fluid, the composition of which is dependent on site specific conditions including the underlying geology<sup>91</sup>. Within the UK<sup>92</sup>, operators disclose the composition of the fracturing

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<sup>86</sup> Groat and Grimshaw (2012), Fact-based regulation for environmental protection in shale gas development, Energy Institute, University of Texas: Austin. Available from: [http://cewc.colostate.edu/wp-content/uploads/2012/02/ei\\_shale\\_gas\\_regulation120215.pdf](http://cewc.colostate.edu/wp-content/uploads/2012/02/ei_shale_gas_regulation120215.pdf) (accessed on September 2013)

<sup>87</sup> Massachusetts Institute of Technology (2011). Study on the Future of Natural Gas. Available from <http://mitei.mit.edu/publications/reports-studies/future-natural-gas> (accessed November 2014))

<sup>88</sup> Considine, T. Waterson, R. Considine, N. Martin, J. (2012) Environmental Impacts During Marcellus Shale Gas Drilling: Causes, Impacts, and Remedies

<sup>89</sup> The Royal Academy of Engineering and Royal Society (2012) Shale Gas in the UK, A Review of Hydraulic Fracturing

<sup>90</sup> Considine, T. Waterson, R. Considine, N. Martin, J. (2012) Environmental Impacts During Marcellus Shale Gas Drilling: Causes, Impacts, and Remedies

<sup>91</sup> The Royal Academy of Engineering and Royal Society (2012) Shale Gas in the UK, A Review of Hydraulic Fracturing

<sup>92</sup> UKOOG (2015), UK Onshore Shale Gas Well Guidelines Issue 2 January 2015

fluids on a well-by-well basis through the UK Onshore Operators Group (UKOOG) website. Information disclosed will include:

- ▶ Any EA/SEPA authorisations for fluids and their status as hazardous/non-hazardous substances.
- ▶ Material Safety Data Sheets information.
- ▶ Volumes of fracturing fluid, including proppant, base carrier fluid and chemical additives.
- ▶ The trade name of each additive and its general purpose in the fracturing process.
- ▶ Maximum concentrations in percent by mass of each chemical additive.

Theoretically, indirect water pollution could occur<sup>93</sup> through the migration of contaminants from the target fracture formation through subsurface pathways including: the outside of the wellbore itself; other wellbores (such as incomplete, poorly constructed, or older/poorly plugged wellbores); fractures created during the hydraulic fracturing process; or natural cracks, fissures and interconnected pore spaces.

Evidence<sup>94 95</sup> suggests that local geological conditions may influence the potential for contamination with the most important parameters and conditions affecting the migration of contaminants from target formations to groundwater being: matrix permeability (i.e. the ability of fluids and gas to flow through the shale gas reservoir); fracture permeability (i.e. the permeability of the shale following hydraulic fracturing); distance between the aquifer and the target formation; and the pressure regimes in the aquifer and the target formation<sup>96</sup>. The likelihood of such effects is highly uncertain given the distances between shale gas formations and groundwater. For example, modelling<sup>97</sup> of fracture pathways within the Marcellus shale formation across Pennsylvania, New York and West Virginia suggests that there is *“substantial geologic evidence that natural vertical flow drives contaminants, mostly brine, to near the surface from deep evaporite sources. Interpretative modelling shows that advective transport could require up to tens of thousands of years to move contaminants to the surface, but also that fracking the shale could reduce that transport time to tens or hundreds of years. Conductive faults or fracture zones, as found throughout the Marcellus shale region, could reduce the travel time further.”*

The Royal Academy of Engineering and Royal Society (2012) summarised the findings of a study which compared fracture growth and depth of overlying water sources in four major US shale formations between 2001 and 2010. Seismic data indicated that the minimum vertical distances between the bottom of the aquifer and the top of the fracture varied between 1,200m and 6,000m, depending on the formation. From a European perspective, the risk of contamination as a result of the hydraulic fracturing process is widely regarded to be low due to the likely distance between the fractures and aquifers. AEA (2012) note that most but not all shale gas reservoirs in Europe exhibit a separation of more than 600m between the depth of shale gas formations and aquifers and given research by Davis et al (2012) indicated that the maximum length of fractures (from hydraulic fracturing) as 588m, although the majority of fractures are less than 100m, this suggests that such a separation may be sufficient to avoid any migration of fluid<sup>98</sup>. However, where hydraulic fracturing takes place at shallower depths the risk of groundwater contamination may be greater.

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<sup>93</sup> Broderick J. et al (2011) Shale gas: an updated assessment of environmental and climate change impacts. Tyndall Centre for Climate Change Research, University of Manchester p.81-86, available at: [http://www.tyndall.ac.uk/sites/default/files/coop\\_shale\\_gas\\_report\\_update\\_v3.10.pdf](http://www.tyndall.ac.uk/sites/default/files/coop_shale_gas_report_update_v3.10.pdf)

<sup>94</sup> Warner NR, Jackson RB, et al (2012). Geochemical evidence for possible natural migration of Marcellus formation brine to shallow aquifers in Pennsylvania. Proc Natl Acad Sci USA 109(30): 11961–6.

<sup>95</sup> Warner NR, Kresse TM, et al (2013). Geochemical and isotopic variations in shallow groundwater in areas of the Fayetteville Shale development, north-central Arkansas. Appl Geochem 35: 207–20.

<sup>96</sup> US EPA (2012) Study of the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources. Progress Report, December 2012. Available from <http://www2.epa.gov/sites/production/files/documents/hf-report20121214.pdf> (accessed November 2014)

<sup>97</sup> Myers T. (2012) Potential Contaminant Pathways from Hydraulically Fractured Shale to Aquifers available at: <http://nofracking.com/static/media/PDF/Fracking-Aquifers.pdf>

<sup>98</sup> Davies RJ, Mathias S, Moss J, Hustoft S and Newport L (2012) Hydraulic fractures: How far can they Go? Marine and Petroleum Geology in press.

Within the UK, the migration of fractures such that they would cause contamination of aquifers has been assessed<sup>99</sup> as being of low risk, with fracking predicted to typically occur 2km to 3km below the surface and the average drinking water aquifer being located roughly 300m below the surface. By contrast *“it is more likely that any pollution would come from drilling down through rock containing methane and where the cement or steel well casing failed.”* This is corroborated by evaluation<sup>100</sup> of operational impacts associated with Marcellus Shale drilling where it was concluded that: *“Water-supply contamination from so-called stray gas occurs more often from failures in well design and construction, breaches in spent hydraulic-fracturing water-containment ponds, and spills of leftover natural gas liquids used in drilling. Where groundwater has been impacted ... the issue stems not from hydraulic fracturing per se, but poorly formulated cement and improperly designed wells.”*

### Water Consumption

Hydraulic fracturing is a water intensive process. Estimates of water use during hydraulic fracturing vary significantly and will ultimately depend on local geological characteristics. The SEA of the 14th Onshore Oil and Gas Licensing Round in the UK (AMEC, 2013)<sup>101</sup> assumed that between 10,000 cubic metres (m<sup>3</sup>) and 25,000 m<sup>3</sup> of water would be required per well during the unconventional oil and gas exploration and production lifecycle. Comparisons of water consumption between unconventional oil and gas production and other users have been made. New York State Department of Environmental Conservation (NYSDEC in AEA, 2012<sup>102</sup>) for example, highlights that water requirements associated with hydraulic fracturing would be expected to be low (less than 0.25% of the total water resource use in New York State based on the peak forecast usage rate for the oil and gas industry in the state). Moore (2012)<sup>103</sup>, meanwhile, highlights that water consumption of 19,000m<sup>3</sup> is the same amount of water needed: to water a golf course or a month; to run a 1GW coal fired power plant for 12 hrs; or the amount lost to leaks in the North West of England every hour. Moore (2012) also notes that the rate of abstraction is important in that water is required only periodically as hydraulic fracturing is not a continuous process.

Whilst the volume of water associated with the hydraulic fracturing process is *relatively* low, effects on water resource availability could be significant locally if demand were generated from multiple wells drawing from the same water sources. AEA (2012) identify a number of potential effects that could occur as a result of water consumption associated with hydraulic fracturing activities:

- ▶ Reduced stream flow affecting the availability of resources for downstream use, such as for public water supply;
- ▶ Adverse impacts on aquatic habitats and ecosystems from effects such as degradation of water quality, reduced water quantity, changes to water temperature, oxygenation and flow characteristics, including the effects of sediment and erosion under altered responses to stormwater runoff;
- ▶ Interplay with downstream dischargers, affecting their ability to discharge where limits are related to stream flow rate, or the overall concentration of pollutants where discharge rates remain unaffected;
- ▶ Impacts on water quality, affecting the use which can be made of surface waters.

<sup>99</sup> Davies R. et al (2014) Can fracking cause contamination of drinking water? Available at: <https://www.dur.ac.uk/.../HydraulicfracturesResearchBrief.docx>

<sup>100</sup> Considine T. et al (2012) Environmental Impacts during Marcellus Shale Gas Drilling: Causes, Impacts and Remedies. Shale Resources and Society Institute p.8. <http://cce.cornell.edu/EnergyClimateChange/NaturalGasDev/Documents/UBSRSI-Environmental%20Impact%20Report%202012.pdf>

<sup>101</sup> AMEC (2013) Strategic Environmental Assessment for Further Onshore Oil and Gas Licensing: Environmental Report. Prepared on behalf of the Department of Energy and Climate Change which drew on the AEA 2012 report which noted that horizontal shale gas wells typically use 10,000 to 25,000 m<sup>3</sup> water per well, based largely on US analysis. The AEA 2012 report also summarised the limited evidence from activity in Europe, which gave a range: 9000 – 29,000 m<sup>3</sup>/well (from Cuadrilla in Holland); 1,600m<sup>3</sup> (Halliburton at Lubocino-1 well in Poland); 7,000m<sup>3</sup> – 8,000m<sup>3</sup> (the Danish Energy Agency). Industry estimates suggest ranges of 10,000m<sup>3</sup> to 20,000m<sup>3</sup> (<http://www.total.com/en/energies-savoir-faire/petrole-gaz/exploration-production/secteurs-strategiques/gaz-non-conventionnels/focus-gaz-de-schiste/environmental-challenges> ).

<sup>102</sup> AEA (2012) Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe: AEAT, report for the European Commission, 2012

<sup>103</sup> Moore, S. (2012) Gas Works? Shale gas and its policy implications, The Policy Exchange, available from <http://www.policyexchange.org.uk/images/publications/gas%20works%20-%20feb%2012.pdf> (accessed September 2013)

AMEC (2013), meanwhile, identified several factors that would need to be taken into consideration in order to determine the significance of water consumption on water resources. These include:

- ▶ The timing, intensity and duration of the demand for water (i.e. any coincidence with periods of water stress, such as summer droughts etc); Availability of existing water resources, any evidence of constraints on water availability and the volume of water presently extracted by existing users in that area;
- ▶ The possibility of cumulative effects occurring either as a result of multi well pads or several pads in one area;
- ▶ The volume of waste water than can be recycled and used as fresh injection fluid.

Within the UK<sup>104</sup>, operators should make available for disclosure specific information about the water to be used in any fracturing operation, including:

- ▶ Location and supply source of the water to be used for the base fluid.
- ▶ Water usage volumes.
- ▶ Baseline water compositional analysis.

From a UK perspective, should water be supplied from a mains supply (either nearby to the site or tankered from a supply nearby), it would be the responsibility of the water utility company to ensure that the extra demand accords with the conditions of their water resource plans and abstraction licences. In considering any licensed abstraction application, the responsible statutory body would also consider the effects on flows, the effects on other water users, the impacts on biota, and demands during low flow periods. Licenses would only be granted where such effects are acceptable to the regulator. Taking these regulatory requirements in to account, the SEA of the 14th Onshore Oil and Gas Licensing Round in the UK (AMEC, 2013) concluded that the risk of significant adverse effects on water resource availability as a result of hydraulic fracturing would be low.

Outside the regulatory process, effects on water resource availability may be mitigated through the recycling and reuse of flowback water (the fractured fluid injected into the shale rock during hydraulic fracturing which returns to the surface through the drilled well). Reported recycling rates in the US vary between 10% and 77%<sup>105</sup>. In the case of a proposed temporary shale gas exploration site in Lancashire, England, the operator (Cuadrilla) has indicated that the reuse of flowback water will reduce water requirements by approximately 20%.

### **Flood Risk**

Pad preparation would involve the removal of vegetation and general groundworks to a site and the laying of an impermeable surface to reduce the risk of contaminants leaking into soil/groundwater. This surface would change the natural drainage patterns of the site and could result in the increase of flooding off site as runoff rates may be faster and the natural water storage the site provides would be lost. This risk is similar to other large (particularly greenfield) construction sites.

Sites located within areas of flood risk may also be susceptible to flooding. AMEC (2013) highlighted that, where sites are in flood risk areas, the following risks may arise:

- ▶ Wells may become inundated with flood water and disrupt drilling or cause damage to the casing;
- ▶ Plant and equipment may be damaged;
- ▶ Storage tanks may become damaged or suffer a loss of power and may release contaminants into the flood water;

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<sup>104</sup> UKOOG (2013), UK Onshore Shale Gas Well Guidelines Issue, 1 February 2013

<sup>105</sup> AEA *et al* (2012) Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe Report for European Commission DG Environment (pp 16) which noted studies identifying fresh water as comprising 80-90% of the water used as well as studies reporting up to 77% of wastewater generated from the Pennsylvania Marcellus Shale being recycled.

- ▶ Hydrocarbons may be released and cause pollution or lead to explosions or fires.

### Production Development

During production, the risk to groundwater and surface water bodies as well as flood risk would be similar to that at Stage 2. However, as additional wells would be drilled/fractured the risk of inadequate well design or accidents occurring could be higher. Water consumption at this stage would also be considerably higher, reflecting the drilling and fracturing of additional wells.

### Production/Operation/Maintenance

Once wells are operational, the primary issue with regards to water will be the collection and disposal of produced water. Produced water is water coming to the surface, under pressure, 'produced' from saturation of the host formation. Whilst flowback water typically returns to the surface within the first few days or weeks following injection of fracturing fluid, produced water is generated from the rocks across the lifetime of the well. Due to low permeabilities and low water content, produced water from unconventional oil and gas wells is typically generated in much lower volumes than flowback fluid, estimated at an average of 57m<sup>3</sup> per year per well in the US.<sup>106</sup> Pads with multiple wells would therefore have corresponding increases in produced water requiring treatment or disposal. The major substances found in produced water typically include: hydrocarbons, sands, dissolved salts and iron, metals and Normally Occurring Radioactive Materials (NORMs). The handling and management of produced water may pose a risk to surface and ground water contamination due to accidental spills and runoff, similar to those described in respect of the exploratory stage.

During the production stage, there would be ongoing risks of surface and ground water contamination issues associated with well integrity. Additionally, re-fracturing may be required in order to stimulate the flow of shale gas. The risks of contamination associated with re-fracturing would be similar to those during stages 2 and 3 although AEA (2012) note that, whilst wells would be monitored during re-fracturing, there is uncertainty with respect to the risks associated with re-fracturing on well integrity. Re-fracturing would also result in additional water demand.

### Decommissioning and Site Restoration

The inadequate sealing of wells following production could result in subsurface pathways for contaminant migration leading to groundwater pollution and potentially surface water pollution. However, AEA (2012)<sup>107</sup> highlight that there is normally no pathway for release of fluids used during hydraulic fracturing to other formations and that some of the chemicals used in fracturing fluids will be adsorbed to the rocks or biodegraded in situ and that for shale gas measures at significant depths, the volume of the rock between the producing formation and the groundwater is substantially greater than the volume of fracturing fluid used.

#### 3.4.2 Summary of Risks and Avoidance, Minimisation and Mitigation Measures

**Table 3.5** summarises the key surface water risks and avoidance, minimisation and mitigation measures.

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<sup>106</sup> *European Parliament* (2011) Impacts of shale gas and shale oil extraction on the environment and on human health

<sup>107</sup> *AEA et al* (2012) Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe Report for European Commission DG Environment.



**Table 3.5 Summary of Risks to Surface Water and Avoidance, Minimisation and Mitigation Measures**

No.	Source	Activity	Summary	Measures
13.	Construction activities leading to pollution event	Site preparation	Sediment, leaks and spills from machinery leading to pollution event contaminating surface water body	<ul style="list-style-type: none"> <li>a) Assessments of surface hydrology and flood risk should be undertaken as part of the site selection process. These assessments should seek to identify and categorise pathways, barriers and the potential risk of flooding to/from a site and appropriate mitigation.</li> <li>b) Surface Water Management Plans should be prepared setting out measures for controlling runoff including, for example, the installation of drainage channels.</li> <li>c) The well pad should be constructed from compacted aggregate laid on an impermeable membrane and geotextile layer. Surface water runoff would be collected and attenuated via perimeter ditches. There should be no connectivity between the runoff ditches from the well pad and any other surface water features adjacent to the well pad. Onsite storage facilities should also be bunded where appropriate.</li> <li>d) Require good practice construction techniques to avoid or minimise spills</li> <li>e) Require Emergency Response Plan to be developed and spill kits provided to ensure the prevention/containment of accidental spills; ensure training on use of spill kits.</li> <li>f) Require pre-licence revocation checks to ensure decommissioned well poses no risk to surface or groundwater.</li> </ul>
14.	Drilling mud leakage and spills	Drilling	Pollutant from muds including from NORM, hazardous substances) Impact is pollution of surface waters	<ul style="list-style-type: none"> <li>a) Require impervious site liner under pad with puncture proof underlay.</li> <li>b) Require double skinned closed storage tanks and bunding.</li> <li>c) Require tank level alarms.</li> <li>d) Require berm around site boundary.</li> <li>e) Ensure no connectivity between any runoff ditches from the well pad and any other surface water features adjacent to the well pad.</li> <li>f) Require collection and control of surface runoff.</li> <li>g) Avoid the use of persistent, bio-cumulative and toxic, carcinogenic and mutagenic chemicals.</li> <li>h) Require good site security.</li> <li>i) Characterisation of drilling muds.</li> <li>j) Disclosure of information on drilling muds to competent authority.</li> <li>k) Use of closed loop system to contain drilling mud.</li> <li>l) Use closed tanks for mud storage.</li> <li>m) Restrict muds to approved list with known properties/safety data or non-toxic drilling muds.</li> <li>n) Require accounting / tracking of mud use.</li> <li>o) Require good site practice to prevent leaks and spills.</li> <li>p) Require Emergency Resonse Plan to be developed and spill kits provided to ensure the prevention/containment of accidental spills.</li> <li>q) Require pollution prevention training (including use of spill kits).</li> </ul>



No.	Source	Activity	Summary	Measures
15.	Leakage from flowback storage (for flowback reuse)	Hydraulic fracturing	Potential impact if leaks occur Impact is pollution of surface waters	<ul style="list-style-type: none"> <li>a) Require impervious site liner under pad with puncture proof underlay.</li> <li>b) Require double skinned closed storage tanks and bunding.</li> <li>c) Require tank level alarms.</li> <li>d) Require berm around site boundary.</li> <li>e) Ensure no connectivity between any runoff ditches from the well pad and any other surface water features adjacent to the well pad.</li> <li>f) Require collection and control of surface runoff.</li> <li>g) Avoid the use of persistent, bio-cumulative and toxic, carcinogenic and mutagenic chemicals.</li> <li>h) Develop a list of approved chemicals for use in fracturing fluids or, as in the UK, a methodology to enable regulators to assess the hazard potential of any chemicals used.</li> <li>i) Require good site security.</li> <li>j) Require good site practice to prevention of leaks and spills.</li> <li>k) Require Emergency Response Plan to be developed and spill kits provided to ensure the prevention/containment of accidental spills.</li> <li>l) Require pollution prevention training (including use of spill kits).</li> </ul>
16.	Pollution risks from chemical transportation, storage, mixing and use	Hydraulic fracturing	Accidents and spillages can result in contamination (e.g. through tank ruptures, equipment and impoundment failures, overfills, vandalism, accidents, fires, poor operational practice) Impact is pollution of surface waters	See measures proposed for issue 15.
17.	Spillage of flowback and / or produced water recovery and management including pipelines and treatment facilities	Hydraulic fracturing and production	Spillage from tank ruptures, leaks from pipelines, equipment failures, overfills, poor operational practice and water transportation. Disposal of flowback and long term produced water. Fluids may contain added chemicals, NORM, heavy metals, organic compounds and are saline Impact is pollution of surface waters	See measures proposed for issue 14 and 15.
18.	Injection of pollutants into ground arising from injection activities	Hydraulic fracturing	Fluid contaminants transferred to groundwater and then to surface water via induced fractures extending beyond target formation, through bio-geological reactions with chemical additives, via pre-existing fractures / faults, via pre-existing man-made structures,	<ul style="list-style-type: none"> <li>a) Establish principle to maintain multiple geological barriers between the target formation and any aquifers.</li> <li>b) Undertake desk study and document potential leakage pathways (e.g. other wells, faults, mines) in sphere of influence of drilling and hydraulic fracturing to inform development of conceptual hydrogeological model.</li> <li>c) Require minimum distance between hydraulic fracture pipes and geological strata containing</li> </ul>

No.	Source	Activity	Summary	Measures
			well casing failures Impacts is pollution of aquifers and surface waters	<p>aquifers (e.g. ~literature review has identified range from between 600m -1,000m depending on source and country) and the surface (e.g. any activity closer than the specified depth requires special permit).</p> <p>d) Measures should be adopted to ensure well integrity including consultation on well design with appropriate regulators, bore testing, cement testing, the installation of a cement bond and continual pressure and formation pressure testing. The results of well integrity testing should be independently verified.</p> <p>e) Permits should require information relating to (inter-alia), the relationship between the zone of interest and any overlapping or adjacent aquifers, methods of well construction, well integrity testing, where the well stimulation fluid is expected to travel, details of the liquids to be injected, water use and disposal of effluents.</p> <p>f) A Hydraulic Fracturing Programme<sup>108</sup> similar to that in operation in the UK should be prepared by the operator and agreed with the relevant regulator.</p> <p>g) Where possible, non-hazardous chemicals should be used in fracturing fluids.</p> <p>h) Develop a list of approved chemicals for use in fracturing fluids or, as in the UK, a methodology to enable regulators to assess the hazard potential of any chemicals used.</p> <p>i) Require development of geo-referenced database of the zone before work commences covering geology, groundwater flows, pathways, microseismicity and subsequent updating of the model as information becomes available.</p> <p>j) Require modelling of fracturing programme to predict extent of fracture growth based on best information.</p> <p>k) Require monitoring and control during operations to ensure hydraulic fractures / pollutants do not extend beyond the gas-producing formations and does not result in seismic events.</p> <p>l) Implement remedial measures if well failure occurs and/or abandon well safely.</p>
19.	Improperly treated flowback or produced water leading to pollution of surface water	Hydraulic fracturing and production	Treatment in municipal sewage or other treatment plant will typically not remove NORM , salinity and other potential industry-specific contaminants Impact is pollution of surface waters	<p>a) Treatment plant operator to accept wastes, taking into account treatability/loading and ability to meet their own discharge consent limits.</p> <p>b) Establish treatment requirements for wastewater.</p> <p>c) Require dedicated wastewater treatment facility.</p> <p>d) Require duty of care / chain of custody arrangements for waste transfer.</p>
20.	Blowout event leading to surface water pollution	Drilling, fracturing and production	Individual events. Impact is pollution of aquifers and surface waters	<p>a) Require independent inspection, testing and audit of well operations (during planning, drilling and completions, production and abandonment) prior to and during the execution of activities (and use measures to manage releases from well).</p> <p>b) Require emergency response plan to be developed and put in place as part of an accident management plan.</p> <p>c) Require reporting of events to competent authority.</p>

<sup>108</sup> UKOOG (2013) guidelines suggest Hydraulic Fracturing Programmes (HFP) are developed “that describes the control and mitigation measures for fracture containment and for any potential induced seismicity” (See Appendix B.3.10 and <http://www.ukoog.org.uk/images/ukoog/pdfs/ShaleGasWellGuidelinesIssue2.pdf>).

No.	Source	Activity	Summary	Measures
				d) Sharing of information to ensure that all operators in a well field are aware of risks and can therefore plan. e) Implement remedial measures if well failure occurs and/or abandon well safely.
21.	Site decommissioning and abandonment activities leading to pollution event	Well pad removal	Improper grading may result in runoff and erosion. Removal of pad, facilities and water impoundment leading to accidental discharge to surface waters Impact is pollution of surface waters	a) Require good practice construction / deconstruction practices, including design for well abandonment. b) Require Emergency Response Plan to be developed and spill kits provided to ensure the prevention/containment of accidental spills; ensure training on use of spill kits. c) Require site reinstatement plan.

Table 3.6 summarises the key ground water risks and avoidance, minimisation and mitigation measures.

**Table 3.6 Summary of Risks to Ground Water and Avoidance, Minimisation and Mitigation Measures**

No.	Source	Activity	Summary	Measures
22.	Pollutants released from the well – (including NORM, chemical substances and gas (methane) contained in muds, cements, fuel oils, formation water)	Drilling Casing Cementing Well completion and subsequently Hydraulic fracturing Flowback management Production	Due to inadequate control and design of drilling, inadequate spacing between fracture zone and aquifers, casing quality, casing design and cementation quality Pathways are cross drilling, casing leaks, surface spills, pressure release, casing failure, cross-formation migration e.g. due to naturally existing faults, fissures or manmade structures such as mines and wells Impact is pollution of aquifers and surface waters	a) Establish and implement principle to maintain multiple geological barriers between the target formation and any aquifers. b) Require minimum distance between hydraulic fracture pipes and geological strata containing aquifers (e.g. ~literature review has identified range from between 600m -1,000m depending on source and country) and the surface (e.g. any activity closer than the specified depth requires special permit). c) Permits should require information relating to ( <i>inter-alia</i> ), the relationship between the zone of interest and any overlapping or adjacent aquifers, methods of well construction, well integrity testing, where the well stimulation fluid is expected to travel, details of the liquids to be injected, water use and disposal of effluents. d) Undertake desk study and document potential leakage pathways (e.g. other wells, faults, mines) in sphere of influence of drilling and hydraulic fracturing to inform development of conceptual hydrogeological model. e) A Hydraulic Fracturing Programme similar to that in operation in the UK should be prepared by the operator and agreed with the relevant regulator. f) Where possible, non-hazardous chemicals should be used in fracturing fluids. g) Consideration should be given to the development of a list of approved chemicals for use in fracturing fluids or, as in the UK, a methodology to enable regulators to assess the hazard potential of any chemicals used; h) Require development of a conceptual model of the zone before work commences covering geology, groundwater flows, pathways, microseismicity and subsequent updating of the model as information becomes available. i) Require modelling of fracturing programme to predict extent of fracture growth based on best information. j) Require microseismic and borehole monitoring and control during operations to ensure hydraulic fractures / pollutants do not extend beyond the gas-

No.	Source	Activity	Summary	Measures
				<p>producing formations and does not result in seismic events.</p> <p>k) Measures should be adopted to ensure well integrity including consultation on well design with appropriate regulators, bore testing, cement testing, the installation of a cement bond and continual pressure and formation pressure testing. The results of well integrity testing should be independently verified.</p> <p>l) Require integrity testing at key stages in well development e.g. before/during/after HF, including:</p> <ul style="list-style-type: none"> <li>• wireline logging (calliper, cement bond, variable density)</li> <li>• pressure / hydrostatic testing)</li> <li>• mechanical integrity testing of equipment (MIT).</li> </ul> <p>m) Require key elements to maintain well safety such as:</p> <ul style="list-style-type: none"> <li>• blowout preventers</li> <li>• pressure &amp; temperature monitoring and shutdown systems</li> <li>• fire and gas detection</li> <li>• continuous monitoring for leaks and release of gas and liquids</li> <li>• modelling to aid well/HF design</li> <li>• real-time monitoring of HF (such as microseismic surveys)</li> </ul> <p>n) Minimum casing and cementing requirements should be considered. For example, surface casing should extend at least 30m below the deepest underground source of drinking water encountered while drilling the well. The surface casing should be cemented before extending well below underground drinking water. Production casing should be cemented down to at least 150 metres above the formation where hydraulic fracturing will be carried out.</p> <p>o) Implement remedial measures if well failure occurs and/or abandon well safely.</p> <p>p) These should include details of any monitoring to be undertaken following well abandonment and the means of well plugging.</p>
23.	Flowback storage leakage leading to pollution	Hydraulic fracturing	Potential impact if leaks occur Impact is pollution of aquifers and surface waters	See measures for issue 15.
24.	Fracturing fluid chemical transportation, storage, mixing and use	Hydraulic fracturing	Accidents and spillages can result in contamination (e.g. through tank ruptures, equipment and impoundment failures, overfills, vandalism, accidents, fires, poor operational practice) Impact is pollution of aquifers and surface waters	See measures for issue 15 and: a) Require hydraulic fracturing specific chemical safety assessment addressing specific risks associated with unconventional gas and associated pathways for exposure of the environment and humans via the environment (including routes via underground pathways). Appropriate risk management measures to be specified in this assessment.
25.	Injection of pollutants into ground arising from injection	Hydraulic fracturing	Contaminants in fluid transferred to aquifers via induced fractures extending beyond target	See measures for issue 22.

No.	Source	Activity	Summary	Measures
	activities		formation, through biological reactions with chemical additives, via pre-existing fractures / faults, via pre-existing man-made structures, well casing failure. Between 0-75% of fracture fluid flows back to the surface in the short term (four weeks) and may remain in the ground or flow back to the surface as a component of produced water Impacts is pollution of aquifers, surface waters and deep groundwater	
26.	Spillage of wastewater (flowback and/ or produced water)	Hydraulic fracturing and production	Spillage from tank ruptures, pipelines, water treatment works, equipment failures, overfills, poor operational practice and water transportation. Disposal of flowback and long term produced water. Fluids may contain added chemicals, NORM, heavy metals, organic compounds and are saline. Produced water may incur a long term impact and is likely to exceed water inputs during fracturing Impact is pollution of aquifers and surface waters	See measures for issue 15 and: a) Characterisation (i.e. composition and volume) of chemicals, waste, flowback and produced water. b) Restrict additives to approved list with known properties/safety data e.g. that have demonstrated safe use specific to the relevant risks of UG extraction. c) Require records of additives, quantities used. d) Disclosure of information (e.g. composition, product name, purpose and volume to be used) to the public on chemicals used for fracturing, waste and wastewater. e) Review whether deep injection of flowback and produced water into designated formations would be a viable, credible and least environmentally damaging option to avoid inappropriate treatment and discharge to surface water and shallow (usable) groundwater. <sup>109</sup> f) Require accounting / tracking of flowback and produced water, including water disposal / reuse.
27.	Subsurface blowout event leading to entry of fluids into groundwater	Drilling, fracturing and production	Individual events. Impact is pollution of aquifers and surface waters	a) Require inspections, testing and audits of well (and use measures to manage releases from well). b) Require emergency response plan to be developed and put in place as part of an accident management plan. c) Require reporting of events to competent authority. d) Sharing of information to ensure that all operators in a well field are aware of risks and can therefore plan. e) Implement remedial measures if well failure occurs and/or abandon well safely.

**Table 3.7** summarises the key water resource risks and avoidance, minimisation and mitigation measures.

<sup>109</sup> Although common practice in North America, in Europe it is not permitted to manage flowback or produced water by reinjection at the present time.

**Table 3.7 Summary of Risks to Water Resource Risks and Avoidance, Minimisation and Mitigation Measures**

No.	Source	Activity	Summary	Measures
28.	Extraction of groundwater	Fracturing (extraction of groundwater for fracture fluid)	Lowering water table; dewatering aquifers and change in water quality (e.g. chemical contamination from mineral exposure to aerobic environment; bacterial growth due to lower water table; release of biogenic methane into superficial aquifers; upwelling of lower quality water or substances into aquifer; subsidence and destabilisation of geology. Potential cumulative effect of large numbers of operations, particularly in drought and dry periods but also in wet regions where there are stresses within existing water supplies due to substantial demands or limited infrastructure)	<ul style="list-style-type: none"> <li>a) Careful consideration should be given during site selection to existing and future water resource availability, in liaison with water providers and regulators.</li> <li>b) Operator to produce demand profile for development of well field, identifying intended sources of water and notifying the regulator and water provider.</li> <li>c) The operator and the relevant regulator(s) should assess the potential impacts on existing and future water resources at an early stage.</li> <li>d) Require water management plan, with water demand profile modified to reflect development of gas play.</li> <li>e) Options to reduce water demand during hydraulic fracturing should be considered where possible. This may include the treatment and re-use of flowback water or the adoption of waterless technologies.</li> <li>f) Require use of lower quality water for fracturing (e.g. non-potable ground / surface water or rainwater harvesting)</li> </ul>
29.	Extraction of surface water	Fracturing (extraction of surface water for fracture fluid)	Impacts on hydrology and hydrodynamics altering the flow regime and water quality. Potential cumulative effect of large numbers of operations, particularly in drought and dry periods but also in wet regions where there are stresses within existing water supplies due to substantial demands or limited infrastructure.	See measures for issue 28.

## 3.5 Air quality

Air quality within this context concerns the levels of pollutants emitted into the air and their significance, in terms of the risk of adverse effects on the environment and/or human health. The principal emissions to air arising from unconventional oil and gas exploration and production include carbon monoxide (CO), sulphur oxides (SO<sub>x</sub>), nitrogen oxides (NO<sub>x</sub>), particulate matter (PM), and carbon dioxide (CO<sub>2</sub>) from plant and vehicle engines; dust; and methane (CH<sub>4</sub>) and Volatile Organic Compound (VOC) releases from fracturing fluids and associated plant.

### 3.5.1 Effects on Air Quality

#### Non-intrusive Exploration

On site non-intrusive exploration surveys would result in emissions from vehicles and machinery, although this would be of minor scale and short term duration. Should significant new road infrastructure be required to facilitate site access then there may be increased emissions to air.



## Exploration drilling and hydraulic fracturing

There are several main sources of emissions to air during this stage, the majority of which would be similar to other large construction projects including conventional oil and gas exploration. One of these is exhaust fumes from HGVs, which arises from the transport of materials to and from the site, especially for the provision of water and removal of wastewater if pipelines to a mains supply are not in place. Dust emissions arise from pad preparation and construction activities such as earthworks, handling of dusty materials and movements over unpaved ground, in addition to the on-site handling (conveying and blending) of the sand-based proppant. The use of diesel generators, heavy machinery and other plant such as pumps for drilling and fracturing are a further source of emissions to air.

Methane and small amounts of VOCs can be released to air from flowback fluid, if the fluid is not contained in an enclosed vessel. It is preferable to capture the methane for use or export off site (green completions), as flaring the gas would result in the production of CO<sub>2</sub>, NO<sub>x</sub>, SO<sub>2</sub>, CO, and PM. Flaring is more likely to occur during the exploratory stages, as gas collection infrastructure is less likely to be in place compared to the later production stages. Fugitive emissions of methane and other pollutants such as NO<sub>x</sub>, CO and hydrocarbons may also occur from pumps, valves, pressure relief valves, flanges, agitators and compressors, as well as emissions of VOCs from oil tanks and hydrocarbon storage tanks.

Well blowouts can result in large scale, uncontrolled releases of fluids and gases which could have significant adverse impacts on local air quality. However, as highlighted in **Section 3.4.1**, blowouts are rare reflecting in particular the low permeability of shale.

## Production Development

Activities which give rise to adverse effects on air quality at this stage would be similar to exploratory drilling and fracturing. These include groundworks and dust generation; deliveries and removal of materials from the site; diesel-powered drilling equipment; and fracturing fluid pumps.

## Production/operation/maintenance

There may be ongoing fugitive emissions of methane and other trace hydrocarbons via leakages from valves, flanges and compressors during production and potentially also from the well itself. In addition, the well may be re-fractured again in the future, which would result in further air emissions as per the original fracturing process, such as releases from vehicle and plant exhausts, methane releases, leakages and dust generation from the proppant.

## Decommissioning and Site Restoration

Activities which may affect local air quality would be primarily associated with the use of vehicles and machinery to remove plant, equipment, well pad, wastes and other materials from the site. The plugging of the well would require some construction related activities but these would be of a small scale and short term in duration. Movements of earth and soil during restoration may give rise to dust depending on ground conditions.

### 3.5.2 Key Risk and Avoidance, Minimisation and Mitigation Measures

**Table 3.8** summarises the key air quality risks and avoidance, minimisation and mitigation measures.

**Table 3.8 Summary of Risks to Air Quality and Avoidance, Minimisation and Mitigation Measures**

No.	Source	Activity	Summary	Measures
30.	Emissions from construction activities and diesel generators (CO, CO <sub>2</sub> , NO <sub>x</sub> , SO <sub>x</sub> , particulates)	Site preparation Drilling Well injection of hydraulic fracturing fluid	Emissions of from diesel generators having a potential to give rise to local air quality impacts Potential cumulative risk due to effect of multiple well drilling pads (e.g. 1500-3000 kW power requirement) Potential for cumulative risk due to effect of multiple fracturing operations (e.g. 1500-3000 kW power requirement) Impact is reduced air quality and GHG releases	<ul style="list-style-type: none"> <li>a) Require preparation and implementation of an Emissions Reduction Plan including an assessment of potential local air quality impacts including implications for compliance with ambient air quality limit values.</li> <li>b) Require a Dust Suppression Plan, which could include positioning of dusty activities away from receptors; erecting screens; covering exposed soil and dusty materials; use of water sprays or exhaust ventilation systems (LEV); use of wheel washers on vehicles and covering of dusty loads; plus regular dust inspections.</li> <li>c) Air emission specifications should be considered during all equipment selection and procurement, including the use of low emission vehicles. Where possible, low or 'zero' sulphur fuels should be used for plant engines. Vehicles and machinery should shut down their engines when stationary or not in use.</li> <li>d) Require and implement Transport Plan to reduce HGV traffic (for example through load sharing); designate parking and storage areas; and identify appropriate transport routes and times e.g. avoiding peak traffic hours to minimise congestion and idling emissions.</li> <li>e) Require low emission power supply (i.e. LPG rather than diesel or use of grid electricity).</li> <li>f) Require lean burn and rich burn drilling rig engines.</li> <li>g) Require application of abatement techniques to minimise emissions e.g. ultra low sulphur diesel, diesel particulate filters.</li> </ul>
31.	Gases released from flowback and produced water (methane)	Flowback and produced water management	Potentially cumulative effect due to many wells over long time period (25 to 35 years) Impact is reduced air quality and GHG releases	<ul style="list-style-type: none"> <li>a) Require preparation and implementation of an Emissions Reduction Plan.</li> <li>b) Require reduced emission completions or green completions to eliminate gas venting and for capturing and cleaning for use of gas released from fracture fluid and produced water.</li> <li>c) Require flares or incinerators to reduce emissions from fracturing fluid at exploration stage (where not connected to gas network).</li> </ul>
32.	Fugitive emissions from valve or flange leakage (methane)	Production	Potential cumulative effect due to many wells over long time period (25 to 35 years) Impact is reduced air quality and GHG releases	<ul style="list-style-type: none"> <li>a) Require management as part of an emissions reduction plan (e.g. instigate programme of audits and checks by operator; gas leak prevention, detection and repair measures to stop leakage at an early stage)</li> </ul>
33.	Air pollutants released from well (fugitive and/or flared) (methane and combustion gases – CO, CO <sub>2</sub> , NO <sub>x</sub> , SO <sub>x</sub> )	Hydraulic fracturing and well completion Testing and transition to production Abandonment	Fugitive releases from wells which may occur over a few weeks to months. Risk from poor capping and closure. Impact is reduced air quality and GHG releases.	<ul style="list-style-type: none"> <li>a) Require preparation and implementation of an Emissions Reduction Plan.</li> <li>b) Require reduced emission completions or green completions to eliminate gas venting and for capturing and cleaning for use of gas released from fracture fluid and produced water.</li> <li>c) Require flares or incinerators to reduce emissions from fracturing fluid at exploration stage (where not connected to gas network).</li> </ul>
34.	Emissions from vehicles (CO <sub>2</sub> ,	Site preparation	Emissions from vehicles having a potential to	<ul style="list-style-type: none"> <li>a) Require preparation and implementation of a traffic</li> </ul>

No.	Source	Activity	Summary	Measures
	CO, NO <sub>x</sub> , SO <sub>x</sub> , particulates)	Drilling Well injection of hydraulic fracturing fluid Production	give rise to local air quality impacts. Related to transport of water and other hydraulic fracturing materials such as silica to site and waste water from site. Potential cumulative effect of many wells over long time period (25 to 35 years). Impact is reduced air quality and GHG releases	management plan b) Controls on phasing of vehicle activity, requirements for vehicles meeting certain standards, use of temporary surface pipes for distribution of water supply and collection of wastewater, select sites close to water sources and waste treatment / disposal facilities to minimise haulage requirements, requirement to provide wastewater treatment facility for given number of wells to minimise haulage
35.	Blowout event	Drilling, fracturing and production	Individual events resulting in releases to air	a) Requirements applied to well design and construction, testing, monitoring b) Require emergency response plan to be developed and put in place as part of an accident management plan

## 3.6 Climate Change

Climate change within the context of this study is concerned with increasing the likelihood of climate change effects through greenhouse gas (GHG) emissions associated with onshore oil and gas exploration and production activities and the ability of facilities to adapt to the effects of climate change such as the occurrence of more extreme weather events. GHGs include methane, carbon dioxide (CO<sub>2</sub>), nitrous oxide, VOCs and fluorinated gases. CO<sub>2</sub> is the primary GHG associated with human activities whilst methane is the second most prevalent. However, methane is more efficient at trapping radiation than CO<sub>2</sub> and its comparative impact on climate change is over 20 times greater than CO<sub>2</sub> over a 100-year period<sup>110</sup>.

### 3.6.1 Effects on Climate Change

#### Non-intrusive Exploration

GHG emissions during this stage would be low such that any effects on climate change are unlikely to be significant. Notwithstanding, should significant new road infrastructure be required to facilitate site access then associated emissions may be more substantive

#### Exploration Drilling and Hydraulic Fracturing

##### Greenhouse Gas Emissions

Sources of GHG emissions during this stage of the unconventional oil and gas exploration and production lifecycle are similar to those associated with conventional oil and gas exploration and production activities and include: pad preparation and drilling; emissions of CO<sub>2</sub> and methane associated with disturbance to soils; and the potential loss of soil carbon sequestration. However, there would be additional GHG emissions associated with hydraulic fracturing and well completion.

The principal source of GHG emissions from energy use would be the drilling of boreholes and hydraulic fracturing associated with the use of drilling equipment, pumping of fracturing fluid and the transportation and treatment of wastes (as well as the embodied carbon in any materials/chemicals used). The exact volume of GHG emissions associated with these activities depends upon a number of factors including the length of the well bore, quantities of water and other chemicals required for fracturing and treatment and transportation requirements. MacKay and Stone (2013) estimate that drilling and hydraulic fracturing operations during the

<sup>110</sup> See <http://www.epa.gov/climatechange/ghgemissions/gases/ch4.html>

pre-production phase (i.e. stages 2 and 3 of the unconventional oil and gas exploration and production lifecycle for the purposes of this study) would generate 711 tCO<sub>2</sub>eq per well<sup>111</sup>. This is based on median values of GHG emissions taken from a range of data sources where the maximum value reported was 1,790 tCO<sub>2</sub>eq per well. Indirect emissions associated with the transportation of water (including wastewater transport and treatment) are estimated to be 21 tCO<sub>2</sub>eq per well and the embodied carbon in chemicals 300 tCO<sub>2</sub>eq.

Following the completion of hydraulic fracturing, a combination of fracturing fluid and water is returned to the surface (flowback) which includes methane (known as well completion). Well completion is likely to be the main source of GHG emissions during the pre-production phase. MacKay and Stone (2013) estimate GHG emissions associated with well completion to be 2,788 tCO<sub>2</sub>eq per well (during stages 2 and 3), assuming that 90% of methane emissions released during flowback are captured and flared. However, estimates of the volume of gas released during well completion vary significantly with the method of well completion being a key factor in influencing levels of GHG emissions. In this respect, gas generated during well completion may be flared (i.e. combusted in an open flame), cold vented or captured/recovered (known as reduced emissions completion (REC) or green completions). A study by Allen et al (2013) concerning methane emissions at natural gas production sites in the US<sup>112</sup> concludes that the application of current good practice (in separation and capture of methane from the flowback fluid, so that it can be flared, utilised or sold) is more successful in reducing well completion emissions than previously estimated.

A further source of GHG emissions are unintentional gas leaks (known as fugitive emissions). These may be attributed to a range of sources including leaks from valves, well heads, equipment and onsite accidents. The work of Jackson et al (2013), amongst others, highlights that a potential source of fugitive emissions could also be from gas that has escaped into aquifers as a result of poor well construction during drilling, production or after abandonment<sup>113</sup>.

### **Climate Change Impacts**

Construction and exploration could be affected by climate change where sites are located, for example, in coastal areas that may be affected by coastal inundation or sea level rise or in areas of flood risk that could be susceptible to extreme weather conditions. This risk is similar to other types of development.

Given the requirement for hydraulic fracturing during this stage and associated water consumption, there is the potential for activities to be both affected by climate change impacts on water resource availability and/or to affect future water resource availability.

### **Production Development**

The range and type of effects associated with Stage 3 of the unconventional oil and gas exploration and production lifecycle would be similar to those identified under Stage 2<sup>114</sup>.

### **Production/Operation/Maintenance**

#### **Greenhouse Gas Emissions**

During the production stage, there would be GHG emissions associated with power generation and onsite combustion plant (e.g. generators), vehicle movements and any fugitive methane releases. However, emissions from these sources would be similar to those associated with conventional gas production. Based on MacKay and Stone's (2013) central estimate of well productivity (estimated total of 85 million m<sup>3</sup> over the

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<sup>111</sup> MacKay, D.J.C. and Stone, T.J. (2013) Potential Greenhouse Gas Emissions Associated with Shale Gas Extraction and Use. Report on behalf of DECC. London: DECC

<sup>112</sup> Allen, D.T., Torres, V.M., Thomas, J., Sullivan, D.W., Harrison, M., Hendler, A., Herndon, S.C., Kolb, C.E., Fraser, M.P., Hill, D. Lamb, B.K. Miskimins, J., Sawyer, R.F. and Seinfeld, J.H. (2013) Measurements of methane emissions at natural gas production sites in the United State. PNAS (2013) published ahead of print September 16, 2013, doi:10.1073/pnas.1304880110.

<sup>113</sup> Jackson et al (2013) Increased stray gas abundance in a subset of drinking water wells near Marcellus shale gas extraction, PNAS, 110 (28), 11250-11255. Available from <http://www.pnas.org/content/110/28/11250.short> (accessed November 2014)

<sup>114</sup> For the purposes of this study, estimates of GHG emissions (as presented in **Section 3.6**) cover activities under both stages 2 and 3 and are therefore not repeated here to avoid double counting.

20 year lifetime of the well<sup>115</sup>), it is assumed that total GHG emissions per well would be 8,500 tCO<sub>2</sub>e during production.

Re-fracturing may be required during the production stage to stimulate the flow of shale gas. This would generate additional GHG emissions similar to those noted in respect of hydraulic fracturing and well completion during stages 2 and 3 (on a per well basis). The removal of fluids to maintain production (liquid unloading) may also be required and which may be a potentially significant source of GHG emissions.

Indirectly, the combustion of extracted hydrocarbons would generate approximately 190 gCO<sub>2</sub>e/kWh (which represents combustion emissions for methane). The extent to which domestic production and consumption of shale gas would affect GHG emissions would vary subject to changes in prices affecting demand and supply relative to other sources of energy, national policy and legislation on energy and, in the long term, changes in investment in alternative supplies of gas and other energy sources. There is also a need to consider the impact of shale gas production and consumption on global emissions. In the US, for example, the switch to shale gas has increased exports of coal, increasing the carbon intensity of energy production in other countries.

### **Climate Change Impacts**

Climate change impacts during this stage would be similar to those identified during stages 2 and 3.

### **Decommissioning and Site Restoration**

#### **Greenhouse Gas Emissions**

During decommissioning there would be emissions of GHGs associated with the use of machinery and plant as well as from construction traffic. There would also be emissions associated with the embodied carbon in concrete used to plug wells and, potentially, the treatment of any waste arising. Emissions in this regard would be similar to those associated with the decommissioning of conventional oil and gas wells.

The inadequate sealing of wells following production could result in the release of fugitive emissions. Whilst there is a lack of data relating to emissions following well abandonment, a recent study of 19 abandoned wells in Pennsylvania by Kang (2014)<sup>116</sup> has identified that methane emissions from abandoned wells could be more substantial than previously thought, and is an area that will require further research.

### **Climate Change Impacts**

Decommissioning could be affected by climate change where sites are located, for example, in coastal areas that may be affected by coastal inundation or sea level rise or in areas of flood risk that could be susceptible to extreme weather conditions. Climate change effects such as intensified weather events therefore have the potential to affect activities during Stage 5, particularly given the fact that decommissioning would take place in the longer term (i.e. beyond the lifetime of a well) during which time the impacts of climate change (e.g. sea level rise) could become more pronounced. This risk would be similar to that associated with the decommissioning of conventional oil and gas wells.

## **3.6.2 Key Risk and Avoidance, Minimisation and Mitigation Measures**

**Table 3.9** summarises the key climate change risks and avoidance, minimisation and mitigation measures.

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<sup>115</sup> 20 years represents the total licence period for Petroleum Exploration and Development Licences in the UK. It should be noted that a well's lifetime may extend beyond a 20 year period (up to around 40 years).

<sup>116</sup> Kang, M. (2014) CO<sub>2</sub>, Methane, and Brine Leakage through Subsurface Pathways: Exploring Modelling, Measurement, and Policy Options. A Dissertation Presented to the Faculty of Princeton University in Candidacy for the Degree of Doctor of Philosophy. Recommended for Acceptance by the Department of Civil and Environmental Engineering. Note that the findings of the study are subject to peer review.

**Table 3.9 Summary of Climate Change Risks and Avoidance, Minimisation and Mitigation Measures**

No.	Source	Activity	Summary	Measures
36.	Effects from site selection	Site selection	Emissions from site selection arising from disturbing/affecting carbon sink. Selection of site that could be affected by future climate change effects	a) Site selection should be informed by an assessment of flood risk to ensure that risks associated with climate change impacts are identified and addressed (e.g. through the implementation of sustainable drainage systems). During the site selection process, careful consideration should be given by the operator to the avoidance of carbon sinks (e.g. peats).
37.	Emissions from construction activities and diesel generators (CO <sub>2</sub> )	Site preparation Drilling Well injection of hydraulic fracturing fluid	Emissions from diesel generators having a potential to give rise to local air quality impacts Potential cumulative risk due to effect of multiple well drilling pads (e.g. 1500-3000 kW power requirement) Potential for cumulative risk due to effect of multiple fracturing operations (e.g. 1500-3000 kW power requirement) Impact is reduced air quality and GHG releases	a) Where possible, measures should be taken to offset (at least in part) GHG emissions arising from construction and operational activities. These measures <i>inter alia</i> may include, for example: <ul style="list-style-type: none"> <li>• the use of construction materials with low embodied carbon;</li> <li>• measures to reduce private vehicle use for workers;</li> <li>• the use of low emission vehicles or HGVs conforming to the highest available standards for vehicle emissions;</li> <li>• the use of low emissions equipment and alternative energy sources;</li> <li>• use low emission power supply (i.e. LPG rather than diesel or use of grid electricity).</li> <li>• require lean burn and rich burn drilling rig engines.</li> <li>• development of a transport plan to reduce HGV traffic (for example through load sharing); designate parking and storage areas; and identify appropriate transport routes and times e.g. avoiding peak traffic hours to minimise congestion and idling emissions;</li> <li>• sourcing local materials, personnel, equipment and waste disposal to help reduce vehicle movements to the site;</li> <li>• connecting to water supplies and wastewater infrastructure to reduce requirements to tanker water to and from site, reducing emissions from vehicles;</li> <li>• provision for the transportation of materials and construction wastes by rail where practicable;</li> <li>• identifying opportunities for the on-site reuse, recycling and recovery of inert and non-hazardous waste; and</li> <li>• where possible, retaining equipment on-site.</li> </ul> b) Require preparation and implementation of an Emissions Reduction Plan including an assessment of potential local air quality impacts including implications for compliance with ambient air quality limit values.
38.	Gases released from flowback and produced water (methane)	Flowback and produced water management	Potentially cumulative effect due to many wells over long time period (25 to 35 years) Impact is GHG releases	a) Require preparation and implementation of an Emissions Reduction Plan based on the principle of as low a level as reasonably practicable (ALARP). b) Require reduced emission completions or green completions to eliminate gas venting and for capturing and cleaning for use of gas released from fracture fluid and produced water. c) Require enclosed completion systems be adopted to



No.	Source	Activity	Summary	Measures
				<p>avoid venting from lagoons or tanks.</p> <p>d) Require flares or incinerators to reduce emissions from fracturing fluid at exploration stage (where not connected to gas network).</p> <p>e) Require monitoring of their sites to: (1) ensure early warning of unexpected leakages; and (2) obtain emissions estimates for regulators and government. This may include, for example, ambient air monitoring, hydrostatic pressure testing of pipework and equipment used to transport gas, regular seismic monitoring and monitoring of fracture propagation.</p>
39.	Fugitive emissions from valve or flange leakage (methane)	Production	Potential cumulative effect due to many wells over long time period (25 to 35 years) Impact is GHG releases	a) Require management as part of an emissions reduction plan (e.g. instigate programme of audits and checks by operator; gas leak prevention, detection and repair measures to stop leakage at an early stage)
40.	Fugitive and/or flared methane releases	Hydraulic fracturing and well completion Testing and transition to production Abandonment	Fugitive releases from well Release may occur over a few weeks to months. Fugitive release from well Risk from poor capping and closure Impact is reduced air quality and GHG releases	See measures for issue 38.
41.	Emissions from vehicles (CO <sub>2</sub> )	Site preparation Drilling Well injection of hydraulic fracturing fluid Production	Emissions from vehicles having a potential to give rise to local air quality impacts  Potential cumulative effect of many wells over long time period (25 to 35 years). Impact is reduced air quality and GHG releases	a) Require preparation and implementation of a traffic management plan b) Controls on phasing of vehicle activity, requirements for vehicles meeting certain standards, use of temporary surface pipes for distribution of water supply and collection of wastewater, select sites close to water sources and waste treatment / disposal facilities to minimise haulage requirements, requirement to provide wastewater treatment facility for given number of wells to minimise haulage
42.	Fugitive emissions from abandoned wells	Site abandonment	Fugitive emissions of methane from poorly capped wells	a) Well design and methods of plugging should minimise long term fugitive emissions. Monitoring should be undertaken to detect any release of emissions.

### 3.7 Waste Arisings

Waste management is defined as the processing, recycling or disposal of a range of waste types including municipal, commercial and industrial, construction, excavation and demolition and hazardous wastes. The principal waste streams generated from the hydraulic fracturing process include: cement, aggregates, and construction waste; drilling muds and cuttings; flowback fluid and produced water; natural gas; and well infrastructure. Other waste that is likely to be generated on site includes: waste oils; paraffins; waxes; oil contaminated rags; used batteries; waste chemicals, scrap metals, used containers and contaminated rainwater. Sanitary wastewater would also be generated from site facilities.

### 3.7.1 Effects on Waste Arising

#### Non-intrusive Exploration

The majority of activities in this stage are desk-based, and it is not expected that substantial quantities of waste would be generated. Seismic surveys would also take place, some of which may require roads or hard surfaces to provide access; however, the majority of such surfaces would be temporary and it is expected that any material used could be recycled after use to reduce waste.

#### Exploration drilling and hydraulic fracturing

The well pad site typically comprises of an area up to 1-2 ha during this stage. The well pad would be constructed from compacted aggregate laid on an impermeable membrane and geotextile layer. Like conventional oil and gas projects, small amounts of waste would be generated through the preparation of the well pad, such as stripped vegetation. Concrete and mixed construction waste is expected to be generated from the construction of site compounds, surface seismic monitoring array, well pad and associated infrastructure.

The drilling of test boreholes and wells would create waste in the form of drill cuttings, spent drill muds, excess cement and spacer fluid. Flowback water returning to the surface during the hydraulic fracturing process is a significant source of waste during this stage. Flowback water is typically very saline and contains minerals dissolved from the rocks, as well as a certain amount of fracturing fluid. NORM can also be present in flowback water, and may result in flowback water being designated as radioactive waste. Produced water is also generated from the rocks across the lifetime of the well and requires appropriate management and disposal.

Flowback water requires treatment on site to enable reuse and reinjection or removal off site to an appropriately licensed wastewater treatment facility. The re-use of flowback water is less likely during exploratory drilling than later production stages due to the infrastructure required. Disposal at a wastewater treatment plant may require pre-treatment to avoid damaging the treatment plant due to the high salinity, pollutant content and the potential radioactivity of flowback water.

Natural gas is released from drilling and flowback fluid, and is classed as an extractive waste. 'Green completion', which involves the capture of methane for use or export off site, is the preferred option, however gases may be disposed of by flaring in the earlier exploration stages if the infrastructure for collection is not in place. Venting natural gas is not permitted in the UK except for safety reasons. Other waste that is likely to be generated on site includes: waste oils; paraffins; waxes; oil contaminated rags; used batteries; waste chemicals, scrap metals and used containers.

#### Production Development

The range and type of effects associated with production development would be similar to those identified under exploration drilling and hydraulic fracturing. However, there would be additional infrastructure such as storage tanks, road connections and on-site pipelines resulting in an increased land take. The extension of the pad is not expected to result in additional waste as the soil would be collected and stored around the site perimeter.

#### Production/operation/maintenance

Once in production, the treatment and reuse of fracturing fluid may be a more economically viable option compared to the exploration stage, as would the collection of waste methane from the fracturing fluid. Wells may be refractured, and for each refracturing that occurs, this would result in similar levels of flowback water and methane emissions being generated as for the earlier exploration stage.

#### Decommissioning and Site Restoration

It is expected that a proportion of the well infrastructure could be re-used at other locations or recycled. Large waste streams are therefore not expected at this stage. Soil that has been stored on site should be reused to restore the site to the previous land use.

### 3.7.2 Summary of Risks and Avoidance, Minimisation and Mitigation Measures

**Table 3.10** summarises the key waste risks and avoidance, minimisation and mitigation measures.

**Table 3.10 Summary of Waste Risks and Avoidance, Minimisation and Mitigation Measures**

No.	Source	Activity	Summary	Measures
43.	Construction activities leading to generation of waste	Site preparation	Waste arising from site preparation and construction requiring offsite management	<ul style="list-style-type: none"> <li>a) Planning resource management should be used to ensure that the minimum amount of waste is generated, for example by avoiding over-ordering supplies; correct storage of materials to avoid damage and wastage; use of suppliers that minimise packaging; and specification of materials, such as recycled or reusable materials, where possible.</li> <li>b) Require a Site Waste Management Plan to ensure that all wastes produced are handled according to regulatory requirements and best practice. Waste management planning should establish a clear strategy for wastes that will be generated including options for waste elimination, reduction, recycling, treatment and disposal.</li> <li>c) Ensure on-site waste management to separate waste streams such as timber, scrap metal and cardboard promotes reuse and recycling and helps reduce volumes of waste sent to landfill.</li> <li>d) Materials used for the construction of access roads should be chosen dependant on their ability to be recycled into a product for which there is a viable market.</li> <li>e) All soils should be handled in suitable conditions (e.g. dry weather) and the most appropriate method of soil handling should be used. Soils should be stored in allocated heaps and protected from erosion, contamination or degradation. Different soil types should be stored separately e.g. topsoil, sub-surface material, and the length of time soils are stored should be minimised where possible.</li> </ul>
44.	Cement waste from the well casing	Drilling	Cement waste arising from cementing well casing	<ul style="list-style-type: none"> <li>a) Require management of cement waste as part of required Waste Management Plan which will set out quantities arising and methods to ensure safe short- and long-term disposal.</li> <li>b) Require recycling of cement where feasible.</li> <li>c) Require residual waste to receive appropriate treatment and disposal.</li> </ul>
45.	Drill cuttings used with polymer based water muds	Drilling	Drill cuttings arising from drilling well require appropriate treatment (assumed to be non-hazardous waste stream)	<ul style="list-style-type: none"> <li>a) Require management of drill cuttings as part of required Waste Management Plan which will set out quantities arising and methods to ensure safe short- and long-term disposal</li> <li>b) Require treatment at a specialist facility.</li> <li>c) Require residual waste to specialist disposal facility.</li> </ul>
46.	Drill mud (assumed to be water based)	Drilling	Used drilling mud as waste requiring appropriate treatment	<ul style="list-style-type: none"> <li>a) Require management of mud as part of required Waste Management Plan which will set out quantities and chemicals to be used and methods to encourage recovery and to ensure safe short- and long-term disposal</li> <li>b) Restrict muds to approved list with known properties/safety data or non-toxic drilling muds.</li> <li>c) Use of closed loop system to contain and store drilling mud.</li> <li>d) Require accounting / tracking of mud use.</li> <li>e) Treat drilling muds on site for reuse in order to reduce the total volume required.</li> <li>f) Require all muds to be disposed through permitted disposal route once they can no longer be recycled and reused.</li> <li>g) Return any unused drilling muds to the vendor.</li> </ul>

No.	Source	Activity	Summary	Measures
				h) Require Emergency Response Plan to be developed and spill kits provided to ensure the prevention/containment of accidental spills; ensure training on use of spill kits.
47.	Flowback and produced water (including water containing NORMS)	Hydraulic fracturing	Flowback and produced water treated as waste requiring appropriate treatment	<ul style="list-style-type: none"> <li>a) Require impervious site liner under pad with puncture proof underlay.</li> <li>b) Require double skinned closed storage tanks and bunding.</li> <li>c) Require tank level alarms.</li> <li>d) Require berm around site boundary.</li> <li>e) Require management of flowback and produced water as part of required Waste Management Plan which will set out quantities and chemicals to be used and methods to encourage recovery and to ensure safe short- and long-term disposal</li> <li>f) Avoid the use of persistent, bio-cumulative and toxic, carcinogenic and mutagenic chemicals.</li> <li>g) Develop a list of approved chemicals for use in fracturing fluids or, as in the UK, a methodology to enable regulators to assess the hazard potential of any chemicals used.</li> <li>h) Require accounting and tracking of fracking chemicals used.</li> <li>i) Consider options for treatment of flowback fluid on site so that it can be reused in the hydraulic fracturing process, for example through separation to remove sand, oil and gas, plus ultraviolet (UV) disinfection. Sand separated through the treatment of flowback fluid can be removed from site and recycled into aggregates.</li> <li>j) Undertake analysis to assess the existence and extent of NORM during the exploratory phase in order to determine the likely requirement for wastewater treatment.</li> <li>k) Ensure that flowback fluid/produced water containing NORM is treated using an approach that ensures environmental protection, and is not disposed of at wastewater treatment works that are unable to process radioactive waste. Options could include pre-treatment with acid-alkali to precipitate out NORM for disposal or treatment at a wastewater treatment site licensed to accept radioactive waste.</li> <li>l) Consider the use of reverse osmosis or evaporation and crystallisation to reduce levels of Total Dissolved Solids (TDS) in wastewater, as wastewater treatment plants may not be designed to remove these substances. Elevated TDS levels may affect the functioning of the wastewater plant and potentially contaminate any receiving waters after discharge.</li> <li>m) Once flowback and/or produced water considered waste water, identify treatment plant operator to accept wastes, taking into account treatability/loading and ability to meet their own discharge consent limits.</li> <li>n) If necessary, require dedicated wastewater treatment facility.</li> <li>o) Require duty of care / chain of custody arrangements for waste transfer.</li> </ul>
48.	Rainwater	Operation	Rainwater collected onsite requiring treatment	a) Rainwater collected on the surface of the pad should be regularly tested to determine whether it is uncontaminated and can be discharged from site or used within the hydraulic fracturing process, or

No.	Source	Activity	Summary	Measures
				whether it requires collection and removal from site as hazardous waste e.g. if contaminated with oil/chemicals.
49.	Gases released from flowback and produced water (methane)	Flowback and produced water management	Potentially cumulative effect due to many wells over long time period (25 to 35 years) Impact is GHG releases	See measures proposed for issue 38.
50.	Site decommissioning and abandonment activities leading to pollution event	Well pad removal	Waste arising from site preparation and construction requiring offsite management	a) Require good practice construction / deconstruction practices, including design for well abandonment. b) Require site reinstatement plan.

## 3.8 Cultural Heritage

Cultural heritage, including architectural and archaeological heritage, is defined as below- and above-ground evidence of past human activity such as archaeological sites, earthworks, buildings, battlefields and historic landscapes. Cultural heritage assets in their widest sense may also include land, buildings and structures/objects that have, for example, an important cultural meaning/use, artistic significance or scientific value.

The significance of cultural heritage assets ranges from very high (assets of international importance such as World Heritage Sites) to negligible (assets with no or very little surviving heritage interest). Effects could be either direct or indirect in character. Direct effects will result from activities associated with construction of the well-pad, access track and seismic arrays involving removal of topsoil and excavations. Indirect effects could arise from changes to local patterns of drainage potentially affecting buried deposits distant from the site. Effects can also be temporary or permanent in nature and could range in significance from very large adverse (partial or total loss of a site of very high importance) to neutral (no appreciable impacts); however, the likelihood of any adverse effects on a known designated heritage site are considered low, as steps will be taken through siting to avoid any consequence for the heritage site.

### 3.8.1 Effects on Cultural Heritage

#### Non-intrusive Exploration

Cultural heritage is unlikely to be affected during the non-intrusive investigation phase.

#### Exploration drilling and hydraulic fracturing

There would be the potential for the loss or damage to cultural heritage features associated with preparation for drilling, although site investigation should have largely anticipated these effects. The potential for effects would depend upon the proximity of any investigations or works to cultural heritage or archaeological sites, features or landscapes, and their current condition and sensitivity.

It is important to note that the potential effects on cultural heritage assets described above would be similar to those associated with the construction of conventional oil and gas well pads as well as any other development projects.

#### Production development

There would be the potential for the loss or damage to cultural heritage features and landscapes associated with preparation for drilling (such as through site expansion), although site investigation should have anticipated these effects.

## Production/operation/maintenance

Subject to appropriate mitigation identified as part of Stages 1-3, no effects on above-ground cultural heritage or archaeological sites or features are anticipated as a result of operational activities as no further surface disturbance will occur.

## Decommissioning and site restoration

No effects on cultural heritage features or landscapes are anticipated as a result of decommissioning, including subsurface and buried archaeological remains as these will have been identified in previous stages.

### 3.8.2 Summary of Risks and Avoidance, Minimisation and Mitigation Measures

**Table 3.11** summarises the risks to cultural heritage and avoidance, minimisation and mitigation measures.

**Table 3.11 Summary of Risks to Cultural Heritage and Avoidance, Minimisation and Mitigation Measures**

No.	Source	Activity	Summary	Measures
51.	Land required for the well pad	Site selection and preparation and all subsequent stages	<p>Potential cumulative risks of impacts on removal of cultural heritage assets or on setting of existing assets</p> <p>Impact arises from the degrading, fragmentation or destruction of cultural heritage</p>	<ul style="list-style-type: none"> <li>a) Avoidance of sites of high cultural heritage value.</li> <li>b) Prohibit operations within specified sites (e.g. World Heritage Sites or within certain distances to specified sites).</li> <li>c) Restrict operations within specified sites (see above) and within certain distances to specified sites.</li> </ul>
52.	Construction activities leading to effects on cultural heritage assets	Site preparation	<p>Potential cumulative risks of impacts on removal of cultural heritage assets or on setting of existing assets</p> <p>Impact arises from the degrading, fragmentation or destruction of cultural heritage</p>	<ul style="list-style-type: none"> <li>a) Plan for site design and layout, in liaison with local and national experts, and should take account of potentially vulnerable cultural heritage assets and their settings, including historic landscapes, which could be affected by construction and operational activities.</li> <li>b) Prior to any works on site, a desk study and site walkover should be undertaken to determine the historic and archaeological value of the sites and potential need for further site evaluation through trial trenching or more specific geophysical surveys;</li> <li>c) Where buried heritage assets known or anticipated, close monitoring during topsoil stripping and excavation works should be undertaken to identify unexpected features or artefacts. This can involve mapping and recording of features which could require further investigation.</li> <li>d) Where potential impacts are identified the construction should be altered to minimise impacts, and if retention is not possible, consideration should be given to moving features or undertaking detailed excavation and recording.</li> <li>e) Identification of appropriate access routes would help to minimise potential negative effects on historic or archaeological features such as listed buildings, caused by transport pollution and vibration associated with lorry movements.</li> <li>f) Forward planting to screen the site could be required to reduce potential visual impacts on cultural heritage assets.</li> <li>g) Require optimisation of well pads to minimise land take, i.e. the number of wells, pad density and pad spacing (e.g. one pad per 2.6 km<sup>2</sup> proposed by New York State).</li> </ul>



## 3.9 Landscape

Landscape is an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors and applies to rural areas, suburban and urban areas. Visual effects are those effects that influence how people see a landscape or townscape, such as the erection of a building or structure. Potential impacts are likely to be principally visual (some of which will be temporary) in character, but can also involve effects on people's wider perception of an area.

### 3.9.1 Effects on Landscape

#### Non-intrusive Exploration

Overall, the effects on landscapes and visual amenity would be localised and of a temporary nature, occurring only during seismic surveys, and as such are of a minimal impact. Notwithstanding, should new road infrastructure be required to facilitate site access then the potential for adverse landscape impacts may be increased.

#### Exploration drilling and hydraulic fracturing

Like conventional oil and gas projects, activity associated with pad preparation, road access and well construction would have short and medium-term impacts on visual amenity and landscapes whilst further visual impacts will result from the presence of well heads, drilling rigs and associated equipment, with drilling operations lasting from 2 – 5 months per well). The drilling rig would be in the range of 30-50m high and could result in locally significant effects depending on the character and sensitivity of the receiving landscape and the extent to which such landscape changes are visible to communities.

#### Production Development

Additional visual impacts are likely to be associated with the expansion of the well pad area, additional materials on site such as storage tanks, and the temporary effects associated with the laying of pipelines. Depending on the density of the well pads, the potential cumulative visual effects of well development are potentially significant, where a network of wells and associated pipelines and roadways could affect a wide area.

#### Production/operation/maintenance

There would be no additional effects resulting from this stage under the assumption that production, operation and maintenance would take place on the existing site.

#### Decommissioning and site restoration

Decommissioning of wells and removal of site equipment would involve some construction activity. The activity would be short-term and take place on the existing site.

### 3.9.2 Summary of Risks and Avoidance, Minimisation and Mitigation Measures

**Table 3.12** summarises the risks to landscape and avoidance, minimisation and mitigation measures.

**Table 3.12 Summary of Risks to Landscape and Avoidance, Minimisation and Mitigation Measures**

No.	Source	Activity	Summary	Measures
53.	Land required for the well pad	Site selection and preparation and all subsequent stages	Potential cumulative risks of impacts on landscape  Impact arises from the changes to landscape and degradation of landscape character	<ul style="list-style-type: none"> <li>a) Site selection to avoid visual intrusion onto sensitive receptors, based on an assessment of landscape and visual impact to judge the relationship between the magnitude of the effects (nature-geographical extent-duration) and the sensitivity (low-medium-high) of the receptor(s).</li> <li>b) Require compatibility with current and future potential land use (Natura 2000 sites, conservation sites, human use, industrial use, appropriate zoning).</li> </ul>
54.	Plant, materials storage, fencing, buildings, waste water tanks, drill rigs, lighting	Operations throughout site lifetime	Potential cumulative affects of multiple well pads, particularly in non-industrial settings. Drill rigs are in place for approximately four weeks per well	<ul style="list-style-type: none"> <li>a) Require best practice construction techniques such as minimising the vertical height of drilling equipment (typically 30-50m high) and site screening through existing features or use of planting and landscaping.</li> <li>b) Creation of bunds to help screen operations using stored topsoil as well as targeted planting of vegetation which would contribute to long-term screening.</li> <li>c) Optimise the phasing of the development of well pads to minimise cumulative impacts.</li> <li>d) Restrict working hours to daylight hours and adopt site screening to avoid light pollution to the surrounding area.</li> <li>e) Require optimisation of well pads to minimise land take, i.e. the number of wells, pad density and pad spacing (e.g. one pad per 2.6 km<sup>2</sup> proposed by New York State).</li> </ul>

## 3.10 Human Health

Human health includes the potential for negative effects on public health and site workers as a result of shale gas activities. Particular pressures and risks relating to human health include emissions to air from vehicles and equipment; contamination of groundwater from fracturing activities; discharges of contaminated wastewater; noise; and exposure to radioactive materials.

### 3.10.1 Effects on Human Health

#### Non-intrusive Exploration

Activities at this stage are expected to be largely desk based, with minimal noise and disturbance generated from site seismic surveys. As a result, no effects on health are expected.

#### Exploration drilling and hydraulic fracturing

Impacts on health may arise from various activities in this stage. Pad preparation and construction can result in noise and dust generation. HGV movements to transport materials and the use of diesel generators for site equipment and drilling processes would result in harmful emissions to air, such as particulate matter (PM10), nitrogen oxides (NOX), carbon monoxide (CO), volatile organic compounds (VOCs) and sulphur dioxide (SO<sub>2</sub>). The number of HGV movements could be more substantial if the water required for hydraulic fracturing and flowback is tankered to/from site. In respect of its proposed site in Lancashire, UK, Cuadrilla estimate that vehicle movements would peak at 250 truck movements per day during the most intense periods, although this would only be sustained for short intervals. HGV movement may generate emissions and dust potentially affecting those with respiratory problems as well as noise and vibrations which may cause stress and anxiety to residents principally alongside local transport networks. However, the potential for negative health impacts would depend on numerous factors such as the proximity of HGV routes to residential or other sensitive areas and the existing background levels of pollution. Drilling is an activity with significantly high noise levels, with continuous operations each day over a period of several weeks or

months. For construction equipment used in the preparatory stages, the maximum calculated composite noise level at 75m is 70dBA. For horizontal drilling, the maximum noise level is 64dBA.<sup>117</sup> Depending on the distance from the noise source, any attenuation and ambient noise levels, noise at 64dBA could disturb local residents, particularly in sensitive areas and noise controls would be necessary. As the oil and gas sector already has widely used noise controls, it is anticipated that effects can largely be avoided if the installation is properly designed and managed.

The hydraulic fracturing process has the potential to contaminate public drinking water supplies through leakage of fracturing fluid as a result of spills and containment vessel failures, the flooding of settlement ponds, the migration of methane and contaminants from well integrity failure and the uncontrolled discharge of contaminated wastewater. The risks of water contamination are however generally low due to the regulatory protection of water supplies, although accidental spillages may still occur<sup>118</sup>. Private water supplies are more vulnerable to contamination as they are more localised, have limited resources, diminishing any benefits from dilution and shorter residence times increasing the potential for exposure. Within the UK, they are also subject to lesser stringent monitoring requirements. Very low levels of radioactive material may also be encountered in drill cuttings and flowback fluid, or through the release of radon gas, which may affect how such wastes are handled and subsequently disposed of.

As with any construction activities, there are health and safety risks for workers on site which require management. Construction and preparation of the pad may also be used as a focus for anti-fracking sentiment and may be subject to protest action from opposition groups and local communities. This could potentially increase the fear of crime, vandalism and personal injury within affected communities.

Public perception of the impacts of hydraulic fracturing can affect mental, physical and emotional wellbeing. This can exacerbate or trigger health effects caused by anxiety or changes in behaviour arising from people's belief about the project.

### Production Development

Most of the activities associated with this stage are expected to be largely similar to exploration. However, the scale, magnitude and duration of health impacts is expected to be greater given the need to drill, complete and hydraulic fracture a greater number of wells, particularly those relating to noise, emissions to air and water contamination.

### Production/operation/maintenance

Health effects are expected to be limited at this stage, with minimal levels of ongoing noise and vehicle movements. Health effects from air pollutants and potential effects on drinking water may arise if the well is refractured.

### Decommissioning and Site Restoration

Health and safety risks associated with the decommissioning process would be similar to those encountered on a conventional demolition site. The process may give rise to dust, noise and emissions which affect local receptors, but this is not expected to be of a significant scale.

## 3.10.2 Summary of Risks and Avoidance, Minimisation and Mitigation Measures

**Table 3.13** summarises the risks to human health and avoidance, minimisation and mitigation measures.

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<sup>117</sup> AEA (2012) Support to the Identification of Potential Risks for the Environment and Human Health arising from Hydrocarbons Operations involving Hydraulic Fracturing in Europe

<sup>118</sup> Public Health England (2014) Review of the Potential Public Health Impacts of Exposures to Chemical and Radioactive Pollutants as a Result of Shale Gas Extraction

**Table 3.13 Summary of Risks to Human Health and Avoidance, Minimisation and Mitigation Measures**

No.	Source	Activity	Summary	Measures
55.	Land required for the well pad	Site selection and preparation and all subsequent stages	<p>Potential cumulative risks of impacts on human health</p> <p>Impact arises from the activities undertaken in proximity to sensitive receptors</p>	<p>a) Sites selected should avoid residential and other sensitive areas.</p> <p>b) Require buffer zone from abstraction points and aquifers (e.g. in the US range from 150m to 1,200m for drinking water related abstraction)<sup>119</sup></p> <p>c) Require buffer zone from residential areas, schools hospitals and other sensitive areas(e.g. industry good practice requires 1,600m distance where possible)<sup>120</sup></p> <p>d) Require buffer zone within which detailed noise assessment is required (e.g. 305m proposed in New York State)</p> <p>e) Require buffer zone from abandoned wells and other potential pathways for fluid migration (e.g. abandoned mines).</p>
56.	Site construction activities	Site preparation	Potential effects from construction activities on health of local communities	<p>a) Require comprehensive high-level assessment of environmental risks, including risks to human health, and to consult with stakeholders including local communities, as early as practicable in the development of their proposals.</p> <p>b) Limit noise, dust and mobilisation of any contaminants during construction as part of Construction Environmental Management Plan (CEMP).</p> <p>c) Set appropriate limits on maximum noise levels and undertake noise monitoring to demonstrate compliance with limits.</p> <p>d) Require a Dust Suppression Plan, which could include positioning of dusty activities away from receptors; erecting screens; covering exposed soil and dusty materials; use of water sprays or exhaust ventilation systems (LEV); use of wheel washers on vehicles and covering of dusty loads; plus regular dust inspections.</p> <p>e) Air emission specifications should be considered during all equipment selection and procurement, including the use of low emission vehicles. Where possible, low or 'zero' sulphur fuels should be used for plant engines. Vehicles and machinery should shut down their engines when stationary or not in use.</p> <p>f) Require and implement Transport Plan to reduce HGV traffic (for example through load sharing); designate parking and storage areas; and identify appropriate transport routes and times e.g. avoiding peak traffic hours to minimise congestion and idling emissions.</p> <p>g) Require low emission power supply (i.e. LPG rather than diesel or use of grid electricity).</p> <p>h) Controls on phasing of vehicle activity, requirements for vehicles meeting certain standards, use of temporary surface pipes for distribution of water supply and collection of wastewater, select sites close to water sources and waste treatment /</p>

<sup>119</sup> AEA (2012) Support to the Identification of Potential Risks for the Environment and Human Health arising from Hydrocarbons Operations involving Hydraulic Fracturing in Europe, pp 129

<sup>120</sup> AEA (2012) Support to the Identification of Potential Risks for the Environment and Human Health arising from Hydrocarbons Operations involving Hydraulic Fracturing in Europe, pp 129

No.	Source	Activity	Summary	Measures
				disposal facilities to minimise haulage requirements, requirement to provide wastewater treatment facility for given number of wells to minimise haulage
57.	Diesel generators	Site preparation	Potential for fire due to diesel ignition	<p>a) Require consideration of major hazards for all stages in the life cycle of the development (early design, through operations to post abandonment) and development of HSE case or similar demonstrating adequacy of the design, operations and HSE management (including emergency response) for both safety and environmental major impacts.</p> <p>b) Require emergency response plan to be developed and put in place (as part of an accident management plan) covering:</p> <ul style="list-style-type: none"> <li>• leaks from the well to groundwater or surface water</li> <li>• releases of flammable gases from the well or pipelines</li> <li>• fires and floods</li> <li>• leaks and spillage of chemicals, flowback or produced water</li> <li>• releases during transportation</li> </ul>
58.	Flammable gas (methane) concentrations from flowback and /or produced water	Flowback and produced water management	Potential for fire due to flammable gas ignition	<p>See measures for issue 31 and:</p> <p>a) Operate to industry good practices to manage gas safety risk (American Petroleum Institute, National Fire Protection Association or similar)</p> <p>b) Require consideration of major hazards for all stages in the life cycle of the development (early design, through operations to post abandonment) and development of HSE case or similar demonstrating adequacy of the design, operations and HSE management (including emergency response) for both safety and environmental major impacts.</p> <p>c) Require preparation and implementation of an Emissions Reduction Plan based on the principle of as low a level as reasonably practicable (ALARP).</p> <p>d) Require reduced emission completions or green completions to eliminate gas venting and for capturing and cleaning for use of gas released from fracture fluid and produced water.</p> <p>e) Require enclosed completion systems be adopted to avoid venting from lagoons or tanks.</p> <p>f) Require monitoring of their sites to: (1) ensure early warning of unexpected leakages; and (2) obtain emissions estimates for regulators and government. This may include, for example, ambient air monitoring, hydrostatic pressure testing of pipework and equipment used to transport gas, regular seismic monitoring and monitoring of fracture propagation.</p> <p>g) Require emergency response plan to be developed and put in place (as part of an accident management plan) covering:</p> <ul style="list-style-type: none"> <li>• leaks from the well to groundwater or surface water</li> <li>• releases of flammable gases from the well or pipelines</li> <li>• fires and floods</li> <li>• leaks and spillage of chemicals, flowback or produced water</li> <li>• releases during transportation.</li> </ul>

No.	Source	Activity	Summary	Measures
59.	Uncontrolled release of gas (blowout event) – poor well/casing/lining integrity or damage - due to design, maintenance, testing or in-situ damage (e.g. due to fracturing)	Hydraulic fracturing and well completion Testing and transition to production Production	Potential for fire due to flammable gas ignition. Potential impacts local to well pad	<p>a) Require integrity testing at key stages in well development e.g. before/during/after hydraulic fracturing, including:</p> <ul style="list-style-type: none"> <li>wireline logging (calliper, cement bond, variable density)</li> <li>pressure / hydrostatic testing</li> <li>mechanical integrity testing of equipment (MIT).</li> </ul> <p>b) Require key elements to maintain well safety such as:</p> <ul style="list-style-type: none"> <li>blowout preventers</li> <li>pressure &amp; temperature monitoring and shutdown systems</li> <li>fire and gas detection</li> <li>continuous monitoring for leaks and release of gas and liquids</li> <li>modelling to aid well/hydraulic fracturing design</li> <li>real-time monitoring of hydraulic fracturing (such as microseismic surveys)</li> <li>casings: minimum distance the surface casing extends below aquifer (e.g. 30m below the deepest underground source of drinking water encountered while drilling the well, and surface casing cemented before reaching depth of 75m below underground drinking water. Production casing cemented up to at least 150 metres above the formation where hydraulic fracturing will be carried out.</li> </ul> <p>c) Implement remedial measures if well failure occurs and/or abandon well safely.</p> <p>d) These should include details of any monitoring to be undertaken following well abandonment and the means of well plugging.</p>
60.	Pollutants released from the well – (including NORM, chemical substances and gas (methane) contained in muds, cements, fuel oils, formation water)	Drilling Casing Cementing Well completion and subsequently Hydraulic fracturing Flowback management Production	<p>Due to inadequate control and design of drilling, inadequate spacing between fracture zone and aquifers, casing quality, casing design and cementation quality</p> <p>Pathways are cross drilling, casing leaks, surface spills, pressure release, casing failure, cross-formation migration e.g. due to naturally existing faults, fissures or manmade structures such as mines and wells</p> <p>Impact is pollution of aquifers and surface waters potentially affecting human health</p>	See measure for issue 22.
61.	Drilling mud leakage and spills	Drilling	<p>Pollutant from muds including from NORM, hazardous substances)</p> <p>Impact is pollution of surface waters</p>	See measures proposed for issue 14.
62.	Pollution risks from chemical	Hydraulic	Accidents and spillages can result in	See measures proposed for issue 15.



No.	Source	Activity	Summary	Measures
	transportation, storage, mixing and use	fracturing	contamination (e.g. through tank ruptures, equipment and impoundment failures, overfills, vandalism, accidents, fires, poor operational practice)  Impact is pollution of surface waters	
63.	Spillage of flowback and / or produced water recovery and management including pipelines and treatment facilities	Hydraulic fracturing and production	Spillage from tank ruptures, leaks from pipelines, equipment failures, overfills, poor operational practice and water transportation. Disposal of flowback and long term produced water. Fluids may contain added chemicals, NORM, heavy metals, organic compounds and are saline  Impact is pollution of surface waters	See measures proposed for issue 15.
64.	Site decommissioning and abandonment activities leading to pollution event	Well pad removal	Risk from poor capping/closure or poor maintenance/monitoring	See measure for issue 8.

### 3.11 Collective Measures for Avoidance, Minimisation and Mitigation

In undertaking the review of effects and available mitigation measures, it became apparent that there are a number of risks and measures that span across the topics considered. These are summarised in **Table 3.14**.

**Table 3.14 Summary of High Level Risks and Avoidance, Minimisation and Mitigation Measures**

No.	Aspect	Summary	Measure
65.	Absence of buffer zones	Buffer zones may be required from certain activities (e.g. water abstraction points, residential areas) to minimise / prevent pollution risk and nuisance (e.g. air quality impact, water pollution, noise nuisance)	<ul style="list-style-type: none"> <li>f) Require buffer zone from abstraction points and aquifers (e.g. in the US range from 150m to 1,200m for drinking water related abstraction).<sup>121</sup></li> <li>g) Require buffer zone from residential areas, schools hospitals and other sensitive areas(e.g. industry good practice requires 1,600m distance where possible).<sup>122</sup></li> <li>h) Require buffer zone within which detailed noise</li> </ul>

<sup>121</sup> AEA (2012) Support to the Identification of Potential Risks for the Environment and Human Health arising from Hydrocarbons Operations involving Hydraulic Fracturing in Europe, pp 129

<sup>122</sup> AEA (2012) Support to the Identification of Potential Risks for the Environment and Human Health arising from Hydrocarbons Operations involving Hydraulic Fracturing in Europe, pp 129

No.	Aspect	Summary	Measure
			<p>assessment is required (e.g. 305m proposed in New York State).</p> <p>i) Require buffer zone from abandoned wells and other potential pathways for fluid migration (e.g. abandoned mines).</p> <p>j) Require additional containment for sites near surface water supply locations (e.g. 800m in Colorado).</p>
66.	Insufficient baseline setting and monitoring	Establishment of environmental baseline conditions and continued monitoring of environmental conditions throughout lifecycle required (exploration, production and abandonment stages) to facilitate impact assessment and ongoing management and performance assessment	<p>a) Require baseline conditions to be established for</p> <ul style="list-style-type: none"> <li>- Air</li> <li>- Surface water</li> <li>- Groundwater</li> <li>- Drinking water abstraction points</li> <li>- Land condition (soil)</li> <li>- Water resources availability</li> <li>- Traffic</li> <li>- Noise</li> <li>- Biodiversity/ecology/invasive species</li> <li>- Microseismicity including conceptual model of geological conditions</li> <li>- presence of methane seepages</li> <li>- Existing landuse, infrastructure, buildings</li> <li>- Existing underground wells, structures.</li> </ul> <p>b) Require ongoing monitoring and reporting programme to assess performance for</p> <ul style="list-style-type: none"> <li>- Air</li> <li>- Surface water</li> <li>- Groundwater</li> <li>- Drinking water abstraction points</li> <li>- Land condition (soil)</li> <li>- Water resources availability</li> <li>- Traffic</li> <li>- Noise</li> <li>- Water volumes and origin</li> <li>- Chemicals and proppant nature and volumes</li> <li>- Energy source and use</li> <li>- Greenhouse gas emissions</li> <li>- Drilling mud volumes and treatment</li> <li>- Flowback water surface return rate</li> <li>- Produced water volume and treatment solution</li> <li>- Biodiversity/ecology/invasive species</li> <li>- Induced seismicity from fracturing</li> <li>- Presence of methane seepages</li> <li>- Spills volume, nature, location and clean-up.</li> </ul> <p>Monitoring may be continuous or periodic as appropriate and necessary for the different parameters.</p>
67.	Lack of data and information collation, research and knowledge base development leading to poor basis for decisions	Information on gas plays, geology, best available techniques and impacts of operations will emerge as exploration and development progresses.	<p>a) Establish central database and information hub for information on unconventional gas operations available from site licences and research.</p> <p>b) Establish and coordinate research programmes across Brazilian states regarding the environmental aspects of unconventional gas.</p>
68.	Inadequate / insufficient regulatory capacity	An emerging industry with limited / no experience within regulators to assess developments, licence applications, EIAs, safety cases etc.	a) Develop capacity building programme across Federal and Brazilian states to share knowledge and experience and appropriate resources for independent and robust regulation.
69.	Lack of clear technical guidance for permitting/licensing	Lack of clear guidance will undermine consistency and quality of regulatory enforcement	a) Develop guidance covering unconventional gas that defines required practice. Guidance and clarity on safety issues e.g. stray gas also needed.

No.	Aspect	Summary	Measure
70.	Well-by-well permitting / licensing inadequacy (cumulative impacts)	Well by well licensing may not enable cumulative effects across a gas field to be properly assessed. Synergies and integrated infrastructure requirements of a number of wells from multiple operators may not be addressed (e.g. water supply, wastewater treatment, roads)	a) Require cumulative effects (e.g. air pollution, traffic impacts, water resource requirements) of gas play development to be assessed in planning and permitting taking into account other (non-unconventional gas) developments and plans.
71.	Industry practice	Industry practices (e.g. material handling, wastewater management) can be the source of pollution/safety incidents and poor environmental/safety performance	a) Industry to develop good practice/codes of practice to be applied as part of site licence requirements and facility design (e.g. well casing, chemical storage, operational practices). b) Industry to develop minimum standards of technical competence of staff ('fit and proper person'). c) Industry to develop Environmental/Safety Management System or Risk Management Process.
72.	Major accidents	Emergency response plans may be lacking	a) Require consideration of major hazards for all stages in the life cycle of the development (early design, through operations to post abandonment) and development of HSE case or similar demonstrating adequacy of the design, operations and HSE management (including emergency response) for both safety and environmental major impacts. b) Require emergency response plan to be developed and put in place covering: - leaks from the well to groundwater or surface water - releases of flammable gases from the well or pipelines - fires and floods - leaks and spillage of chemicals, flowback or produced water - releases during transportation.
73.	Potential for unforeseen environmental impacts due to lack of characterisation of chemicals, wastes and wastewaters	Without characterisation and disclosure of information, environmental performance can not be assessed, monitoring requirements cannot be defined, stakeholder confidence will be low and independent scrutiny not possible	a) Characterisation (i.e. composition and volume) of chemicals used for fracturing, waste and wastewaters by operator prior to treatment. b) Disclosure of information (e.g. composition, product name, purpose and volume to be used) to the public on chemicals used for fracturing, waste and wastewater.
74.	Potential environmental pollution risks from chemicals (air, water, soil, human health)	New chemicals or new uses for existing chemicals result from fracturing operations. Risks to the environment may not be understood and managed if uses and exposure are not sufficiently well established within chemical safety assessments	a) Require hydraulic fracturing specific chemical safety assessment addressing specific risks associated with unconventional gas and associated pathways for exposure of the environment and humans via the environment (including routes via underground pathways). Appropriate risk management measures to be specified in this assessment.
75.	Pollution arising from temporarily abandoned wells	Wells may be temporarily abandoned between exploration, completion and production stages presenting pollution risks if not plugged and managed correctly	a) Requirements for risk assessment, well plugging, inspection and monitoring (e.g. for releases to air, well integrity, periodicity of inspections, wellhead monitoring every 90 days).

No.	Aspect	Summary	Measure
76.	Pollution arising from permanently abandoned wells	Risk of pollution due to inadequate well abandonment (e.g. releases to air due to inadequate well plugging)	<p>a) Require risk assessment and well plugging (e.g. plug with 30m of cement every 760m and at least 30m cement at the surface with 30m cement in the horizontal section; plug at least 30m above and 15m below each fluid bearing stratum; ensure a micro annulus is not formed at temporary plugs.</p> <p>b) Require ownership and liability of wells to be transferred to a competent authority on surrender of the site licence.</p> <p>c) Require abandonment survey, comprising of monitoring of</p> <ul style="list-style-type: none"> <li>- Air quality</li> <li>- Surface water</li> <li>- Groundwater</li> <li>- Drinking water abstraction points</li> <li>- Land condition (soil)</li> <li>- Biodiversity</li> <li>- Presence of methane seepages</li> <li>- Landuse, infrastructure, buildings</li> <li>- Underground wells, structures*.</li> </ul> <p>The operator is responsible for restoring the site to its previous state or a suitable condition for re-use. The monitoring of the environmental parameters will enable the operator to demonstrate that restoration works have been completed (by comparison with baselines established before works began).</p> <p>c) Require post closure well inspection by regulator to ensure the well has been sealed, and there is no risk of release of fluids or emissions.</p>
77.	Risks related to insufficient financial security leading to inability to remediate environmental damage	Operators may have insufficient financial security to address pollution events that may require substantial resources to address	a) Require operators to demonstrate financial security (e.g. through the provision of performance bonds).
78.	Potential for environmental impacts due to inadequate public scrutiny	Inadequate stakeholder engagement (public, regulators, industry, etc.) during permitting leads to lack of trust, understanding of issues and probity	a) Require public consultation and engagement by operators at all stages (pre-permitting, permitting, exploration, testing, production and abandonment).

\*This measure follows Recommendation 2014/70/EU on minimum principles for the exploration and production of hydrocarbons (such as shale gas) using high-volume hydraulic fracturing which sets out that “Member States should ensure that a survey is carried out after each installation’s closure to compare the environmental status of the installation site and its surrounding surface and underground area potentially affected by the activities with the status prior to the start of operations as defined in the baseline study”.

### 3.12 Summary

Overall, the study has identified a considerable range of potential environmental and human health impacts associated with unconventional gas exploration and production.

The range and type of impacts identified are largely similar to those associated with conventional gas exploration and production and include impacts arising from construction and drilling activity (such as land take, noise, emissions to air and wastes), the accidental release of contaminants and the presence of new infrastructure.

With regard to the risks arising from hydraulic fracturing alone, potential risks are likely to include: induced seismic events; the local sourcing of water, creating of additional demand during periods of water stress; the

management of chemicals and the mixing, storage and use of the fracture fluid; the generation and management of flowback water and fugitive greenhouse gas emissions.

The potential magnitude and significance of these impacts could grow with the scale of unconventional oil and gas exploration and development activity.

The study has identified a range of avoidance, minimisation and mitigation measures to manage and lessen the risks arising from the impacts that may arise from unconventional oil and gas exploration and production.

These measures can be broadly categorised as those to be considered by regulators (e.g. in terms of developing a legislative/regulatory framework for exploration and production and in respect of determining proposals for unconventional gas exploration and production) and those that are targeted at operators (e.g. measures related to site selection or design at the project level).

When considering the extent to which the proposed measures are applicable to the Brazilian context, we would anticipate that the potential risks from shale gas exploration could be evaluated 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;
- ▶ Identification of risk management options;
- ▶ Estimation of the residual risk after the use of regulatory controls.

It is recommended that this work is undertaken by identified experts from Brazilian ministries, regulators and industry representatives.





## 4. European Regulatory Framework for the Environmental Effects of Shale Gas

### 4.1 Introduction

The following section provides a review of the regulatory framework for shale gas exploration and development in Europe. It includes European Union law as well as that developed by Member States. The section refers to regulations, directives and recommendations.

A regulation is a legal act of the European Union that becomes immediately enforceable as law in all Member States simultaneously.

A directive is a legal act of the European Union, which requires member states to achieve a particular result without dictating the means of achieving that result. Directives normally leave Member States with a certain amount of leeway as to the exact rules to be adopted. Directives can be adopted by means of a variety of legislative procedures depending on their subject matter.

In the case of hydraulic fracturing, the European Commission has also adopted a recommendation. Whilst recommendations are without legal force they are negotiated and voted on according to the appropriate procedure. Recommendations differ from regulations, directives and decisions, in that they are not binding for Member States. Depending on Member State responses to recommendations, they can however anticipate further legislation. Given its relevance and overarching nature, the section begins with a summary of the recommendation and then goes on to consider the framework of other existing directives and regulations, whose application is less specific to unconventional oil and gas exploration and development.

### 4.2 European Community Recommendation

The European Commission adopted Recommendation 2014/70/EU<sup>123</sup> in January 2014. The Recommendation sets out the minimum principles that may be used for Member States that are looking to develop the exploration and production of hydrocarbons using high-volume hydraulic fracturing (HVHF)<sup>124</sup>. The principles aim to ensure that activities can be carried out with appropriate and adequate safeguards for public and the environment, that resources are used efficiently and that the public is informed. In addition, the Recommendation aims to provide a common framework for competent authorities, operators and the civil society to work within. Principles are set out for the key areas of:

- ▶ Project planning;
- ▶ Assessment of environmental impacts and risks;
- ▶ Well integrity;
- ▶ Baseline measurements and monitoring;
- ▶ Emission reduction;
- ▶ Use of fracturing fluids; and
- ▶ Dissemination of information.

An overview of some of the Recommendation's key points is provided in the following Box.

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<sup>123</sup> On minimum principles for the exploration and production of hydrocarbons (such as shales gas) using high-volume hydraulic fracturing (HVHF).

<sup>124</sup> Defined as injecting 1,000 m<sup>3</sup> or more of water per fracturing stage or 10, 000 m<sup>3</sup> or more of water during the entire frac-turing process into a well

### Box 1 Overview of the Recommendation

In 2012 the European Parliament invited the Commission to establish a European framework to exploit shale gas in a safe way for the environment, especially in framing and eliminating the possible risks involved. Having examined the new possibilities offered by shale gas and potential challenges associated with its extraction, the Commission published on 22 January 2014 a Recommendation on minimum principles for the exploration and production of hydrocarbons (such as shale gas) using high-volume hydraulic fracturing (or the 'Recommendation'), accompanied by an explanatory Communication.

The recommendation attempts to strike a balance between three different objectives: (i) security of energy supply, (ii) sustainability and protection of environment and (iii) the competitiveness of European industries. In its Recommendation, the Commission relies on the *acquis communautaire*<sup>125</sup> in the field of environmental protection, which is composed of numerous Regulations and Directives on the prevention of air pollution, water protection, protection of wildlife and flora, human health, treatment of wastes and protection of workers. Some of the Directives of this *acquis* allow the adoption of diverse Best Available Techniques (or 'BAT'). The Recommendation analyses, synthesises and clarifies a set of non-binding minimum principles for Member States wishing to exploit their hydrocarbon resources (the Recommendation is not limited to shale gas) through high-volume hydraulic fracturing (HVHF).

The following provide a few examples of those set out by the Recommendation. This is a non-exhaustive list and it follows the typical stages of a shale gas extraction project:

- Site selection: The Recommendation contains five categories at this stage of the process:
  1. Before granting licences for the exploration and/or the production of hydrocarbons which may lead to the use of HVHF, Member States should prepare a strategic environmental assessment (SEA).
  2. Operators should then carry out an environmental impact assessment (EIA) on the basis of the EIA Directive. The Recommendation potentially expands the scope of this Directive, as under the Directive, an assessment of the environmental impacts is not always required. Below a certain threshold, the Directive only requires a case-by-case screening procedure, the outcome of which can lead (but not always) to the obligation to carry out an EIA. (
  3. Operators should ensure that the geological formation of a site is suitable for the exploration or production of hydrocarbons using HVHF, and carry out a risk assessment. A site should only be selected if the risk assessment shows that the HVHF 'will not result in a direct discharge of pollutants into groundwater'.
  4. The Recommendation indicates that a site should only be chosen if the risk assessment shows that the HVHF 'will not result in a direct discharge of pollutants into groundwater and that no damage is caused to other activities around the installation'. The WFD already establishes such a prohibition of direct discharges of pollutants into groundwater, but the Directive also provides for exceptions to prohibition.
  5. The Recommendation states that before the beginning of any hydraulic fracturing operation, 'the operator determines the environmental status (baseline) of the installation site and its surrounding surface and underground area potentially affected by the activities';
- Well construction: The second phase of the project consists in the construction of wells. This phase is very sensitive due to the risk of unwanted leaks and water contamination that could occur. The Recommendation states in this regard that the facility should be constructed in a manner that 'prevents possible surface leaks and spills to soil, water or air'. The operators should also ensure well integrity through well design, construction and integrity tests. The result of integrity tests should be reviewed by an independent and qualified third party;
- HVHF: If the operator decides to move to the operational phase and high-volume hydraulic fracturing, the recommendations become more numerous. In general, operators should apply the 'Best Available Techniques' (BAT) in order to 'prevent, manage and reduce the impact of exploration and production of hydrocarbons'. Operators have also obligations related to regular monitoring of the facility and its surroundings. For example, it is their responsibility to monitor the pressure in the well and its stability, the volume of water injected into the well and released from it, or air emissions. Operators should also develop risk management plans and, in case of loss of well integrity or if pollutants are accidentally discharged into groundwater, they must stop operations and urgently take any necessary remedial actions;
- Disclosure of chemicals: the Recommendation states that operators should disclose the precise chemical composition of the fracturing fluids. On this point, the Recommendation goes beyond what is required by the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) Regulation, which organises the registration process of chemicals, their marketing and their control. REACH establishes a requirement to disclose the composition of registered chemicals, but only to the European Chemicals Agency (ECHA), which must keep confidential certain aspects of the composition of chemicals;
- End of activities: After each installation's closure, the operator should carry out a survey to compare the environmental status of the installation site and its surrounding surface and underground area potentially affected by the activities with the status of it prior to the start of operation as defined in the baseline study.

A list of the measures included in the Recommendation is included in **Table 4.1**. These measures are split between regulatory and non-regulatory; however it must be noted that this is not a firm classification but rather an indication that some of these aspects would be best addressed through regulatory measures (e.g. through integration into regulation) and others would be best addressed through non-regulatory measures (e.g. through integration into guidance).

<sup>125</sup> The "acquis communautaire" covers all treaties, EU legislation, international agreements, standards, court verdicts, fundamental rights provisions and horizontal principles relating to environmental protection and so to shale gas.

**Table 4.1 Regulatory and non-regulatory measures included in the Recommendation**

Reference	Measures
<b>Regulatory measures</b>	
Point 3.1	Member State to prepare a SEA to prevent, manage and reduce the impacts on, and risks for, human health and the environment.
Point 3.1	SEA to be carried out on the basis of the requirements of Directive 2001/42/EC.
Point 3.2	Member States should provide minimum distances between authorised operations and residential and water-protection areas.
Point 3.2	Member States should provide minimum depth limitations between the area to be fractured and groundwater.
Point 3.3	Member States should take the necessary measures to ensure that an EIA is carried out on the basis of the requirements of Directive 2001/42/EC.
Point 3.4.	Member State should provide opportunities for public to participate in SEA procedure (note that this is also a requirement of the SEA Directive).
Point 3.4.	Member State should provide opportunities for public to participate in EIA procedure (note that this is also a requirement of the EIA Directive).
Point 5.1	Member State should ensure that operators carry out a characterisation and risk assessment of the potential site and surrounding surface and underground area. The risk assessment should assess the risk of leakage or migration of drilling fluids, hydraulic fracturing fluids, naturally occurring material, hydrocarbons and gases from the well or target formation as well as of induced seismicity
Point 5.3	The risk assessment should respect a minimum vertical separation distance between the zone to be fractured and groundwater.
Point 5.4	A site should only be selected if the risk assessment shows that HVHF will not result in a direct discharge of pollutants into groundwater and that no damage is caused to other activities around the installation.
Point 6	Before HVHF operations start Member State should ensure that the operator determines the environmental status (baseline) of the installation site and its surrounding surface and underground area potentially affected by the activities.
Point 9.1	Member State should ensure that operators use best available techniques.
Point 9.2	Member State should ensure that operators develop project-specific water management plants, transport management plants, capture gases for subsequent use, minimise flaring and avoid venting. Operators should also carry out HVHF in a controlled manner and with appropriate pressure management with the objective to contain fractures within the reservoir and avoid induced seismicity.
Point 10.1	Member State should ensure that manufacturers, importers and downstream users of chemical substances used in hydraulic fracturing refer to hydraulic fracturing, that using chemical substances in HVHF is minimised and that the ability to treat fluids that emerge at the surface after HVHF is considered during the selection of the chemical substances to be used.
Point 10.2	Member State should encourage operators to use fracturing techniques that minimise water consumption and waste streams and do not use hazardous chemical substances.
Point 11.1	Member State should ensure that the operator regularly monitors the installation and the surrounding surface and underground area potentially affected by the operations during the exploration and production phase and in particular before, during and after HVHF.
Point 11.2	The baseline study should be used as a reference for subsequent monitoring.
Point 11.3	The Member State should ensure that the operator monitors the following operational parameters such as the precise composition of the fracturing fluid, the volume of water used, the pressure applied, the fluids that emerge and air emissions.
Point 11.4	Member State should ensure that operators monitor the impacts of HVHF on the integrity of wells and other manmade structures.

Reference	Measures
Point 11.5	Member State should ensure that the monitoring results are reported to the competent authorities.
Point 12	Member State should apply the provisions on environmental liability to all activities taking place at an installation site. In addition Member State should ensure that the operator provides a financial guarantee or equivalent covering the permit provisions and potential liabilities for environmental damage prior to the start of operations involving HVHF.
Point 14	Member State should ensure that a survey is carried out after each installation's closure to compare the environmental status of the installation and its surrounding surface and underground area potentially affected by the activities with the status prior to the start of operations as defined in the baseline study.
Point 15. (a)	Member State should ensure that the operator publicly disseminate information on the chemical substances and volumes of water that are intended to be used and are finally used for the HVHF.
Point 15. (b)	Member State should ensure that the Competent Authorities should publish a range of information on their internet website.
Point 15. (c)	Member State should ensure that Competent Authorities should also inform the public of incidents and accidents, the results of inspections, non-compliance and sanctions.
<b>Non regulatory measures</b>	
Point 3.2	Member States to provide clear rules on possible restrictions of activities (e.g. flood-prone, seismic-prone, protected areas).
Point 4.(a)	Member State should ensure that the permitting procedures are fully coordinated when more than one authority is responsible, more than one operator is involved, more than one permit is needed for a specific project phase and more than one permit is needed under national or European legislation.
Point 5.1	Member State should take the necessary measure to ensure that the geological formation of a site is suitable for the exploration or production of hydrocarbons using HVHF.
Point 5.2	Risk assessment should be based on sufficient data to make it possible to characterise the potential exploration and production area and identify all potential exposure pathways.
Point 5.3	Risk assessment should be based on best available techniques and take into account the relevant results of the information exchange between Member States, industries concerned and NGOs. It should anticipate the changing behaviour of the target formation, geological layers and existing wells or other manmade structures exposed to the high injection pressures used in high-volume hydraulic fracturing and the volumes of fluids injected. The risk assessment should be updated whenever new data are collected.
Point 6.1	Before HVHF operations start, Member States should ensure that the operator determines the environmental status (baseline) of the installation site and its surrounding surface and underground area potentially affected by the activities.
Point 6.2	The baseline should include: (a) quality and flow characteristics of surface and ground water; (b) water quality at drinking water abstraction points; (c) air quality; (d) soil condition; (e) presence of methane and other volatile organic compounds in water; (f) seismicity; (g) land use; (h) biodiversity; (i) status of infrastructure and buildings; (j) existing wells and abandoned structures
Point 7	Member State should ensure that the installation is constructed in a way that prevents possible surface leaks and spills to soil, water or air.
Point 8	Member State should ensure that operators apply an integrated approach to the development of a production area with the objective of preventing and reducing environmental and health impacts, and risks both for workers and the general public. Adequate infrastructure requirements for servicing the installations should be established before the production begins.
Point 9.3	Member State should promote the responsible use of water resources in HVHF.

Reference	Measures
Point 13.1	Member State should ensure that the competent authorities have adequate human, technical and financial resources to carry out their resources.
Point 13.2	Member State should present conflicts of interest between regulatory function of competent authorities and their function relating to the economic development of the resources.

#### 4.2.1 Recommendation Commitments and Review

The Recommendation included an invitation to Member States to report annually to the Commission (with the first reports received by December 2014<sup>126</sup>), the measures put in place in response to the Recommendation. Furthermore, the Commission is required to review the effectiveness of the Recommendation by August 2015. In particular, the review should include an assessment of the Recommendation's application, the progress of the information exchange on best available techniques (BAT), of the application of relevant BAT reference documents as well as any need for updating the Recommendation's provisions. To convey the outcomes of such review work, the Commission intends to develop a publicly available scoreboard of Member States' performance.

### 4.3 Relevant European Community Directives and Regulations

**Table 4.2** presents a list of European Directives and Regulations that have been reviewed as part of this study and reflect the most significant components of the "acquis communautaire" with regard to shale gas. Please note however that there are additional Directives and Regulations and these are set out in **Appendix C**.

**Table 4.2 Summary of Relevant Directives and Regulations**

Reference	Measures
<b>Strategic Environmental Assessment Directive (SEAD)</b>	Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment (OJ L 197, 21.7.2001, p. 30-37)
<b>Environmental Impact Assessment Directive (EIAD)</b>	Directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment (OJ L 26, 28.1.2012, p. 1-21)
<b>Habitats Directive (HD)</b>	Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (OJ L 206, 22.7.1992, p. 7-50) Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds (OJ L 20, 26.1.2010, p. 7-25)
<b>Mining Waste Directive (MWD)</b>	Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries and amending Directive 2004/35/EC (OJ L 102, 11.4.2006, p. 15-34)
<b>Water Framework Directive (WFD)</b>	Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (OJ L 327, 22.12.2000, p. 1-73)
<b>SEVESO II</b>	Council Directive 96/82/EC of 9 December 1996 on the control of major-accident hazards involving dangerous substances (OJ L 10, 14.1.1997, p. 13-33)
<b>SEVESO III</b>	Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC (OJ L 197, 24.7.2012, p. 1-37)
<b>Environmental Liability</b>	Directive 2004/35/CE of the European Parliament and of the Council of 21 April 2004 on environmental

<sup>126</sup> <https://ec.europa.eu/eusurvey/publication/ShalegasRec2014>

Reference	Measures
<b>Directive (ELD)</b>	liability with regard to the prevention and remedying of environmental damage (OJ L 143, 30.4.2004, p. 56–75)
<b>Groundwater Directive (GD)</b>	Council Directive 80/68/EEC of 17 December 1979 on the protection of groundwater against pollution caused by certain dangerous substances (OJ L 20, 26.1.1980, p. 43–48)
<b>Groundwater Deterioration Directive (GWD)</b>	Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration (OJ L 372, 27.12.2006, p. 19–31)
<b>Registration, Evaluation, Authorisation and Restriction of Chemicals Regulation (REACH)</b>	Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC (OJ L 396, 30.12.2006, p. 1–849)

The following is a brief summary of how these differing Directives and Regulations relate to the stages of shale gas development.

## 4.4 Strategic Environmental Assessment

The SEAD is a systematic decision support process, aiming to ensure that the likely significant environmental effects of plans and programmes<sup>127</sup> are identified, described and evaluated. The SEAD requires the completion of a strategic environmental assessment (SEA) according to the procedure defined in the Directive<sup>128</sup>. It is relevant for unconventional gas extraction as it requires a SEA for plans/programmes which are prepared in the fields of land use, transport, energy, waste/waste management or for the projects which must be assessed under the Habitats Directive (see below). The purpose is to encourage relevant national/regional/local authorities to organise territorial planning in a way that integrates environmental considerations into the development of any plan or programme. Generally a SEA is therefore conducted before<sup>129</sup> an EIA is undertaken under the EIAD requirements. As experience shows, the SEAD can clearly impact energy policy, forcing for instance an Energy Ministry to coordinate with an Environment Ministry<sup>130</sup>.

The SEA should seek to identify, describe and evaluate the likely significant effects on the environment of implementing the plan or programme and to propose measures to avoid, manage or mitigate any significant adverse effects and to enhance any beneficial effects. This could include specifying areas to be excluded from exploration and production activities, as well as proposing specific measures to inform site selection and project development with minimal impact on the environment.

With regard to onshore licensing, all 10 key SEA topics and objectives are relevant. These topics are presented in **Table 4.3**.

<sup>127</sup> 'Plans and programmes' are defined as 'plans and programmes including those co-financed by the European Community, as well as any modification to them: – which are subject to preparation and/or adoption by an authority at national, regional or local level or which are prepared by an authority for adoption, through a legislative procedure by Parliament or Government, and – which are required by legislative, regulatory or administrative provisions' (Art. 2, a, SEAD).

<sup>128</sup> As elaborated under Articles 3 to 10 of the Directive, which require the performance of a screening, scoping, documentation of the state of environment, determination of the likely (non-marginal) environmental impacts, information and consulting the public, decision-making and monitoring of the effects of plans/programmes after their implementation.

<sup>129</sup> Although overlaps between the EIAD and the SEAD are deemed to exist, as the EC reports it, without further analysing them, see EUROPEAN COMMISSION, 'Report on the application and effectiveness of the Directive on Strategic Environmental Assessment', Brussels, 14 September 2009, COM(2009) 469final, p. 6.

<sup>130</sup> See the case-study on Slovak Energy Policy 2000 reported by A. KULSUM, S. SANCHEZ-TRIANA, 'Strategic Environmental Assessment for Policies: An Instrument for Good Governance', World Bank publication, Washington, DC, 2008, available at <https://openknowledge.worldbank.org/handle/10986/6461> (accessed in February 2013), pp. 18 to 20.



**Table 4.3 SEA Topics**

SEA Topics	SEA Objectives
<b>Air</b>	To minimise emissions of pollutant gases and particulates and enhance air quality, helping to achieve the objectives of the Air Quality and Ambient Air Quality Directives and Cleaner Air for Europe programme
<b>Biodiversity, Flora and Fauna</b>	To protect and enhance biodiversity (habitats, species and ecosystems) working within environmental capacities and limits
<b>Climatic Factors</b>	To minimise greenhouse gas emissions as a contribution to climate change, ensure resilience to any consequences of climate change
<b>Cultural Heritage, including Architectural and Archaeological heritage</b>	To protect and where appropriate enhance the historic environment including cultural heritage resources, historic buildings and archaeological features
<b>Health</b>	To protect and enhance health, safety and wellbeing of workers and communities and minimise any health risks associated with onshore oil and gas operations
<b>Landscape</b>	To protect and enhance landscape and townscape quality and visual amenity
<b>Soil, Material Assets</b>	To conserve and enhance soil and geology and contribute to the sustainable use of land
<b>Population</b>	To promote a strong, diverse and stable economy with opportunities for all; minimise disturbance to local communities and maximise positive social impacts
<b>Material Assets</b>	To minimise waste arisings, promote reuse, recovery and recycling and minimise the impact of wastes on the environment and communities. To contribute to the sustainable use of natural and material assets
<b>Water</b>	To maximise water efficiency, protect and enhance water quality and help achieve the objectives of the Water Framework Directive  To minimise the risks of coastal change and flooding to people, property and communities

So far, two Member States have adopted legislation requiring that an SEA of their oil and gas licensing plan is conducted before the procedure for granting licences for the prospecting and extraction of hydrocarbons with or without the use of HVHF can be initiated. These two member states are the UK and Lithuania<sup>131</sup>. The Netherlands are currently preparing an SEA. A review of the information available has found that the SEA is expected to be ready by mid-2015.<sup>132</sup>

In addition to the development of an SEA, Point 3.2 of the Recommendation indicates that Member States should provide clear rules on possible restrictions of activities, for example in natural protected areas, in flood prone areas or in seismic-prone areas. The UK has recently published its invitations to operators to bid for oil and gas licences under its Licensing Plan. One of the plan guidelines indicates that for “*National parks, Broads and Areas of Outstanding Natural Beauty, the mineral planning authorities should give great weight to conserving their landscape and scenic beauty*”. It continues to state that licensing in these areas should be refused except in exceptional circumstances and where it can be demonstrated that they are in the public interest.<sup>133</sup> For these areas, a special test for the environmental impact assessment needs to be conducted by the mineral planning authority. Section 50 of the recently enacted Infrastructure Act 2015 in the UK has inserted an amendment to the Petroleum Act 1998 regarding safeguards for onshore hydraulic fracturing. These include a commitment that “hydraulic fracturing will not take place within other protected areas”, which

<sup>131</sup> *Natural Gas Europe*, Active Participation, Knowledge of Legal Procedures: Tools for Sustainable Development of Shale Investments in Poland, April 2014. <http://www.naturalgaseurope.com/btk-legal-michal-tarka-shale-gas-law-poland-eera>

<sup>132</sup> *Shale Gas Europe*, The Netherlands moving closer to lifting its moratorium, June 2014, <http://shalegas-europe.eu/netherlands-moving-closer-lifting-moratorium/>

<sup>133</sup> [http://planningguidance.planningportal.gov.uk/blog/guidance/minerals/planning-for-hydrocarbon-extraction/determining-the-planning-application/#paragraph\\_223](http://planningguidance.planningportal.gov.uk/blog/guidance/minerals/planning-for-hydrocarbon-extraction/determining-the-planning-application/#paragraph_223)

will be defined in regulations issued by the Secretary of State for Energy and Climate Change. It is noted however, that in the originally proposed amendment at the third reading of the Bill, protected areas included:

- ▶ Special areas of conservation under the Conservation (Natural Habitats, &c) Regulations 1994,
- ▶ Special protection areas under the Wildlife and Countryside Act 1981,
- ▶ Sites of special scientific interest under the Wildlife and Countryside Act 1981, and
- ▶ National parks under the National Parks and Access to the Countryside Act 1949.

Member States are encouraged to provide minimum distances between authorised operations and residential and water-protection areas. Minimum depth limitations between the area to be fractured and groundwater should also been set. This has been done by Germany, which has recently banned the use of HVHF for activities less than 3,000m from the surface. Within the UK, the recently enacted Infrastructure Act prohibits hydraulic fracturing from taking place in land at a depth of less than 1,000 metres.

## 4.5 Environmental Impact Assessment

The EIAD requires<sup>134</sup> a mandatory environmental impact assessment (EIA) for Annex I projects, notably for 'extraction of petroleum and natural gas for commercial purposes where the amount extracted exceeds 500 tonnes/day in the case of petroleum and 500,000 m<sup>3</sup> /day in the case of gas'. EIA is not mandatory when the thresholds are not met, although determination is dependent on an accurate forecast of production volumes, which maybe challenging.<sup>135</sup> Proposals for a revised EIAD were considered in 2012 and an amended directive adopted in 2014<sup>136</sup> which left these thresholds unchanged.

If an EIA is not required, a screening procedure is to be carried out for all activities listed in Annex II<sup>137</sup>, according to the criteria laid down in Annex III of the Directive. Annex II catches unconventional gas extraction due to the fact that it includes 'extractive industries', including deep drilling, in particular geothermal drilling, surface industrial installations for the extraction of coal, petroleum, natural gas and ores as well as bituminous shale, etc. Annex II also includes 'chemical industry', including storage facilities for chemical products.

The status of EIA requirements for exploration and/ or extraction (i.e. whether a full EIA is required or only a screening) differ amongst the Member States selected. It depends on how the EIA Directive requirements have been transposed and applied. **Table 4.4** summarises the status of EIA requirements specific to unconventional gas in selected Member States.

**Table 4.4 EIA and screening status in selected Member States**

Member States	EIA status with relation to unconventional hydrocarbons exploration and production
Denmark	EIA compulsory for the exploration and extraction of shale gas since July 2012
Hungary	'Unconventional hydrocarbons' included in the legislation since 2008, applies to specific license area and royalty
Germany	Proposal for mandatory EIA for deep wells involving HVHF

<sup>134</sup> Article 4, (1) EIAD.

<sup>135</sup> Which potentially can be the case as far as unconventional gas is concerned as AEA 2012 points it out: as preliminary indications from exploratory drilling in Europe suggest that product rates are likely to be lower than in the US, it is unlikely that the threshold of 500,000 m<sup>3</sup> per day will be met in case of shale gas production at a single well.

<sup>136</sup> <http://ec.europa.eu/environment/eia/review.htm>

<sup>137</sup> Article 4, (2), EIAD.

**Table 4.4 (continued) EIA and screening status in selected Member States**

Member States	EIA status with relation to unconventional hydrocarbons exploration and production
Spain	Proposal for mandatory EIA for wells involving HVHF
Lithuania	Mandatory EIA for exploration and production of unconventional hydrocarbons wells, particularly shale gas and oil
Netherlands	The Netherlands Commission for Environmental Assessment (NCEA) recommended a mandatory EIA for projects including HVHF. This advice was published on 19 September 2013 <sup>138</sup> .
Romania	Legislation does not go beyond the requirements of the EIA Directive and does not include specific elements for unconventional gas
Portugal	Working group has been set to develop recommended practices to be followed during shale gas exploration and production activities
UK	Legislation does not go beyond the requirements of the EIA Directive and does not include specific elements for unconventional gas
Sweden	Before any exploration work starts, which can have a significant impact on the natural environment, notice of consultation shall be made to the supervisory authority (The County Administrative Board) in accordance with the provisions in the Environmental Code
Poland	Project need to be classified as per its national legislation (Regulation of the Council of Ministers of 9 November 2010 on Projects Likely to have significant impact on the Environment). EIA is not required if the drilling takes place at a depth of 5,000m and outside sensitive zones.

The EIAD implies that the operator (licensee) cannot start a project without obtaining a permit. Within the context of the development consent procedure, the public and the statutory environmental protection agencies must be given the right to express an opinion on the permit. Those opinions, along with the EIA statement, should be taken into account by the competent authority when deciding whether to grant development consent for a shale gas exploration projects.

The EIAD sets out the topics to be considered within each and every assessment; however, it is only through an initial phase of scoping that this is refined, to ensure only those topics relevant to the proposed development are considered. The topics included at the outset are:

- ▶ Population and human health;
- ▶ Biodiversity, with particular attention to species and habitats protected under Directive 92/43/EEC and Directive 2009/147/EC;
- ▶ Land, soil, water, air and climate ■ ;
- ▶ Material assets, cultural heritage and the landscape; and
- ▶ The interaction between the factors referred to in points (a) to (d).

It should be noted that there is an overlap between these topics and those considered by the SEAD and this reflects the natural extension of matters considered by the EIAD from those required by the SEAD; however, whilst there is overlap of topics, the scale and determination of what constitutes a likely significant effect will be markedly different.

With the UK, the environmental regulator for England (the Environment Agency) in technical guidance on onshore oil and gas exploratory operations<sup>139</sup> has outlined specific issues that should be included in an EIA for an onshore oil and gas exploration site and is summarised below:

<sup>138</sup> <http://www.lexology.com/library/detail.aspx?g=de996fa6-8a2d-4f91-8290-10f3871a7a3d>

<sup>139</sup> *Environment Agency* (2013), Onshore oil and gas exploratory operations: technical guidance, Consultation Draft, August 2013

- ▶ A description of the development including:
  - ▶ a full and detailed description of the physical characteristics and design of the whole development, its location and land use requirements during set up and operation;
  - ▶ the main characteristics of the proposed operation including the nature, quantities, types of equipment, fluids, chemicals and materials to be used in construction and operation;
  - ▶ an estimate by type and quantity of expected residues and emissions resulting from the operation of the proposed development;
  - ▶ a description of the management of the development to prevent soil and water contamination and consideration of cumulative, short-, medium- and long-term effects, both permanent and temporary.
- ▶ A hydrogeological assessment of the potential impacts on groundwater and surface water, including the impacts on any aquifers or groundwater sensitive receptors, especially abstraction boreholes, using the following information:
  - ▶ the location of all surface and groundwater features in the area around the proposed development;
  - ▶ the local and regional geological structures likely to be affected by the operations;
  - ▶ the exact nature of any well stimulation fluids proposed;
  - ▶ the proposed design of the borehole and drilling platform to prevent spills and leaks;
  - ▶ the proposed methods of containment, treatment and disposal of any such spills and leaks;
  - ▶ the potential for the migration of well stimulation fluids into sensitive geological formations including those containing groundwater;
  - ▶ the methods to monitor any fluid migration and seismic activity, and the mitigation techniques to reduce the likelihood and magnitude of such events.
- ▶ Identification of the waste streams likely to be generated by the project, along with the predicted methods of recovery, treatment and disposal, focusing on:
  - ▶ well stimulation fluid remaining underground;
  - ▶ flowback fluid;
  - ▶ radioactive scale and sediments;
  - ▶ waste gas;
  - ▶ waste drilling muds and drill cuttings.
- ▶ The likelihood of induced seismic activity occurring, the maximum possible magnitude of such activity and the equipment, both onsite and offsite, at risk of damage from seismic activity.
- ▶ The requirement for water during the operation and the percentage of water that will be re-used or recycled.
- ▶ An assessment of the risk of flooding from all potential sources.
- ▶ An assessment of the impacts on sensitive ecological receptors i.e. European and nationally protected or notable species and habitats such as those designated under the Biodiversity Action Plan.
- ▶ An assessment of the air quality impacts arising from the set up and development of the site – such impacts should be investigated in relation to the amenity of nearby sensitive receptors and should form part of a wider ecological assessment relating to any nearby designated sites.
- ▶ An assessment of the impact of the development on emissions of greenhouse gases.

- ▶ A monitoring and site management plan.

In one country, the UK, additional information on environmental impacts is requested as part of the application for an exclusive right licence<sup>140</sup>. In addition to the analysis of the geology of the area, applicants are required to demonstrate awareness of environmental issues and regulatory requirements in the form of an 'Environmental Awareness Statement' including information on the applicant's understanding of the UK's onshore environmental legislation relevant to the exploration, development and production stages of the project and on particular sensitivities associated with operational planning (e.g. Special Areas of Conservation, Special Protection Areas). Further the statement should include details of the applicant's pollution liability arrangements and its commitment to environmental management and details of any failure to comply with environmental standards or requirements within the previous five years (e.g. any civil or criminal action against the operator, or any convictions for breaches of environmental legislation).

#### 4.5.1 Habitats Directives

The HD (along with Directive 2009/147/EC on the conservation of wild birds (the "Wild Bird Directive")) focus on the protection of various types of wildlife and habitats and include measures to maintain or restore important natural habitats and species including through the designation of Special Areas of Conservation (SACs) and Special Protection Areas (SPAs).

Among the protections accorded, certain plans or projects are required to be screened to determine whether they are likely to have a significant effect on a protected site. Where such effects are considered likely, an appropriate assessment of the implications of the plan or project for the conservation objectives of the site must be carried out, before that plan or project is agreed. If an appropriate assessment were to determine that harm were likely to occur, appropriate prevention or mitigation measures would need to be adopted.

#### 4.5.2 Mining Waste Directive

The MWD is an important piece of legislation for unconventional gas extraction as it provides for a comprehensive framework for the safe management of waste resulting from extractive activities. It specifically applies to waste resulting from the prospecting, extraction, treatment and storage of mineral resources and the working of quarries, known as 'extractive waste'.<sup>141</sup>

Before a shale gas project may start, the operator must also meet the obligations under the MWD. In particular, given that flowback fluid is considered as an 'extractive waste' and given that any area designated for the accumulation or deposit of extractive waste should be considered a waste facility, the operator must obtain a permit under that Directive which will have to be based on Best Available Techniques (BAT). The Commission is currently developing a reference document (the BREF note) covering the management of waste from shale gas extractive activities. Like the EIAD, the MWD requires the operator who requests authorisation to give information on his project and its impacts and provide the public with rights to be consulted and to express an opinion. The operator also has to draw up a waste management plan and a major accident prevention policy if the facility is classified as 'Category A' according to the Directive. Finally, the operator has to give a financial guarantee before the start of the operation to show that they are able to implement all of the obligations under the permit.

#### 4.5.3 Water Framework Directive

The operator of the shale gas proposed project may also have to obtain an authorisation under the WFD, if the project would require abstraction of large amounts of water from a surface or groundwater body. Discharge of pollutants (waste water with hazardous chemicals) into groundwater bodies is also prohibited.

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<sup>140</sup> The Petroleum Act 1998, which consolidated a number of earlier pieces of primary legislation, vests all rights to the petroleum (oil and gas) resources of Great Britain in the Crown. The Secretary of State for Energy and Climate Change, on behalf of Her Majesty, may grant licences over a limited area and period of time that confer exclusive rights to "search and bore for and get" petroleum. These licences are called Petroleum Exploration and Development Licences (PEDLs). PEDLs are generally offered in Licensing Rounds. Before a licence can be awarded, the applicant must satisfy DECC of the competence of its proposed operator, and each member of the applicant group must satisfy DECC of its financial viability and financial capacity. Applications which meet these requirements are then subject to assessment, on the basis of published criteria, of the geological understanding displayed, and the exploration effort proposed. Where two or more applications are for the same area, the application with the highest ranking is selected.

<sup>141</sup> Article 1, MWD.

#### 4.5.4 SEVESO II/SEVESO III

SEVESO II/SEVESO III<sup>142</sup> aims to prevent major accidents involving dangerous substances, while limiting their consequences and ensuring high level of protection in a consistent and effective manner.

It is the subject of some debate whether shale gas activities fall under SEVESO II due to the thresholds identified in the Directive. For example, SEVESO II would be considered as applicable on this basis if 50 tonnes or more of the dehydrated natural gas were stored on site (without the well being considered as part of the site) which appears unlikely since storage of gas on site is not a common procedure, and in fact takes place in the well itself.<sup>143</sup>

However, if the shale gas extraction site falls under the SEVESO II Directive, the operator will have to fulfil several obligations before starting the project, such as informing the competent authority on the quantity of dangerous substances that would be stored within the establishment. Failure to meet these requirements will mean that the activity could not proceed.

#### 4.5.5 REACH

REACH aims to ensure a high level of protection of human health and the environment. To do so it establishes procedures for collecting and assessing information on the properties and hazards of substances. It requires companies to register their substances to the European Chemicals Agency, 'ECHA'. ECHA receives and evaluates registrations dossiers for their compliance while Member States Competent Authorities (MSCAs) evaluate selected substances to clarify any grounds for considering that a substance constitutes a risk for human health or for the environment. Authorities' and ECHA's scientific committees assess whether the risks of substances can be managed<sup>144</sup>. As fracturing fluid is partly composed of chemicals, REACH is a relevant piece of legislation of the EU legal framework applicable to unconventional gas extraction.

REACH in principle required producers/importers to register the substances with ECHA by December 2010 if manufactured/imported above 1,000 tonnes per year per manufacturer/importer or with a lower tonnage for specific hazardous substances<sup>145</sup> and to assess risks to health and the environment.

Operators of unconventional gas extraction projects are most likely not those who manufacture or import the chemical substances used in fracturing fluid. Rather, they would most likely be considered as a 'downstream users' of such products. Under REACH, the main registration obligations lie upon the manufacturer/importer of chemicals/biocidal products. However, if the operator identifies that the exposure scenarios provided by its supplier during the registration/authorisation process do not cover its specific use, in its capacity of downstream user, the operator is obliged to report to ECHA and to provide relevant information in accordance with Article 38 of REACH. Until the consideration is met, the substances cannot be used.

#### 4.5.6 ELD

The ELD is applicable to the prevention and restoration of 'environmental damages', which include three limited types of specific natural resources, that is: damage to protected species and habitat; damage to water; and damage to land<sup>146</sup>. If shale gas project leads to significant environmental damage, the operator will be held liable in accordance with the ELD and will be asked to bear the remediation costs. Article 4, (5) that the ELD could also potentially apply to diffuse/gradual pollution provided the causal link<sup>147</sup> with the polluter/the occupational activity covered by the Directive is established. With respect to unconventional gas extraction, this causal link might be difficult to establish due to the presence of numerous operators of

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<sup>142</sup> The report and the map use as a basis the provisions of SEVESO III rather than those of SEVESO II, which – although into force at the date of submitting the present report – will soon be repealed by SEVESO III, unless relevant (e.g. when there is a relevant difference between the two pieces of legislation).

<sup>143</sup> AEA *et al* (2012) Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe Report for European Commission DG Environment p. 93.

<sup>144</sup> See: <http://echa.europa.eu/web/guest/regulations/reach/understanding-reach>

<sup>145</sup> Other substances manufactured/imported under 1,000 tonnes per year must be registered in 2013 or 2018.

<sup>146</sup> As further defined under Art. 2, (1), ELD.

<sup>147</sup> Required by Article. 3, (1),( a), ELD.



numerous pads wells (it will be easier to identify if there is only one operator per pad or well in a given/specific site, but this is unlikely to occur).

#### 4.5.7 GD and GWD

The GD and GWD require Member States to ensure all measures necessary to prevent or limit inputs of pollutants to groundwater are included in programmes of measures. The GD requires the prevention/limitation of introduction of pollutants into groundwater by way of BAT. The directive places obligations on Member States in relation to monitoring and measures to protect groundwater; it does not regulate directly potentially polluting installations. It is therefore only indirectly applicable to the impacts of hydraulic fracturing installations, although Article 6(3) excludes measures related to, inter alia, the consequences of accidents or exceptional circumstances of natural cause that could not reasonably have been foreseen, avoided or mitigated. GWD (Article 4.4) refers to WFD (Annex V 2.4) which requires operational monitoring at a frequency sufficient to detect the impacts of relevant pressures on groundwater bodies.

## 4.6 European Member State Regulations

In 2011, Philippe and Partners completed a study for DG ENER ('Final Report on Unconventional Gas in Europe') on the permitting and licensing of shale gas extraction in various Member States<sup>148</sup>. The work provided an overview of the respective applicable licensing and permitting regimes in four Member States (Poland, France, Germany and Sweden) to contribute to the assessment of the appropriateness of the EU regulatory framework as well as of its transposition and implementation in the Member States. The purpose was to provide the Commission with some first thoughts on the applicable legal background both nationally and internationally.

In July 2013, the report 'Regulatory provisions governing key aspects of unconventional gas extraction in selected Member States' (Milieu, 1st July 2013), examined regulatory practices in eight Member States (Bulgaria, Denmark, Germany, Lithuania, Poland, Romania, Spain and United Kingdom)<sup>149</sup>. Given that the second report is more recent, provides information on a greater number of Member States (including two<sup>150</sup> from the original study), this has been used to provide an overview of the position in Europe.

Key points are summarised as follows:

- ▶ **Permitting regime and competent authorities:** None of the selected Member States have set in place a legislation and permitting procedure specific to unconventional gas activities. They all rely on the current mining and/or hydrocarbon legislation.
- ▶ **Public participation and consultation requirements and access to information:** Public participation requirements in the selected Member States mainly derive from the transposing legislation of the SEAD and the EIAD:
  - ▶ In the UK for the SEAD, public consultation can take place at scoping (for a minimum period of 5 weeks) and must take place at the Environmental Reporting stage (no minimum or maximum period specified; however, common practice ranges from 6 weeks to 3 months). The responsible authority must notify the statutory environmental consultees and provide a hard copy of the Environmental Report (and the plan or programme to which it relates) available in its offices for review. The extent to which further engagement is undertaken is dependent on the responsible authority's commitments towards consultation; however, it is usual practice to make the Environmental Report available on line, and to host at least one public meeting.

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<sup>148</sup> *Philippe & Partners* (2011), Final Report on Unconventional Gas in Europe: In the framework of the multiple framework service contract for legal assistance TREN/R1/350-2008 lot 1, Prepared by the law firm Philippe & Partners, Brussels, 8 November 2011

<sup>149</sup> *Milieu* (2013), Regulatory provisions governing key aspects of unconventional gas extraction in selected EU Member States 070307/2012/630593/SER/ENV.F1

<sup>150</sup> *Milieu* (2013), Regulatory provisions governing key aspects of unconventional gas extraction in selected EU Member States 070307/2012/630593/SER/ENV.F1

- ▶ In the UK for the EIAD, public consultation can take place at scoping and must take place at the Environmental Statement stage. The competent authority (the local planning authority) is required to undertake a formal period of public consultation, prior to deciding a planning application. Local Authorities have discretion about how they inform communities and other interested parties about planning applications; however, publishing information online in an open data format is usual. The time period for making comments will be set out in the publicity accompanying the planning application. This will be not less than 21 days, or 14 days where a notice is published in a newspaper.

However, in these instances, the public is only allowed to consult and comment on the resulting Environmental Report (for the SEAD) and the Environmental Statement (for the EIAD) and not on the final authorisations. Public participation requirements are also imposed by the rules governing the permitting procedure under the legislation transposing the MWD.

- ▶ **Setback and zoning:** In all selected Member States, setback, zoning and minimum well spacing requirements are derived from general mining operations and are not specific to unconventional hydraulic fracturing activities. They might also arise from local planning permission and from the water legislation transposing EU directives regulates, controls or prohibits activities in specific protection zones.
- ▶ **Requirements on baseline monitoring prior to drilling or fracturing:** No specific requirements on baseline monitoring prior to drilling or fracturing have been identified. Notwithstanding that existing conventional oil and gas commitments apply.
- ▶ **Gas leakage and air pollution incl. from methane (e.g. via venting, flaring):** There appears to be no legislation in the selected Member States that explicitly addresses venting and flaring in the context of hydrocarbon projects. Venting and flaring of methane and other emissions are expected to be addressed through permitting conditions. In some selected Member States, a differentiation is made between flaring and venting. As part of the consenting process in the UK, an applicant must demonstrate that flaring or venting will be kept to the minimum that is technically and economically justified. Consent to venting would not normally be given unless flaring is not technically possible. In Denmark, a prohibition of venting is not set in legislation but would be applied in practice. Flaring is only accepted to a limited extent (e.g. for safety reasons).
- ▶ **Well design, construction integrity and casing:** There are no specific legal requirements relating to casing and cementing for unconventional gas wells. Notwithstanding that existing conventional oil and gas commitments apply.
- ▶ **Hydraulic fracturing:** The study identified some of the key requirements associated to the carrying out of the fracturing activity:
  - ▶ **Obligation on the operator to monitor the effects of fracturing operations (e.g. induced seismicity):** None of the countries assessed have set in place measures to control and monitor the effects of the hydraulic fracturing process, with the exception for induced seismicity in the UK.
  - ▶ **Injection of wastewater resulting from hydraulic fracturing for underground disposal and potential re-use in fracturing operations:** There was no common understanding of the application of the transposing provisions of the WFD leading to some Member States not permitting reinjection for the purposes of disposal (Romania and the UK) whilst others able to permit it (Germany, Denmark and Poland).
  - ▶ **Treatment and discharge to surface waters:** None of the selected Member States provide specific requirements for the treatment and discharge to surface waters of wastewater from unconventional gas operations. They rely on the water legislation transposing the WFD and UWWDD.
  - ▶ **Water abstraction:** The general water legislation transposing EU directives on water applies, pursuant to which a permit would typically be required for water abstraction. None of the selected Member States have set specific requirements relating to the authorisation,

monitoring, reporting and verification of water abstraction and use during hydraulic fracturing, beyond these general provisions.

- ▶ Obligation on the operator to disclose information on the chemicals contained in the fracturing fluids and requirements (including possible prohibition) regarding use or non-use of certain chemicals: In the Member States assessed, operators of unconventional gas activities are not explicitly obliged by national legislation to disclose information to public authorities and the general public on the substances they are planning to use during the fracturing phase. In the UK, when assessing whether a permit will be required for groundwater activities, or whether any discharge to groundwater is to be prohibited, the authorities will require information on any chemicals contained in the fracturing fluids.
- ▶ Permanent monitoring of the impacts of hydraulic pressure on the well or ground and adoption of measures (stopping or resuming activity): None of the selected Member States have established requirements relating to monitoring of the hydraulic pressure during fracturing activities, except in the UK with a traffic light system to identify unusual seismic activity, and Germany, with a requirement to constantly monitor the pressure in the well and to shut off the well where it exceeds standards.

The report concluded that the selected Member States were relying mainly on the general mining, hydrocarbons and environmental legislation and related permitting procedures to regulate unconventional gas activities and that there were few adopted specific requirements for this type of operation. However, the report noted that there were on-going reviews in a number of Member States aimed at addressing the specificities of unconventional gas exploration and production.

#### 4.6.1 Advances in the UK

Within the UK, the Infrastructure Act 2015<sup>151</sup>, which received Royal Assent on 12<sup>th</sup> February 2015, includes specific provisions regarding hydraulic fracturing. This followed extensive debates in the House of Parliament<sup>152</sup>. Under the requirements of the Act, it is now prohibited to undertake hydraulic fracturing in land at a depth of less than 1,000 metres. An operator now needs to obtain a hydraulic fracturing consent from the Department of Energy and Climate Change (DECC) where hydraulic fracturing is proposed at a depth below 1,000m. In order to obtain the hydraulic fracturing consent, the operator needs to demonstrate that it has met the following conditions:

- ▶ That the environmental impact of the development which includes the relevant well has been taken into account by the local planning authority.
- ▶ Appropriate arrangements have been made for the independent inspection of the integrity of the relevant well.
- ▶ The level of methane in groundwater has, or will have, been monitored in the period of 12 months before the associated hydraulic fracturing begins.
- ▶ Appropriate arrangements have been made for the monitoring of emissions of methane into the air.
- ▶ The associated hydraulic fracturing will not take place within protected groundwater source areas.
- ▶ The associated hydraulic fracturing will not take place within other protected areas.
- ▶ In considering an application for the relevant planning permission, the local planning authority has (where material) taken into account the cumulative effects of— (a) that application, and (b) other applications relating to exploitation of onshore petroleum obtainable by hydraulic fracturing.

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<sup>151</sup> <http://www.legislation.gov.uk/ukpga/2015/7/section/50/enacted>

<sup>152</sup> <http://www.publications.parliament.uk/pa/cm201415/cmhansrd/cm150126/debtext/150126-0001.htm#1501264000001>

- ▶ The substances used, or expected to be used, in associated hydraulic fracturing— (a) are approved, or (b) are subject to approval, by the relevant environmental regulator.
- ▶ In considering an application for the relevant planning permission, the local planning authority has considered whether to impose a restoration condition in relation to that development.
- ▶ The relevant [energy, water, wastewater] undertaker has been consulted before grant of the relevant planning permission.
- ▶ The public was given notice of the application for the relevant planning permission.

The legislation defines hydraulic fracturing as involving or expected to involve the injection of:

- (i) more than 1,000 cubic metres of fluid at each stage, or expected stage, of the hydraulic fracturing, or
- (ii) more than 10,000 cubic metres of fluid in total.

Currently secondary legislation is required to be issued in the summer 2015 that clarifies the meaning of two of the conditions: areas which are “protected groundwater source areas”, and areas which are included within “other protected areas”.

## 4.7 Moratoria

Two European Member States have a ban or moratorium on hydraulic fracturing: France and Bulgaria. In addition, North Rhine Westphalia in Germany and Fribourg and Vaud in Switzerland have also instituted moratoria.

The Scottish Government announced a moratorium<sup>153</sup> in February 2015 on granting consents for unconventional oil and gas developments for onshore Scotland whilst further research and a public consultation is carried out.

### 4.7.1 France

In 2011, following strong lobbying from Europe Écologie Euro MP José Bové against shale gas exploration in the Larzac area of southern France, the French government suspended three gas exploration permits. A commission was launched charged with evaluating the environmental impact of shale gas production.

In July 2012, following the conclusion of the commission, the French Environment Minister confirmed that the government would maintain a moratorium on shale gas exploration. In September 2012, President Francois Hollande announced a continued ban on hydraulic fracturing in France until the end of his Presidential Term and called for the revocation of seven outstanding permit applications for hydraulic fracturing operations.

Following a challenge from Schuepbach Energy LLC, a Dallas-based explorer, who argued that the law was unfair after having two exploration permits, France’s constitutional court upheld the ban on hydraulic fracturing in October 2013. The Court ruled that the law against hydraulic fracturing was a valid means of protecting the environment. The court concluded that the 2011 law “conforms to the constitution” and lawmakers were pursuing a legitimate goal in the general interest of protecting the environment. The court also rejected an argument that the ban went against property rights.

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<sup>153</sup> <http://news.scotland.gov.uk/News/Moratorium-called-on-fracking-1555.aspx>

#### 4.7.2 Bulgaria

The Bulgarian Government has imposed a moratorium on hydraulic fracturing since January 2012 due to pressure from environmental groups. Since then, a parliamentary committee has been established to assess the moratorium.

## 4.8 Voluntary Measures

Although to date, experience of unconventional oil and gas exploration and production is limited in Europe, potential best practice/voluntary actions by unconventional gas operators in Europe are beginning to emerge. Two examples are found in Det Norske Veritas' 'Risk management of shale gas operations – Recommended practice' (DNV, 2013<sup>154</sup>) and the UK Onshore Operators' Group 'UK Onshore Shale Gas Well Guidelines. Exploration and Appraisal Stage' (UKOOG, Issue 3 March 2015<sup>155</sup>).

DNV's risk management approach provides an approach to the management of environment and safety risks. It stems from a traditional approach of identifying consequence categories, risk identification and assessment, engagement and communication of risk management with stakeholders and a management system to address risks. The approach focuses on the following areas:

- ▶ Health and safety risk management;
- ▶ Environmental risk management;
- ▶ Well risk management;
- ▶ Water and energy resources risk management;
- ▶ Infrastructure and logistics risk management;
- ▶ Public engagement and stakeholder communication; and
- ▶ Permitting.

The UKOOG guidelines focus on the exploration and appraisal stage only (i.e. not extending to the production and closure stages at this time). The approach of the guidelines is based on objective-setting rather than prescriptive requirements. It reflects the existing UK regulatory framework and addresses the following:

- ▶ Well design and construction;
- ▶ Fracturing/flowback operations;
- ▶ Environmental management (construction and operations);
- ▶ Fracturing fluids and water management;
- ▶ Minimising fugitive emissions to air; and
- ▶ A proposed format for the public disclosure of fracture fluids.

The UKOOG guidelines highlight the use of effective management systems to assist in discharging their operators and other duty holders responsibilities. It states that "operators' management systems should be developed and applied to all operations including any pre-drilling operations such as seismic acquisition work". The core principle of the management system should be a "best practice, continuous improvement, approach" and once implemented should, preferentially be, externally certified. The UKOOG guidelines indicate that it is the intention to develop a National Standard for shale gas operations as experience is

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<sup>154</sup> [http://www.dnv.com/industry/oil\\_gas/services\\_and\\_solutions/technical\\_advisory/process\\_integrity/gas\\_consulting/shale\\_gas/](http://www.dnv.com/industry/oil_gas/services_and_solutions/technical_advisory/process_integrity/gas_consulting/shale_gas/)

<sup>155</sup> <http://www.ukoog.org.uk/images/ukoog/pdfs/ShaleGasWellGuidelinesIssue3.pdf>

gained, within the framework of a Publicly Available Specification (PAS) that will be independently accredited by the British Standards Institute (BSI).

Both the DNV and UKOOG approaches are voluntary. The DNV approach stems from a classical risk management perspective that has been adapted and made specific to the risk aspects arising from unconventional gas and made available for use by the industry. However, obtaining industry-wide commitment to its application is not part of the approach.

The UKOOG guidelines stem from the industry in the UK and are a first attempt to set out and encourage the industry to operate to a consistent set of objectives (specific measures are not proposed) focussed on the early stages of development.

In North America, where unconventional gas exploration and production is mature relative to Europe, the oil and gas industry has developed best practice guidance relating to unconventional gas extraction. This forms part of an overall management framework for unconventional gas, particularly if regulatory frameworks do not address all aspects. The International Energy Association's (2012) 'Golden Rules for a Golden Age of Gas' publication<sup>156</sup> defines a number of key best practice elements for unconventional gas development and could make a useful contribution to developing industry practice in Brazil. The Golden Rules cover the following key areas for industry:

- ▶ Measurement, disclosure and engagement;
- ▶ Site selection;
- ▶ Isolation of wells to prevent leaks;
- ▶ The responsible use and management of water;
- ▶ Elimination of venting and minimisation of flaring and other emissions;
- ▶ The need to 'think big' to realise economies of scale of innovative solutions and cumulative effect mitigation; and
- ▶ Ensuring a consistently high level of environmental performance.

The Golden Rules were developed with reference to best practice for unconventional gas developed by such organisations as the American Petroleum Institute, the Canadian Association of Petroleum Producers and the US Department of Energy. As with the DNV and UKOOG guidelines, adoption of the 'golden rules' is voluntary.

In conclusion, whilst best/recommended practice and voluntary approaches are emerging in Europe and becoming more developed in North America, they are not well established or fully integrated. The industry across Europe may be aware of best practices but there remains no coherent industry approach or agreement to implement a recognised set of objectives or practices.

Furthermore, in the absence of a developed industry in the EU and with a lack of commitment from an established industry to apply such measures, there is no guarantee that any voluntary approach would be implemented by any/many/all of the companies which in the future would become active in unconventional gas extraction.

## 4.9 Summary

The European Commission adopted Recommendation 2014/70/EU provides a set of coherent minimum principles that may be used for Member States that are looking to develop the exploration and production of hydrocarbons using HVHF. The Recommendation provides a common framework for competent authorities, operators and the civil society to work within. It reflects a considerable body of work, including an assessment of risks, Member State practice and the scope of the environmental acquis and potential policy

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<sup>156</sup> [http://www.worldenergyoutlook.org/media/weowebiste/2012/goldenrules/weo2012\\_goldenrulesreport.pdf](http://www.worldenergyoutlook.org/media/weowebiste/2012/goldenrules/weo2012_goldenrulesreport.pdf)



options. It is however, not a Directive and so the extent to which it will be implemented across Member States remains uncertain.

The Recommendation attempts to address the gaps identified within the existing suite of Directives and Regulations (the *acquis communautaire*). These include:

- ▶ Insufficient requirement for site characterisation and setting of baseline conditions for air, water and soil;
- ▶ Insufficient requirement for subsurface site characterisation, including baseline conditions for deep ground/geology/seismicity;
- ▶ No criteria or common principles available against which to perform a geological risk assessment;
- ▶ No monitoring of injection tests/'mini-fractures' required;
- ▶ Requirement for cumulative effects may be inconsistently implemented (e.g. of environmental impacts, traffic related impacts and land take);
- ▶ Public participation not always required as it generally occurs upon the performance of an EIA, which, at exploration stage, is not required if the screening procedure concludes that the project is not likely to have significant effect on the environment;.
- ▶ Post closure monitoring requirements.

At the Member State level:<sup>157</sup>

- ▶ None of the Member States examined in this study have a regulatory regime specifically for unconventional gas although these are evolving;
- ▶ There are legal uncertainties. For example, regulation may be primarily focussed on water, industrial and/or mining waste law (or a combination, requiring operators to have several permits). As a result requirements at national level are not only different, but sometimes contradictory;
- ▶ Regulatory uncertainties and gaps are prompting Member States to review legislation and draft new law. Divergence may continue and not all regulatory development at Member State level may deliver the necessary and required management of environmental impacts and risks, notably in the light of possible cross-border effects. Also developments at Member State level run the risk of providing a fragmented regulatory framework across the EU which could result in an uneven 'playing field' for business and increased business costs as individual companies adapt to different regulatory regimes.

Regarding best practice/voluntary actions by industry:

- ▶ Whilst best/recommended practice and voluntary approaches are emerging, they are not well established or fully integrated, particularly taking into account the early stage in development of certain unconventional gas resources such as shale gas in Europe. The industry across Europe may be aware of best practices but there remains no coherent industry approach or agreement to implement a recognised set of objectives or practices, although there are national positions e.g. UKOOG<sup>158</sup> being established.
- ▶ The completion of guidance by member states is still in its early stages. However, under the Recommendation, the Commission is also reviewing the current reference document (BREF) on extractive waste under the MWD. The aim is to ensure that the BREF covers the management of waste from hydrocarbon exploration and production involving HVHF, in order to ensure that waste is appropriately handled and treated and the risk of water, air and soil pollution is

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<sup>157</sup> Based on the conclusions of the report 'Regulatory provisions governing key aspects of unconventional gas extraction in selected Member States' (Milieu, 1<sup>st</sup> July 2013) for the European Commission.

<sup>158</sup> <http://www.ukoog.org.uk/onshore-extraction/industry-guidelines>



minimised. Such information will be publicly available and so could help inform emerging guidance in Brazil.

## 5. Brazilian Regulatory Framework for the Environmental Effects of Oil and Gas

### 5.1 Introduction

This section outlines the policy and regulatory framework for oil and gas in Brazil. It presents details in a chronological order, building up over time the framework of legislation relevant to the management of environmental effects associated with unconventional oil and gas. Necessarily this includes considerable reference to the management of environmental effects associated with conventional oil and gas.

### 5.2 Environmental Regulatory Requirements for the Oil and Natural Gas industry

#### 5.2.1 Environmental Permitting and EIA

**Law 6,938**, of 1981, in its Article 10, requires the "*prior environmental permitting*" for the "*construction, installation, expansion and operation of establishments and activities which make use of environmental resources, considered effective or potentially polluting, as well as those tending, in any form, to cause environmental degradation*".

The law also established the "National System of Environment" - SISNAMA, formed by "*organs and entities of the federal government, states, federal district, of the territories and the municipalities, as well as other public institutions, responsible for protecting and improving the quality of the environment*". Moreover, the law established the National Environment Council (CONAMA), a consultative and deliberative board, with the following purpose, to "*advise, study and propose to the Council of Government, guidelines for governmental policies for the environment and natural resources, and to deliberate, within the scope of its competence, on standards compatible with the ecologically balanced environment and essential to a healthy quality of life*".

CONAMA, following discussion with stakeholders, technical reviews and proposals from the Brazilian Institute of the Environment and Renewable Natural Resources - Ibama (the federal environmental agency) will establish:

- ▶ Standards and criteria for the effective permitting of potentially polluting activities;
- ▶ Evaluate the possible environmental consequences of public or private projects and require the consideration of alternatives to such projects, where the environmental effects are significant;
- ▶ Establish standards and criteria relating to the control and the maintenance of environmental quality, taking into account the safe use of environmental resources, especially water.

The **CONAMA Resolution 01/1986** defines environmental impact as "*any change in the physical, chemical and biological properties of the environment, caused by any form of matter or energy resulting from human activities that, directly or indirectly, affect the health, safety and the well-being of the population; social and economic activities; the biota; the aesthetic conditions and health of the environment; and the quality of environmental resources*".

Further, it specifies that, among other activities, the deployment of oil and gas pipelines and the extraction of oil and natural gas will depend on development of an environmental impact assessment - EIA and its environmental impact report - RIMA, to be submitted for approval to the competent environmental body. The text defines a scale only in the case of transmission lines (above 230KV) and power generation (above 10MW).

For each case the scope of the study (EIA) may vary and will depend on a Term of Reference prepared by the environment agency. According to the CONAMA Resolution 1/86, the environmental impact study should consider at least the following technical activities:

- i. Environmental analysis of the area of influence of the project and analysis of the environmental resources and their interactions, considering:
  - a) the physical environment - the subsoil, water, air and climate, highlighting the mineral resources, topography, soil types and aptitudes, water bodies, the hydrologic regime, ocean currents, air currents;
  - b) the biological environment and natural ecosystems - the flora and fauna, highlighting the indicator species of environmental quality, and scientific and economic value, rare and endangered, as well as areas reserved to permanent preservation;
  - c) the socioeconomic environment - the use and occupation of land, water use and the socioeconomics highlighting the sites and archaeological, historical and cultural monuments of the communities, the dependency relationships between the local society, environmental resources and the potential future use of these resources.
- ii. Analysis of environmental impacts of the project and its alternatives, through identifying, predicting the magnitude and interpretation of the significance of the likely significant impacts, showing: the positive and negative impacts (beneficial and adverse), direct and indirect, immediate and medium and long-term, temporary and permanent; their degree of reversibility; their cumulative and synergistic properties; the distribution of social benefits and burdens.
- iii. Definition of measures to mitigate negative impacts, including wastes processing strategies and their efficiency.
- iv. Development of follow-up and monitoring (to both positive and negative impacts) and indicating the factors and parameters to be considered.

**CONAMA Resolution 23/1994** was the first standard to establish specific procedures for the environmental permitting of activities related to the exploration and production of oil and natural gas. The resolution defined different categories of environmental permit, for each phase of the exploration and production activity (drilling, installation and production), as well as the mandatory studies corresponding to each of them.

**CONAMA Resolution 237/1997** determines that "*the environmental permit for projects and activities considered effectively or potentially causing significant environmental degradation will depend on prior environmental impact study and respective report (EIA / RIMA), ... submitted to public hearings, when appropriate, in accordance with the regulations*". The resolution establishes, therefore, that the decision on the amount of impact is up to the environmental agency prior to the study development. This Resolution applies to any kind of activity or project and not specifically to the oil and gas sector.

CONAMA resolution 237/1997 also defined the competences of the three levels of government (Federal, states and municipalities) concerning the granting of environmental permits:

- ▶ Federal environment agency, Ibama has responsibility for "projects and activities with significant environmental national or regional impact<sup>159</sup>": located or developed jointly in Brazil and in a neighbouring country; in the territorial sea; on the continental shelf; in the exclusive economic zone; in indigenous lands or federal conservation areas; located or developed in two or more states; whose direct environmental impacts extends beyond the territorial limits of the country or of one or more states; related to radioactive material, or using nuclear energy in any of its forms and applications ... ; and military bases or projects."
- ▶ State environment agencies are responsible for permits onshore. The exception in this case applies to pipeline or seismic lines that span more than one state and should be evaluated by Ibama.

Given that the two resolutions coexist, the federal environment agency adopted a pragmatic approach concerning the permitting of oil and gas activities - the resolution 23/1994 is used for the cases considered

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<sup>159</sup> The definition of the "significance" of the project or activity impact is up to the "competent environmental body".

as environmentally less impacting, and resolution 237/1997 in more complex situations requiring more comprehensive environmental studies.

It is worth noting that, in accordance with the resolution, the environment agency has discretion as regards the definition of the significance of the environmental effects and, consequently, as to the requirements and constraints on the process of granting of the environmental permit. If the environment agency defines the impacts as significant the EIA will be mandatory and more strict measures will be demanded to issue the environmental permit. At this stage, a project can be declined on environmental grounds, if the effects are significant and cannot be controlled or mitigated.

In the case of oil and gas activities, each stage of the exploration and production process (seismic surveys, drilling, extended well tests and production and transportation) is likely to require permitting. Resolution 237, however, admits a single environmental permit for "small projects and similar activities in the same vicinity or to those included in development plans previously approved by the responsible governmental body, provided that defined a single legal liability for the whole set of activities". As an example, Ibama has been adopting a regional approach to drilling activities of the Brazilian state company – Petrobras, in some offshore basins. In this case, a single environmental study, including modeling of oil drift, as well as monitoring programs and contingency plans, makes viable the permitting of a preset number of projects in the same permitting administrative process. The procedure is restricted, however, to the set of tasks or activities, under the "legal liability" of a single entrepreneur.

**Ordinance 422** was published by the Ministry of the Environment in 2011 which deals with procedures for the federal environmental permitting of oil and gas activities and projects offshore and in land-sea transition zone. The ordinance specifies types of permits, deadlines and studies required for the activities of seismic, drilling, extended well tests and production and transportation in offshore environment. For each activity of the exploration and production life cycle, the ordinance specifies studies and specific constraints in accordance with the environmental sensitivity of the area and depth range and/or distance from the coast. The regulation, sought to detail the procedures required for the permitting and, thus, to overcome possible ambiguities arising from the application of CONAMA Resolutions 23 and 237<sup>160</sup>.

It should be noted that the specific permitting for the onshore activities, including those related to the oil and gas industry continues to be treated on the basis of the two CONAMA Resolutions. Considering that onshore activities include "linear" projects, such as pipelines deployment and seismic surveys and those activities eventually extend over more than one state or include activities with significant environmental national or regional impact, they might also be a matter of competence of the federal environmental agency.

The **Complementary Law 140** was published in 2012 by the federal government aiming at a more precise definition of competences for the environmental permitting. The role of the federal government and states have not changed; however the new law eliminated the criterion concerning the "extension" of impacts as determinants for the definition of permitting competence. Therefore, the distinction of competences is now defined only upon the activity location. Thus, the responsibility of the federal agency in permitting remained restricted to enterprises located or developed jointly in Brazil and in a neighbouring country; in two or more states; in the territorial sea, the continental shelf or the exclusive economic zone; in indigenous lands; in federal conservation units (e.g. national parks and reserves); as well as military projects; or those involving radioactive material or the use of nuclear energy.

The law no longer mentions those projects "*whose direct environmental impacts extends beyond the territorial limits of the country or of one or more states*"<sup>161</sup>. On the other hand, it opens a possibility for the

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<sup>160</sup> Resolution 237 applies to any activity considered effectively or potentially causing significant environmental degradation and not only to the oil and gas sector. The resolution is a "guide" to the environment agencies, both state and federal, in charge of evaluating environmental studies and issuing environmental permits. There are not requirements to be followed directly by oil and gas companies. The same applies to Resolution 23 and Ordinance 422. Nowadays, Ibama when considering offshore activities has to comply only with Ordinance 422, but as stated before, for the onshore basins Resolution 23 is still in force. Just to give a broader idea of the Brazilian environmental regulation, it is important to note that there are other CONAMA resolutions with precise requirements to be followed by oil and gas companies. For example CONAMA Resolution 393/2007 and 398/2008, which detail, respectively, contents of oils and greases in produced water and the platforms and drilling rigs "Individual Emergency Plans".

<sup>161</sup> One example of "enterprise located or developed jointly in Brazil and in a neighboring country" is the Itaipu hydroelectric dam on the Paraná River located on the border between Brazil and Paraguay; "in two or more states" refers to another case when the project lies exactly on the border of two or more states. For the oil and gas sector this refers to pipelines or seismic lines.

expansion of federal authority, including projects in accordance with “*typologies to be established by an act of the Executive Power, based on propositions of a National Tripartite Commission,<sup>162</sup> ensured the participation of a member of the CONAMA, and considered the criteria of size, polluting potential and the nature of the activity or project*”. Such typologies should be defined by a decree yet to be published. The proposal is to transfer the responsibility of environmental permit from the state to the federal agency, for projects such as small hydroelectric plants above a given generation capacity, some harbour facilities in inland waters and the “*production of unconventional resources*”<sup>163</sup>. If this is so, the environmental permit for onshore exploratory phase, including the drilling of wells, will be granted and supervised by the state, until the commerciality of an unconventional reservoir is established and the production phase begins, when Ibama will assume the permitting process. In consequence, when considering unconventional oil and gas, the same activity (for example hydraulic fracturing, with injection of high volumes of fluid associated to horizontal wells), which will occur in both the exploratory phase and the production phase, will be permitted by the state at exploration stage and permitted by the federal agency at production stage. There is, however, no definition so far of what studies and/or procedures will be required to the concessionaries by either the state or federal environmental agency.

### 5.3 Other Activities

Other aspects or activities related to the oil and gas industry are dealt by other specific regulations, as follows:

- ▶ **Land take:** it is necessary to have an authorization from the land owner (even for seismic lines), but as the underground resources are owned by the Union, the “agreement” is mandatory on practical grounds; otherwise the land may be expropriated. Permit constraints determined by the environment agency may prohibit the activity in certain areas due to the presence of vegetation (e.g. riparian).
- ▶ **Area reclamation:** There are ANP resolutions regulating the recovery of areas after seismic activities; drilling and production phase. Well abandonment is also dealt by an ANP resolution. These resolutions and other constraints are often demanded by state environmental agencies.
- ▶ **Effects on biodiversity:** (direct loss of habitat and wildlife, impacts on connectivity from “linear features”, as deployment of pipelines, impacts from noise and intrusion) are considered at the EIA or other studies and is up to the environment agency to demand for changes or mitigation measures in the original project.
- ▶ **Effects on air quality from construction/transport activities:** Some environment state agencies demand studies on the activities effects on air quality and require the necessary changes or mitigation measures in the original project.
- ▶ **Effects on water courses and ground water from discharges and accidental releases:** Some state agencies demand the monitoring of water courses and groundwater in the potentially affected area.
- ▶ **Effects on water resources from additional demand:** The use of water under federal domain is regulated by federal law 9,433/1997. A specific grant is demanded by the National Water Agency in case of “*derivation or abstraction of water body for final consumption, including public supply or input of the production process; the extraction of water from underground aquifer for final consumption or as an input to the production process; release of sewage and other liquid*”

<sup>162</sup> A Commission formed by representatives of federal government, states, federal district and municipalities, with the aim of promoting shared and decentralized environmental management among federative instances.

<sup>163</sup> The definition of unconventional resources at the draft version of the decree is the same as the one adopted at the concession agreements for the 12<sup>th</sup> bidding round for exploratory blocks: “accumulation of oil and natural gas that unlike conventional hydrocarbons is not significantly affected by hydrodynamic influences and whose existence is not conditioned by a geological structure or stratigraphic condition, typically requiring special extraction technologies, such as horizontal or high angle wells and hydraulic fracturing or heating retort. Included in this definition are the extra-heavy oil, the oil extracted from the tar sands, the shale oil, as well the oil extracted from the rich organic matter shale (oil shale) and from very low porosity formations (tight oil). Also to be considered in the definition, are the coal bed methane and methane hydrates, as well as the natural gas extracted from shale (shale gas) and formations with very low porosity (tight gas).



or gaseous waste, treated or not, for the purpose of dilution, transport or disposal; use of water resources for the purpose of hydroelectric generation; other uses that modify the system, the quantity or quality of existing water in a body of water". Although the 9,433/1997 Federal Law determines that the extraction of water from aquifers for final consumption or for use in a production process is subjected to water use right (Article 12), the Brazilian Federal Constitution settles that groundwater is a State domain good and in consequence, the water use right will be granted by the state where the activity is located. Article 12 also defines when a grant is not required:

- ▶ the use of water resources to meet the needs of small populations groups scattered in rural areas;
- ▶ deviation, catchment or discharge that are considered insignificant;
- ▶ impoundment of volumes of water that are considered insignificant.

Each state has broadly the same regulation for state water use. Nevertheless the CONAMA Resolutions related to environmental permit don't explicitly mention the use of water.

- ▶ **Produced water** in the offshore environment is dealt by CONAMA Resolution 393/2007; emergency plans are considered in CONAMA Resolution 398/2008; the classification of water bodies, environmental guidelines for framework, conditions and standards to effluent discharge, among other issues, are dealt by CONAMA Resolutions 357/2005 and 430/2011; CONAMA Resolution 396/08 provides the classification of groundwater.
- ▶ **Management of wastes, including management of wastewater:** Generally the permit is conditionally issued demanding the development of a waste management programme previously approved by the environment agency. The discard of produced water offshore is regulated by CONAMA resolution 393/2007 and the injection or discard of produced water should be detailed in the development plans approved by ANP, concerning production fields. Ibama has determined procedures for the disposal of drill cuttings and oil and synthetic-based muds, at sea (e.g. oil and synthetic-based muds may be discarded when adhered to drill cuttings and with polyaromatic hydrocarbons concentration less than 10ppm).
- ▶ **Effects on climate change from fugitive, vented and flaring:** ANP resolution 249/2000 establish limits to flaring and venting, but not to fugitive emissions. Although there is no clear standards or limits defined in any specific legislation, Ibama imposes constraints on flaring associated to an environmental permit (e.g. environmental permit for "Operation" of an offshore platform - "*no production of oil and natural gas are authorized beyond the period of 150 days from the start of production, if the reinjection of surplus gas is not possible*"). There is no prohibition on the use of ponds in ANP resolution 21/2014 (hydraulic fracturing).
- ▶ **'Local' commitments to use local labour:** no requirement in force. However the concessionaires consider the use of local labour as a "positive impact" in the environmental studies.
- ▶ **Monitoring commitments and well closure:** commitments/obligations once wells are completed are considered in ANP resolution 21/2014.
- ▶ **Compensation for GHG emission:** Ibama has been demanding compensations for emissions of GHG during extended well tests and even during the production phase of offshore fields.

## 5.4 Strategic Environmental Assessment

In 2003, the CNPE<sup>164</sup> issued **Resolution nº 8**, which required that ANP should select areas for bidding, considering the exclusion of those with environmental restrictions, supported by a “joint agreement” of ANP, Ibama and state environmental agencies.

Prior to this resolution, there was no systematic evaluation of the suitability of proposed exploration and production activities to the environmental features of areas/blocks to be licensed by ANP. This had led to cases of conflict, with delays in the issuing of environmental permits, especially in blocks in shallow water and near the coast. One example was the denial of the environmental permit for the seismic activity in block BM-ES-21, in the Espírito Santo basin, granted by ANP in 4th bidding round in 2002, due to the existence of “environmentally sensitive areas”<sup>165</sup>.

ANP identifies initial exclusions based on sensitivities (such as overlapping conservation units or indigenous lands) and after submissions received from federal and state agencies, proposes exclusions from the areas to be licensed for the final approval by the CNPE. The subsequent award of the licence does not exempt the licensee from requirements to meet in full the conditions defined in CONAMA resolutions and Ordinance 422.

In 2012, the Ministries of the Environment and Energy and Mines, also with the participation of oil and gas industry representatives, established a discussion forum in order to seek a more consistent basis to the definition of environmentally suitable areas for the development of exploration and production activity. The discussions led to the publication of the **Interministerial Ordinance 198/2012**.

The ordinance adopted a procedure of prior environmental evaluation (“environmental assessment of sedimentary area”), similar to Strategic Environmental Assessment.<sup>166</sup> The proposal considers that the assessments will be developed over the next few years, by defining a set of areas “suitable”, “not suitable” or under moratorium (on the basis of the need for more in-depth studies), in relation to the exploration and production of oil and natural gas. While the evaluations are not concluded, the ordinance determines an open ended period, along which prevail the agreements, as provided for in Resolution CNPE 8/2003, that is, as long as a specific basin is not assessed the approach determined by the Resolution 8/2003 will be maintained – a joint agreement of ANP, Ibama and state environmental agencies, excluding those areas considered by environment agencies as not suitable for exploration and production activities.

Yet, even for the areas classified as suitable for exploration and production activities according the assessment of sedimentary areas, the environmental permit itself, for each project or exploration and production activity, will be still needed as a discretionary act of the competent environmental agency. What is assumed is that the necessary procedures to get the environmental permit will be simplified, depending only on supplementary studies.

## 5.5 Unconventional Resources and Resolution ANP 21/2014

ANP published a specific resolution (Resolution ANP 21/2014), based on a comprehensive compilation of international experiences, aiming to regulate “*well drilling followed by the employment of the technique of hydraulic fracturing for the production of unconventional resources*”. Specifically, it established the essential

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<sup>164</sup> The National Council for Energy Policy - CNPE, chaired by the Minister of Mines and Energy, is an advisory body to the President to formulate policies and guidelines for energy.

<sup>165</sup> Environmental sensitive area is not a formal term. Any area may be considered “sensitive” by the environment agency for its biodiversity and degree of conservation.

<sup>166</sup> The ordinance 198/2012 defines the responsibilities concerning the assessments (The Ministries of Mines and Energy and the Environment) and the composition of a “Technical Committee” (the federal environment agency – Ibama; the “Chico Mendes Institute for the Conservation of Biodiversity” – ICMBio, responsible for the management of conservation areas in Brazil and ANP). The Ministries of Mines and Energy and the Environment may also invite representatives of other agencies or entities to compose the Committee (e.g. the states environment agencies). The ordinance also establishes the timing for the public hearings (for the appreciation of the Term of Reference and the final report) concerning oil and gas activities; present an environmental diagnosis considering regional characterization of physical, biotic and socioeconomic resources; development of a hydrodynamic baseline, implemented by means of “numerical modeling using updated historical data” as input for modeling of oil and pollutants drift in the study region (offshore); and recommendations to be considered for environmental permits, such as: specific mitigating measures, technological requirements and specific studies and monitoring.

requirements and safety standards for operating and preserving the environment for the activity of hydraulic fracturing in an unconventional reservoir.

The Resolution defines "*hydraulic fracturing in unconventional reservoir*" as the "*injection technique of pressurized fluids in a well, in volumes above 3,000 m<sup>3</sup>, with the objective of creating fractures in a particular rocky formation whose permeability is less than 0.1 mD, enabling the recovery of hydrocarbons contained in this formation*"<sup>167</sup>.

It includes requirements for:

- ▶ Environmental Management Systems;
- ▶ Studies and surveys required for approval of drilling operations followed by hydraulic fracturing in unconventional reservoir;
- ▶ Well design with hydraulic fracturing in unconventional reservoirs; and
- ▶ Technical Regulations.

Sampling parameters for flowback waters are also provided.

In completing this study, a review of the current draft of the Resolution has been undertaken. The following observations on the text of the Resolution are made for further consideration by ANP:

- ▶ The definition of hydraulic fracturing in the Resolution is different from the definition provided by the Community Recommendation 2014/70/EU. The Resolution definition is based, in part, on an exceedance of one volume (3,000m<sup>3</sup>) whereas the Community Recommendation defines it as a process requiring the injection of 1,000m<sup>3</sup> or more of water per fracturing stage or 10,000m<sup>3</sup> or more of water during the entire fracturing process into a well. There could be merit in considering whether the Resolution definition should be revised to provide clarity on whether it should be read as minimum total per well (over the lifetime of the well) or per fracture.
- ▶ Article 6 outlines the requirements for the operator to publish information in an Annual Report on its website and is consistent with the principles of openness and transparency, which are essential to build public confidence. Article 6 (iii) states that "*specific information about the water used in fracturing clearly nominating origin, volume, type of treatment adopted and final disposal*". This could be extended to include the availability and capacity of existing water resources. A water demand profile could also be required which would be revised, when considering the effects of multiple wells on local water resources.
- ▶ Article 6 could be extended to include a requirement that the operator provides, as part of the Annual Report, specific information on waste water arising from the fracturing activity, including volume, composition, treatment options and final disposal of residual waste water;
- ▶ Article 6 could be extended to include a requirement that the operator provides, as part of the Annual Report, specific information on the monitoring of induced seismicity arising from any hydraulic fracturing activity.
- ▶ Article 7 amongst other matters prohibits the hydraulic fracturing in unconventional reservoirs on wells whose distance is less than 200 meters of water wells used for domestic supply, public or industrial, irrigation, watering livestock, among other human uses. The use of a minimum distance is consistent with international practice; however, it is noted that in other regulatory environments, which require a minimum distance between hydraulic fracture pipes and geological strata containing aquifers, this ranges from 600m -1,000m depending on source and country. Either any activity closer than this specified distance is prohibited or a special permit is required.

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<sup>167</sup> It is understood that the intention was to consider the volume per frack, but this is not clear in ANP Resolution. The aim was simply to distinguish the technique from the "conventional" fracturing, which is already part of the set of current methods used by oil and gas industry in the stimulation of reservoirs, in Brazil. As far as it is known the maximum injection volume used in the Recôncavo basin (Bahia state) was around 2,200 m<sup>3</sup> in a single interval.

- ▶ Article 8 requires that the operator provides ANP with a range of documents for approval, which includes a study and assessment of natural and induced seismic events. The Resolution does not currently state would should or could be included in such a study. Potentially this could be expanded to include matters such as:
  - ▶ Review of available information on geology, structure (including faults) and in situ stresses in the vicinity of the proposed site to avoid hydraulically fracturing into, or close to, existing critically stressed faults.
  - ▶ Results of 2D/3D seismic survey to identify faults and fractures.
  - ▶ Engagement with third parties (e.g. regulators, other operators, researchers) to ensure full awareness of any seismicity issues / proximity (e.g. to other underground activities).
  - ▶ Development of geo-referenced database of the zone before work commences covering geology, groundwater flows, pathways, natural microseismicity. Require ongoing development as data is collected through exploration.
  - ▶ Modelling and risk based geomechanical assessments of proposed hydraulic fracturing with regard to faults (including maximum magnitude estimates).
  - ▶ Apply ground motion prediction models to assess the potential impact of induced earthquakes.
  - ▶ Identify potential seismic receptors within a defined radius of the well site (5km) including: wells, infrastructure, special buildings, residential buildings and industrial/commercial buildings. Avoid high seismicity risk areas.
  - ▶ Minimum distance between hydraulic fracture pipes and geological strata containing aquifers (consistent with any amendments to Article 7).
  - ▶ Appropriate well design, construction, testing and monitoring.
  - ▶ Smaller test preinjection prior to main operations to enable induced seismicity response to be assessed, followed by succession of injections over short duration of casing length.
  - ▶ Monitor the fracture growth and direction during hydraulic fracturing using buried microseismic arrays to ensure hydraulic fractures / pollutants do not extend beyond the gas-producing formations and do not result in seismic events or damage to buildings/installations that could be the result of fracturing.
- ▶ Article 10 sets out the specifications of well design and should identify risks, aimed at ensuring the integrity throughout the life cycle of the well, even after its abandonment. The requirement to consider whether any risks are associated with well abandonment may require a separate article requiring information from an operator regarding commitments towards monitoring (from either capped well head or any other ground water boreholes) for specific period (possibly 5 years) and at what point any liabilities associated with the well would be transferred from the operator to the state (if at all).
- ▶ Article. 11 concerns the casing and cementing program. This could be extended to include a requirement that casing depth extends to a specified depth below any aquifer used for domestic consumption/public water supply. For example, surface casing should extend at least 30m below the deepest underground source of drinking water encountered while drilling the well. The surface casing should be cemented before extending well below underground drinking water. Production casing should be cemented down to at least 150 metres above the formation where hydraulic fracturing will be carried out.
- ▶ Article 12 includes a statement that the operator may only continue the project if it is considered that there is an insignificant possibility that the generated fractures or reactivation of any preexisting faults extending up intervals and into overlying formations such as Water Bodies and Groundwater adjacent wells. Currently, "insignificant possibility" is not defined; however, it could be linked to the use of a traffic light system approach, similar to that used by UK using

threshold values to suspend activity; however, would require a judgment on what was acceptable (UK uses 0.5ML) and could be linked to Article 25.

- ▶ Annex II contains a series of parameters for which information is required from the operator. These include sulphides, metals and NORM. It would be useful if threshold values could be provided with guidance for any further action when thresholds are exceeded. For example, in UK, when NORM exceeds certain values, it is classified as radioactive waste and requires different disposal route to licensed disposal site.
- ▶ There is a gap in the Resolution concerning the use of green completions as identified by UK and US government for the management of methane and VOC emissions and this could be included as a requirement. The use of green completions could also lead to closed systems for frack fluid/flowback and the avoidance of storage pits/ponds (in UK the environmental regulators 'will not accept storage of flowback fluid in open surface lagoons'<sup>168</sup>).

The Resolution also states that the approval of hydraulic fracturing in unconventional reservoirs by ANP will depend on, among other requirements, the "*presentation by the operator of the environmental permit issued by the competent agency, with specific authorization for operations of hydraulic fracturing in unconventional reservoir, when applicable*".

The environmental legislation so far does not include any requirement of specific studies or procedures relating to hydraulic fracturing in the case of federal responsibilities or in cases regarded as state competence. In both instances, such studies and procedures might be required as a condition for approval and issuing of environmental permits previous of drilling and production. It is also possible that such studies and procedures will be defined in the scope of a set of new types of permitting specifically related to drilling and production of unconventional. Within the UK, under the Infrastructure Act 2015, an operator now needs to obtain a hydraulic fracturing consent from the Department of Energy and Climate Change (DECC) where hydraulic fracturing is proposed at a depth below 1000m (see Section 4.6.1).

## 5.6 Conclusion

The ANP resolution 21/2014 stands so far as the only regulatory framework for managing operational safety issues, as well as possible effects on the environment and human health, related with unconventional oil and gas. However, under existing Brazilian legislation it is mandatory that the development of unconventional resources, particularly the employment of hydraulic fracturing will depend on gaining an environmental permit.

The environmental issues related to activities associated with the exploration and production of unconventional resources in onshore basins, such as drilling, production, transporting and further decommissioning, will be dealt by state environmental agencies. However, should the Decree regulating the Complementary Law 140 be approved, the environmental permit of the production phase of unconventional resources will be transferred to the federal agency.

Given the importance therefore of the permitting process, it will be important to establish the appropriate matters for inclusion in the permit covering the management and control of any emissions and discharges arising from exploration and production activities.

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<sup>168</sup> Environment Agency (2013), Onshore oil and gas exploratory operations: technical guidance, Consultation Draft, August 2013





## 6. Potential Implication for Brazilian Regulatory Framework for Shale Gas

The exploration and production of shale gas represents a significant opportunity for many countries. It could help address energy security, energy costs and the need for transitional energy sources in moving towards a low carbon future. Brazil, as one of 10 countries that have collectively been estimated to contain nearly 80% of the world's estimated technically recoverable shale gas resources<sup>169</sup>, is actively considering the potential for shale gas. However, in common with many other nations<sup>170</sup> considering the potential for unconventional oil and gas, the proposed development of shale gas in Brazil has also raised concerns regarding the potential effects on the environment<sup>171</sup>.

Brazil is taking a measured approach to the development of a regulatory framework to secure the safe and environmentally responsible management of the effects arising from hydraulic fracturing (review of international research debated through stakeholder forums (the PROMINP project), informing a Government 'white paper' leading to legislation). Like Europe, unconventional oil and gas exploration in Brazil is in its infancy, and there is an undoubted opportunity to capitalise on the studies and experience of regulators and policy makers in Europe and elsewhere to identify the key effects arising from hydraulic fracturing and build on the lessons learned to develop and implement the measures necessary to minimise risks to the environment and communities.

This study is a contribution to the PROMINP project, providing information and research from the UK and Europe as part of the review of international practice. It has drawn from a substantial evidence base of international policy making, regulatory frameworks and studies regarding the likely significant effects and principal risks associated with hydraulic fracturing; however, due to the low level of exploration and development activity in Europe, much of the research into effects completed in Europe has had to use evidence from the US. When considering its applicability to Brazil, allowance is needed, for the differing socio-economic, regulatory, environmental, geological and political context. Timing is also an important factor. A number of the US studies reflect past practice in differing US states, from an emerging industry operating under differing regulatory environments that would not be repeated in Brazil. For example, evidence from the US suggests that up to 750 chemicals were used between 2005 and 2009 in shale gas drilling throughout the US<sup>172</sup> and which included the use of toxic and carcinogenic substances, such as benzene and lead. Given the stated intention in ANP Resolution 21/2014 to preserve the environment and enforce best practice, it seems improbable that the same concerns highlighted in the US regarding the under regulated use of chemicals in fracture fluid would be repeated, given the incompatibility with the stated aims of the ANP Resolution.

The study has attempted to answer the following questions:

- ▶ What are the likely significant effects and principal risks associated with hydraulic fracturing as a means to extract shale gas?
- ▶ Can these effects be effectively avoided, minimised or mitigated to ensure that the risks to the environment and human health can be effectively managed? If so, how?
- ▶ What regulations are used in the UK and Europe to address the specific risks to the environment and human health from hydraulic fracturing? To what extent (if at all) are voluntary and best practice measures effective in managing these risks?

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<sup>169</sup> *US Energy Information Administration, Technically Recoverable Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41 Countries Outside the United States, 2013*

<sup>170</sup> *BIO Intelligence Service (2013), Presentation of the results of the public consultation "Unconventional fossil fuels (e.g. shale gas) in Europe" Brussels – 7<sup>th</sup> June 2013, for the European Commission and DG Environment, [http://ec.europa.eu/environment/integration/energy/pdf/Presentation\\_07062013.pdf](http://ec.europa.eu/environment/integration/energy/pdf/Presentation_07062013.pdf)*

<sup>171</sup> *Brazilian Academy of Sciences Letter to President Rouseff, 5<sup>th</sup> August 2013, <http://jonathandeaiblog.com/2013/08/29/fracking-not-welcomed-with-open-arms-in-brazil/>*

<sup>172</sup> *US House of Representatives Committee on Energy and Commerce in 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*

- ▶ What lessons can be learned from the regulatory frameworks employed in UK and Europe to the management of risks associated with hydraulic fracturing that could be relevant to the Brazilian context? What specific recommendations could be made?

### What are the Likely Significant Effects?

**Table 6.1** provides a summary of the potential environmental effects associated with unconventional gas exploration and production and, for comparative purposes, conventional oil and gas. It shows that the majority of effects associated with unconventional oil and gas exploration and development are common to those associated with conventional oil and gas development. Differences however do occur when considering the technologies and requirements of the hydraulic fracturing process itself. With regard to the risks arising from hydraulic fracturing alone, potential risks are likely to include: induced seismic events; the local sourcing of water, creating additional demand during periods of water stress; the management of chemicals and the mixing, storage and use of the fracture fluid, the management of flowback water and fugitive greenhouse gas emissions.

**Table 6.1 Potential Environmental Impacts Associated with Conventional and Unconventional Gas Exploration and Production**

Theme	Risk/Impact	Conventional	Un-conventional
<b>Biodiversity</b>	Direct loss and/or fragmentation of habitat from construction and operation of well site and well pad activities.	✓	✓
	Indirect impacts on habitats/species due to, for example, disturbance from noise, human presence and light pollution and the introduction of invasive species and the exposure to pollution through causal pathways.	✓	✓
<b>Land Use and Geology</b>	Land requirements for pad and pipelines, disruption to soil layers and compaction and resulting impacts on removal of land for alternative uses (natural or anthropogenic) and ecology/ environment impacts.	✓	✓
	Induced seismicity from hydraulic fracturing activities and the potential impact on well integrity, creation of geological pathways for pollutants and possible minor earth tremors.	✓ (in limited circumstance <sup>173</sup> )	✓
<b>Water Resources</b>	Surface spillage of pollutants such as diesel and drilling fluids and silt-laden run-off resulting in surface water pollution.	✓	✓
	Surface spillage of hydraulic fracturing fluids and wastewaters resulting in surface water pollution.		✓
	Well failure resulting in pollutants released from the well to groundwaters.	✓	✓
	Introduction of pollutants due to induced fractures providing pathways to groundwater resources through either pre-existing man-made or natural structures.		✓
	Inappropriate selection of chemicals in hydraulic fracturing and/ or unsuitable assessment leading to unacceptable risks to the environment from releases.		✓
	Water consumption associated with hydraulic fracturing activities affecting the availability of water resources, aquatic habitats and ecosystems and water quality.		✓
	Well pad development at risk of flooding and/or resulting in increased flood risk off site due to increase in impermeable area and/or location of facilities in areas of flood risk.	✓	✓

<sup>173</sup> *Davies et al* (2012) Induced Seismicity and Hydraulic Fracturing for the Recovery of Hydrocarbons, Marine and Petroleum Geology Manuscript, <https://www.dur.ac.uk/resources/refine/InducedSeismicityfull.pdf>

**Table 6.1 (continued) Potential Environmental Impacts Associated with Conventional and Unconventional Gas Exploration and Production**

Theme	Risk/Impact	Conventional	Un-conventional
<b>Air Quality</b>	Emissions to air from well pad construction and drilling resulting in adverse local air quality impacts.	✓	✓
	Emissions associated with hydraulic fracturing activities resulting in adverse local air quality impacts.		✓
<b>Climate Change</b>	Greenhouse gas (GHG) emissions from well pad construction and drilling.	✓	✓
	GHG emissions associated with hydraulic fracturing activities.		✓
	GHG emissions arising from well completion.	✓	✓
	Fugitive GHG emissions.	✓	✓
	Combustion of extracted hydrocarbons generating GHG emissions.	✓	✓
<b>Waste Arisings</b>	Generation of construction and drilling wastes.	✓	✓
	Generation of flowback water following hydraulic fracturing activities.		✓
<b>Cultural Heritage</b>	Direct loss of or damage to cultural heritage features and landscapes from construction of well pad and associated infrastructure.	✓	✓
	Indirect effects on the setting of cultural heritage assets as a result of the well pad construction and operation.	✓	✓
<b>Landscape</b>	Impacts and landscape character and visual amenity due to well pad construction and operation activities.	✓	✓
<b>Human Health</b>	Emissions to air, dust and noise associated with construction and drilling activities resulting in adverse impacts on nearby receptors.	✓	✓
	Contamination of drinking water supply due to hydraulic fracturing activities.		✓
	Risks associated with the health and safety of workers onsite.	✓	✓
	Disturbance and nuisance issues	✓	✓

### Can these Effects be Effectively Avoided, Minimised or Mitigated?

Given the commonality between the effects arising from unconventional oil and gas and conventional oil and gas exploration, there is a considerable body of practice available to address the issues concerning site selection, technology, construction practice, operation and decommissioning. These measures to avoid, minimise and mitigate risks are contained in **Section 3** of this report which itself summarises details contained in **Appendix B**. Within the UK there is a long track record of undertaking conventional oil and gas exploration and production in an environmentally and socially acceptable manner, which suggests that such measures are effective in managing those effects that are common between unconventional and conventional oil and gas exploration and production<sup>174</sup>.

The remaining mitigation measures identified for those effects associated with hydraulic fracturing (induced seismic events; the local sourcing of water, creating additional demand during periods of water stress; the management of chemicals and the mixing, storage and use of the fracture fluid, the management of flowback

<sup>174</sup> House of Commons Energy and Climate Change Committee (2011), Shale Gas Fifth Report of Session 2010–12, HC 795, May 2011

water and fugitive greenhouse gas emissions) are, within the UK context, unproven; however, reflect expert judgment on what is most effective:

- ▶ **Management of induced seismicity:** recommendations from the Royal Society and Royal Academy of Engineering in their 2012 report, 'Shale gas extraction in the UK: a review of hydraulic fracturing'<sup>175</sup>.
- ▶ **Management of chemicals used in fracture fluids:** requirements of the Environment Agency<sup>176</sup>, and the assessment of effects against the requirements of the Joint Agencies Groundwater Directive Advisory Group.
- ▶ **Management of water demand and flowback water:** recommendations from Water UK research<sup>177</sup> and recommendations from CIWEM report on Shale Gas and Water<sup>178</sup>.
- ▶ **Management of fugitive greenhouse gas emissions:** recommendations from the Mackay and Stone report<sup>179</sup> into potential greenhouse gas emissions associated with shale gas extraction and use.

### What Regulations are used in the UK and Europe to Address the Risks?

The European Commission adopted Recommendation 2014/70/EU provides a set of coherent minimum principles that may be used for Member States that are looking to develop the exploration and production of hydrocarbons using HVHF. The Recommendation provides a common framework for competent authorities, operators and the civil society to work within. It reflects a considerable body of work, including an assessment of risks, Member State practice and the scope of the environmental acquis and potential policy options. It is however, not a Directive and so the extent to which it will be implemented across Member States remains uncertain.

The Recommendation attempts to address the gaps identified within the existing suite of Directives and Regulations (the *acquis communautaire*). These include:

- ▶ Insufficient requirement for site characterisation and setting of baseline conditions for air, water and soil;
- ▶ Insufficient requirement for subsurface site characterisation, including baseline conditions for deep ground/geology/seismicity;
- ▶ No criteria or common principles available against which to perform a geological risk assessment;
- ▶ No monitoring of injection tests/'mini-fractures' required;
- ▶ Requirement for cumulative effects may be inconsistently implemented (e.g. of environmental impacts, traffic related impacts and land take);
- ▶ Public participation not always required as it generally occurs upon the performance of an EIA, which, at exploration stage, is not required if the screening procedure concludes that the project is not likely to have significant effect on the environment;.
- ▶ Post closure monitoring requirements.

No member states within Europe have yet introduced specific regulations for hydraulic fracturing; however, a recent amendment to UK law (the Infrastructure Act 2015) introduces the requirement for a hydraulic

<sup>175</sup> *Royal Society and Royal Academy of Engineering* (2012), Shale gas extraction in the UK: a review of hydraulic fracturing (Terms of Reference, pp 8) June 2012

<sup>176</sup> *Environment Agency* (2013), Onshore oil and gas exploratory operations: technical guidance, Consultation Draft, August 2013

<sup>177</sup> *Amec Foster Wheeler* (2013), Understanding The Potential Impacts Of Shale Gas Fracking On The Uk Water Industry-Stage 1, Report Ref. No. WR09C301

<sup>178</sup> *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

<sup>179</sup> MacKay, D.J.C. and Stone, T.J. (2013) *Potential Greenhouse Gas Emissions Associated with Shale Gas Extraction and Use*. Report on behalf of DECC. London: DECC

fracturing consent, to be issued by DECC to the operator, where hydraulic fracturing is proposed at a depth below 1000m.

Whilst best and recommended practice and voluntary approaches are emerging in Europe and becoming more developed in North America, they are not well established or fully integrated. Examples include a number of voluntary approaches which aim to codify and promulgate best practice, the Det Norske Veritas' 'Risk management of shale gas operations – Recommended practice' (DNV, 2013<sup>180</sup>), the UK Onshore Operators' Group 'UK Onshore Shale Gas Well Guidelines Exploration and Appraisal Stage' (UKOOG, Issue 3 March 2015<sup>181</sup>) and International Energy Association's (2012) 'Golden Rules for a Golden Age of Gas' publication<sup>182</sup>. Collectively, these combine risk management approaches with definitions of a number of key best practice elements for unconventional gas development which could make a useful contribution to developing industry practice in Brazil.

### What Lessons can be Learned from the Regulatory Frameworks Employed in UK and Europe?

In considering the environmental implications of shale gas exploration and production, both Brazil and the EU have recognised the importance of undertaking a high level assessment of areas to be licensed. Within the EU, this is through the implementation of the Strategic Environmental Assessment Directive (2001/42/EC), whilst in Brazil, it is under the Interministerial Ordinance 198/2012 ("environmental assessment of sedimentary area"). Both require the licensing body to set out its proposed areas, identify the nature of any effects and identify where development will not be "suitable". There is potential for the Ordinance 198/2012 to go further in the consideration of the scope of the effects considered (to ensure that they are aligned with those considered at the project stage) and to issue guidance to operators on matters to consider at the project stage. At the project level, EIA is a common assessment tool across both Brazil and Europe, with appropriate matters identified through scoping. As further SEAs are undertaken however, there should be greater linkages between the strategic level assessment and the specific issues addressed at the project level.

The ANP resolution 21/2014 provides the clear basis for a regulatory framework for managing operational safety issues, as well as possible effects on the environment and human health, related with unconventional gas in Brazil. In this approach it is analogous to the role played by the European Commission adopted Recommendation 2014/70/EU which provides a set of minimum principles that may be used when looking to develop the exploration and production of hydrocarbons using HVHF.

Drawing on the contents of Recommendation 2014/70/EU and the research findings completed as part of this study, there is an opportunity to refine the ANP Resolution further to clarify certain aspects of the Resolution in order to improve its effectiveness. These are as follows:

- ▶ Requiring operators to use green completions or reduced emission completions (as identified by UK and US government) for the management of methane and VOC emissions.
- ▶ Reviewing the definition of hydraulic fracturing to clarify whether the volume of water referred to should be read as minimum total per well (over the lifetime of the well) or per fracture.
- ▶ Extending the information required to be provided from operators to include consideration of:
  - ▶ the availability and capacity of existing water resources;
  - ▶ information on waste water arising from the fracturing activity, including volume, composition, treatment options and final disposal of residual waste water;
  - ▶ information on the monitoring of induced seismicity arising from any fracturing activity.
- ▶ Ensuring any separation distances between wells and aquifers is supported by the most recent research and international practice.

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<sup>180</sup> [http://www.dnv.com/industry/oil\\_gas/services\\_and\\_solutions/technical\\_advisory/process\\_integrity/gas\\_consulting/shale\\_gas/](http://www.dnv.com/industry/oil_gas/services_and_solutions/technical_advisory/process_integrity/gas_consulting/shale_gas/)

<sup>181</sup> <http://www.ukoog.org.uk/images/ukoog/pdfs/ShaleGasWellGuidelinesIssue3.pdf>

<sup>182</sup> [http://www.worldenergyoutlook.org/media/weowebsite/2012/goldenrules/weo2012\\_goldenrulesreport.pdf](http://www.worldenergyoutlook.org/media/weowebsite/2012/goldenrules/weo2012_goldenrulesreport.pdf)

- ▶ Providing greater detail to operators on what should be included within the requirement to provide a study and assessment of natural and induced seismic events.
- ▶ Requiring further detail from the operator regarding monitoring post well decommissioning and abandonment (from either capped well head or any other ground water boreholes) and clarifying at what point any liabilities associated with the well would be transferred from the operator to the state (if at all).
- ▶ Requiring surface casing and cementation to extend to a specified depth below any aquifer used for domestic consumption/public water supply.
- ▶ Providing a traffic light system approach to the control of hydraulic fracturing and any induced seismicity, similar to that taken by UK using threshold values to suspend activity.
- ▶ Providing threshold values for specified parameters in flowback fluid for which action is required.

The Resolution also states that the approval of hydraulic fracturing in unconventional reservoirs by ANP will depend on, among other requirements, the "*presentation by the operator of the environmental permit issued by the competent agency, with specific authorization for operations of hydraulic fracturing in unconventional reservoir, when applicable*". The environmental legislation so far does not define what should be included within the environmental permit, and what supporting studies would be necessary. It is possible that such studies and procedures will be defined in the scope of a set of new types of permitting specifically related to drilling and production of unconventional oil and gas. As noted above, within the UK, a hydraulic fracturing consent is now required by the operator from DECC where hydraulic fracturing is proposed at a depth below 1,000m (see **Section 4.6.1**). In applying for this consent, the operator needs to demonstrate that it has met the following conditions:

- ▶ The environmental impact of the development which includes the relevant well has been taken into account by the local planning authority.
- ▶ Appropriate arrangements have been made for the independent inspection of the integrity of the relevant well.
- ▶ The level of methane in groundwater has, or will have, been monitored in the period of 12 months before the associated hydraulic fracturing begins.
- ▶ Appropriate arrangements have been made for the monitoring of emissions of methane into the air.
- ▶ The associated hydraulic fracturing will not take place within protected groundwater source areas.
- ▶ The associated hydraulic fracturing will not take place within other protected areas.
- ▶ Cumulative effects have been taken into account.
- ▶ Regulator approval has been given to the substances to be used.
- ▶ Appropriate arrangements are made for restoration of the site, once exploration and/or production activity has concluded.
- ▶ Relevant consultations have been completed.

In absence of a current definition of what to include within an environmental permit for hydraulic fracturing within Brazil, the current UK hydraulic fracturing consent information provides a useful starting point and it is recommended that the PROMINP project considers the application of these requirements (or similar) in more detail.

The PROMINP project also provides a basis to address a number of additional issues, to facilitate the safe and effective regulation of unconventional gas. As part of this project, and aligned with developments in Europe we would encourage the consideration of the following issues to address the key risks identified through the completion of this study as part of the PROMINP work.



### 6.1.1 Capacity Building

The need to improve data and information collation, research and knowledge base to establish a central database and information hub for information on unconventional gas operations available from site licences and research.

The need to develop guidance covering unconventional gas that defines required practice (from a regulators perspective).

The need for industry to develop good practice/codes of practice to be applied as part of site licence requirements and facility design (e.g. well casing, chemical storage, operational practices).

The need for capability to be developed and enhanced within the federal and state environmental agencies to ensure that there could be effective implementation of any new regulatory requirements introduced (either under ANP resolution 21/2014 or under Complementary Law 140).

The need for wider sustained engagement with the public, institutions, academia and industry to build a common understanding of the benefits, the risks, their management and mitigation involved in the exploration of unconventional oil and gas resources.

### 6.1.2 Zoning and Minimum Distances

Buffer zones may be required from certain activities (e.g. water abstraction points, residential areas) to minimise / prevent pollution risk and nuisance (e.g. air quality impact, water pollution, noise nuisance) and potentially, it could be beneficial to establish minimum thresholds at the national level to ensure consistency in their application across the country. It is recognised that this is a precautionary position; however, at present there are concerns regarding the potential effects of an industry new to Brazil, on sensitive receptors, and such a stance would help ensure such concerns are addressed directly.

Require buffer zone from abstraction points and aquifers (e.g. in the US range from 150m to 1,200m for drinking water related abstraction).

Require buffer zone from residential areas, schools hospitals and other sensitive areas (e.g. industry good practice requires 1,600m distance where possible)

Require buffer zone within which detailed noise assessment is required (e.g. 305m proposed in New York State)

Require buffer zone from abandoned wells and other potential pathways for fluid migration (e.g. abandoned mines)

Require additional containment for sites near surface water supply locations (e.g. 800m in Colorado). NB HVHF requires monitoring for surface water bodies (natural or artificial reservoirs, lakes and ponds) and existing water wells within 1,000 meters of the head of the horizontal well in resolution 21/2014.

Require multiple geological barriers including minimum vertical distance (e.g. 600m) between the target formation and aquifers.

Require minimum distance between hydraulic fracture pipes and geological strata containing aquifers (e.g. ~600m) and the surface (e.g. <600m depth requires special permit).

Require optimisation of the number of wells pad density and pad spacing (e.g. one pad per 2.6 km<sup>2</sup> proposed by New York State).

### 6.1.3 Baseline conditions

Establishment of environmental baseline conditions to facilitate credible impact assessment (to be undertaken as part of the completion of the SEA and then individual EIAs) which enjoy widespread support. As part of the completion of the EIA for individual projects, this could require baseline conditions are established for:

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<b>Air quality</b>
<b>Surface water quality</b>
<b>Groundwater quality (and any groundwater source protection zones)</b>
<b>Drinking water abstraction points</b>
<b>Land condition (soil)</b>
<b>Water resources availability (current and forecast)</b>
<b>Traffic (particularly HGVs on local network)</b>
<b>Noise (ambient levels for day time and night time and key receptors)</b>
<b>Biodiversity and any protected species or habitats</b>
<b>Microseismicity including conceptual model of geological conditions</b>
<b>Presence of methane seepages</b>
<b>Existing landuse, infrastructure, buildings</b>
<b>Existing underground wells, structures</b>

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#### 6.1.4 **Monitoring**

Require continued monitoring of environmental conditions throughout lifecycle (exploration, production and abandonment stages) to facilitate ongoing management and performance assessment (to be undertaken as part of the fulfilment of permit conditions). This could include:

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<b>Air quality</b>
<b>Surface water quality</b>
<b>Groundwater quality</b>
<b>Drinking water abstraction points</b>
<b>Land condition (soil)</b>
<b>Water resources availability</b>
<b>Traffic</b>
<b>Noise</b>
<b>Water volumes and origin</b>
<b>Chemicals and proppant nature and volumes</b>
<b>Energy source and use</b>
<b>Greenhouse gas emissions</b>
<b>Drilling mud volumes and treatment</b>
<b>Flowback water surface return rate</b>
<b>Produced water volume and treatment solution</b>
<b>Biodiversity</b>
<b>Induced seismicity from fracturing</b>
<b>Presence of methane seepages</b>

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## Spills volume, nature, location and clean-up

As part of the monitoring for key topics, information should be used to update models (for groundwater flows, pathways, microseismicity) to ensure fracturing programme is based on most recent information. The microseismic and borehole monitoring and controls during operations should be used to ensure hydraulic fractures / pollutants do not extend beyond the gas-producing formations and do not result in seismic events/pollution incidents.

### 6.1.5 Disclosure of Information

Without public disclosure of information, environmental performance cannot be openly assessed, monitoring requirements cannot be defined, stakeholder confidence will be low and independent scrutiny not possible. In consequence, open and consistent transparency will be necessary to build public confidence in the new industry. The following could be required consistently as part of any permitting conditions.

**Disclosure of information (e.g. composition, product name, purpose and volume to be used) to the public of chemicals used for fracturing, quantities and composition of waste and wastewater, results of monitoring of key pollutants pathways (so monitoring borehole data) and seismicity data.**

### 6.1.6 Hydraulic Fracturing

Fluid contaminants transferred to groundwater and then to surface water via induced fractures extending beyond target formation, through bio-geological reactions with chemical additives, via pre-existing fractures / faults, via pre-existing man-made structures, well casing failures. This can impact on aquifers and surface waters and is the cause of considerable stakeholder concerns. The following could be required as part of any permitting conditions to address the risks associated with hydraulic fracturing.

**Maintain multiple geological barriers including minimum vertical distance (e.g. ~literature review has identified range from between 600m -1,000m depending on source and country) between the target formation and aquifers.**

**Undertake desk study and document potential leakage pathways (e.g. other wells, faults, mines) in sphere of influence of drilling and HF to inform development of conceptual hydrogeological model.**

**Require minimum distance between hydraulic fracture pipes and geological strata containing aquifers (e.g. ~600m – 1,000m) and the surface (e.g. less than specified depth requires special permit).**

**Measures should be adopted to ensure well integrity including consultation on well design with appropriate regulators, bore testing, cement testing, the installation of a cement bond and continual pressure and formation pressure testing. The results of well integrity testing should be independently verified.**

**Permits should require information relating to (inter-alia), the relationship between the zone of interest and any overlapping or adjacent aquifers, methods of well construction, well integrity testing, where the well stimulation fluid is expected to travel, details of the liquids to be injected, water use and disposal of effluents.**

**A Hydraulic Fracturing Programme similar to that in operation in the UK should be prepared by the operator and agreed with the relevant regulator.**

**Where possible, non-hazardous chemicals should be used in fracturing fluids.**

**Consideration should be given to the development of a list of approved chemicals for use in fracturing fluids or, as in the UK, a methodology to enable regulators to assess the hazard potential of any chemicals used.**

**Require development of a geo-referenced database of the zone before work commences covering geology, groundwater flows, pathways, microseismicity and subsequent updating of the model as information becomes available.**

**Require modelling of fracturing programme to predict extent of fracture growth based on best information.**

**Require monitoring and control during operations to ensure hydraulic fractures / pollutants do not extend beyond the gas-producing formations and does not result in seismic events.**

**Implement remedial measures if well failure occurs and/or abandon well safely.**

**Maintain multiple geological barriers including minimum vertical distance (e.g. 600m) between the target formation and aquifers.**

### 6.1.7 Induced Seismicity

There is the potential for minor earth tremors (e.g. the largest of the earth tremors at the Preese Hall well in the UK during April and May 2011 had a magnitude of 2.3 following hydraulic fracturing) arising from HVHF. Multiple developments could increase the risk of events affecting other operations, e.g. affecting well integrity. It has been the cause of considerable stakeholder concerns, although within the UK, the effects as described in the media have been overstated. The following could be required as part of any permitting conditions to address the risks associated with induced seismicity.

**Operator to review available information on geology, structure (including faults) and in situ stresses in the vicinity of the proposed site to avoid hydraulically fracturing into, or close to, existing critically stressed faults.**

**Operator to conduct 2D seismic survey to identify faults and fractures and to develop 3D model of target formation, including identification of faults.**

**Operator to engage with third parties (e.g. regulators, other operators, researchers) to ensure fully aware of any issues / proximity (e.g. to other underground activities). Sharing of information to ensure that all operators in a gas play are aware of risks and can therefore plan.**

**Require development of geo-referenced database of the zone before work commences covering geology, groundwater flows, pathways, natural microseismicity. Require ongoing development as data is collected through exploration.**

**Carry out modelling and risk based geomechanical assessments of proposed hydraulic fracturing with regard to faults (including maximum magnitude estimates).**

**Apply ground motion prediction models to assess the potential impact of induced earthquakes.**

**Identify potential seismic receptors within a defined radius of the well site (5km) including: wells, infrastructure, special buildings, residential buildings and industrial/commercial buildings. Avoid high seismicity risk areas.**

**Require minimum distance between hydraulic fracture pipes and geological strata containing aquifers (e.g. ~600m – 1,000m) and the surface (e.g. less than specified depth requires special permit).**

**Require appropriate well design, construction, testing and monitoring.**

**Require smaller preinjection prior to main operations to enable induced seismicity response to be assessed, followed by succession of injections over short duration of casing length.**

**Monitor the fracture growth and direction during hydraulic fracturing using buried microseismic arrays to ensure hydraulic fractures / pollutants do not extend beyond the gas-producing formations and do not result in seismic events or damage to buildings/installations that could be the result of fracturing.**

**Monitoring background induced and natural seismicity before, during and after hydraulic fracturing.**

**Implementation of the Traffic Light System (via the surface seismic monitoring array) and cessation of operation if induced seismic event exceeds 0.5M<sub>L</sub>.**

**Determine the presence and levels of methane in groundwater, including drinking water through sampling of shallow groundwater during wet and dry periods and/or borehole to sample deep groundwater and characterise the hydrological series.**

### 6.1.8 Carbon Emissions

Gases released from flowback and produced water have the potential for cumulative effects over the lifetime of the well. The following could be required consistently as part of any permitting conditions.

**Require preparation and implementation of an Emissions Reduction Plan based on the principle of as low a level as reasonably practicable (ALARP).**

**Require reduced emission completions or green completions to eliminate gas venting and for capturing and cleaning for use of gas released from fracture fluid and produced water.**

**Require enclosed completion systems be adopted to avoid venting from lagoons or tanks.**

**Require flares or incinerators to reduce emissions from fracturing fluid at exploration stage (where not connected to gas network).**

### 6.1.9 Well Closure

Wells may be temporarily suspended between exploration, completion and production stages presenting pollution risks if not plugged and managed correctly. The following could be required consistently as part of any permitting conditions.

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**Requirements for risk assessment, well plugging, inspection and monitoring (e.g. for releases to air, well integrity, periodicity of inspections, wellhead monitoring every 90 days)**

**Require post closure well inspection and monitoring/reporting programme**

**Require ownership and liability of wells to be transferred to a competent authority on surrender of the site licence**

**Require abandonment survey for**

- **Air**
- **Surface water**
- **Groundwater**
- **Drinking water abstraction points**
- **Land condition (soil)**
- **Biodiversity/ecology/invasive species**
- **Presence of methane seepages**
- **Landuse, infrastructure, buildings**
- **Underground wells, structures**

We recommend that a risk assessment is undertaken of these proposed measures (and those identified elsewhere in the report, (see **Section 3**) for their refinement and applicability to Brazil. We encourage consideration be given to this work being undertaken by members of the PROMINP project team.





## 7. Glossary and Abbreviations

Term	Definition
<b>ALARP</b>	As Low As Reasonably Possible. This involves weighing a risk against the trouble, time and money needed to control it. Thus, ALARP describes the level to which see workplace risks should be controlled.
<b>BAT</b>	Best Available Technique. BATs are required to be considered (under EC Directive 96/61) in order to avoid or reduce emissions resulting from certain installations and to reduce the impact on the environment as a whole
<b>CEMP</b>	Construction Environment Management Plan. A Plan which details management measures to adopt and implement during construction activities to avoid and manage construction effects on the environment and surrounding communities.
<b>CO</b>	Carbon monoxide (a colourless, odourless and toxic gas)
<b>CO2</b>	Carbon dioxide. A naturally occurring gas, also a by-product of burning fossil fuels and other industrial processes. It is the principal anthropogenic greenhouse gas that affects the Earth's radiative balance.
<b>Conventional Oil and Gas</b>	Refers to hydrocarbons which have been previously sought in sandstone or limestone.
<b>Cumulative effects</b>	Effects that occur where several individual activities which each may have an insignificant effect, combine to have a significant effect.
<b>DCLG</b>	Department for Communities and Local Government.
<b>DECC</b>	Department of Energy and Climate Change.
<b>Drilling fluids / drilling mud</b>	Fluid or lubricant added to the wellbore to facilitate the drilling process by suspending cuttings or controlling pressure for example.
<b>EA</b>	Environment Agency. The non-departmental public body of the Department for Environment, Food and Rural Affairs within England.
<b>Flowback water</b>	Water and excess proppant that flow back up to the surface after the hydraulic fracturing procedure is complete.
<b>GHG</b>	Greenhouse gases. These gases absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect.
<b>Green Completions</b>	Green Completions are techniques used to complete wells to reduce the emissions of gases to air (also known as Reduced Emissions Completions; REC).
<b>H2S</b>	Hydrogen sulphide (a colourless, toxic, highly flammable gas).
<b>Ha</b>	Hectare; a metric unit of area defined as 10,000m <sup>2</sup>
<b>HGV</b>	Heavy Goods Vehicle. Typically these vehicles are designed or adapted to have a maximum weight of 3,500 kg when in normal use.
<b>HVHF</b>	High Volume Hydraulic Fracturing or "fracking" is a technique that uses fluid, usually water, pumped at high pressure into the rock to create narrow fractures to create paths for the gas to flow into the well bore and to surface. The water normally contains small quantities of other substances to improve the efficiency of the process, e.g. to reduce friction. Once the fractures have been created, small particles, usually of sand, are pumped into them to keep the fractures open. ANP Resolution 21/2014 defines HVHF as in volumes above 3,000 m <sup>3</sup> whereas the Community Recommendation 2014/70/EU defines it as a process requiring the injection of 1,000 m <sup>3</sup> or more of water per fracturing stage or 10, 000 m <sup>3</sup> or more of water during the entire frac-turing process into a well.
<b>Induced seismicity</b>	Earthquake and tremor activity caused by human activity.

<b>Term</b>	<b>Definition</b>
<b>ML</b>	Megalitre; a unit of volume defined as a million litres.
<b>ML</b>	ML (local magnitude) from the Richter magnitude scale (often shortened to Richter scale) developed to quantify the energy released during an earthquake. The scale is a base-10 logarithmic scale. An earthquake that measures 5.0 on the Richter scale has a shaking amplitude 10 times larger than one that measures 4.0, and corresponds to a 31.6 times larger release of energy.
<b>MWD</b>	Mining Waste Directive. Directive 2006/21/EC on the management of waste from extractive industries and amending Directive 2004/35/EC
<b>NORM</b>	Natural Occurring Radioactive Material. Material that contains radioactive elements of natural origin. NORM primarily contains uranium and thorium (elements that also release radium and radon gas once they begin to decay) and potassium.
<b>NOx</b>	NOx is the generic term for a group of highly reactive gases, all of which contain nitrogen and oxygen in varying amounts
<b>Produced water</b>	Water that returns from the well along with the natural gas after fracturing has taken place. The water may be naturally occurring and may contain residual fracturing fluid.
<b>Proppant</b>	Solid material, typically treated sand or man-made ceramic materials, designed to keep an induced hydraulic fracture open.
<b>REC</b>	Reduced Emissions Completions are techniques used to complete wells to reduce the emissions of gases to air (also known as green completions).
<b>SEA</b>	Strategic Environmental Assessment
<b>SEAD</b>	Strategic Environmental Impact Assessment Directive. Directive 2001/42/EC on the assessment of the effects of certain plans and programmes on the environment
<b>SO2</b>	Sulphur Dioxide (a toxic and odorous gas).
<b>SAC</b>	Special Areas of Conservation are strictly protected sites designated under the EC Habitats Directive
<b>SPZ1</b>	Groundwater Source Protection Zone 1. SPZs are areas defined by the Environment Agency as areas that highlight the risk of groundwater contamination from any activities that might cause pollution in the area. SPZ1 is the inner protection zone; it is defined as the 50 day travel time from any point below the water table to the source. This zone has a minimum radius of 50 metres.
<b>TDS</b>	Total dissolved solids.
<b>UKOOG</b>	United Kingdom Onshore Operators' Group, the representative body for the UK onshore oil and gas industry.
<b>Unconventional oil and gas</b>	Refers to hydrocarbons which are located in tight sands, shale or coal which are now the focus of unconventional exploration. However, the techniques used to extract hydrocarbons are essentially the same. What has changed are advancements in technology over the last decade (e.g. – hydraulic fracturing) which have made shale gas development economically viable.
<b>WFD</b>	Water Framework Directive. Directive 2000/60/EC establishing a framework for Community action in the field of water policy

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# Appendix A

## Terms of Reference



## Terms of Reference

AMEC E&I UK Ltd has been appointed by the FCO to lead a study to provide an independent review of the risks to the environment and human health of shale gas exploration and production and the approaches to managing these risks through regulatory frameworks in the UK and Europe in order to provide the Brazilian Government (ANP officials) with information and best practices to develop strong regulation for the safe exploration of shale gas.

The terms of reference of this review are:

- ▶ What are the likely significant effects and principal risks associated with hydraulic fracturing as a means to extract shale gas, including geological risks, such as induced seismicity, environmental risks, such as groundwater contamination, and climate change risks, such as from fugitive methane emissions?
- ▶ Can these effects be effectively avoided, minimised or mitigated to ensure that the risks to the environment and human health can be effectively managed? If so, how?
- ▶ What regulations are used in the UK and Europe to address the specific risks to the environment and human health from hydraulic fracturing? To what extent (if at all) are voluntary and best practice measures effective in managing these risks?
- ▶ What lessons can be learned from the regulatory frameworks employed in UK and Europe to the management of risks associated with hydraulic fracturing that could be relevant to the Brazilian context? What specific recommendations could be made?

The study will focus on the likely significant effects and associated risks to the environment and human health restricted to those associated with the onshore extraction of shale gas from hydraulic fracturing. Offshore shale gas extraction and the subsequent use of shale gas will not be addressed. The effects and risks of other types of unconventional oil and gas, such as virgin coalbed methane will not be considered in the study.

The study will concentrate on the risks to the environment and human health of hydraulic fracturing. It is assumed that the existing oil and gas regulatory framework in Brazil is sufficiently robust to manage those aspects that will be common to shale gas exploration and development as well as conventional oil and gas extraction. This is consistent with the focus of the Royal Society and Royal Academy of Engineering report .

The study will focus on the regulatory framework itself rather than provide any commentary on responsibilities and effectiveness of regulatory bodies in Brazil. A current area of comment in the UK is on the potential to reduce the complexity and increase the transparency of the regulatory regime ; although no UK Government response has yet been made.



# Appendix B

## Environmental Topic Chapters

**Appendix B** contains a detailed review of the potential effects of unconventional oil and gas exploration and production activities on the environment and human health. The review is presented by topic, as follows:

- ▶ B1: Biodiversity
- ▶ B2: Land Use, Geology and Soils
- ▶ B3: Water and Flood Risk
- ▶ B4: Air
- ▶ B5: Climate Change
- ▶ B6: Waste and Resource Use
- ▶ B7: Cultural Heritage
- ▶ B8: Landscape
- ▶ B9: Health

Each topic chapter contains:

- ▶ Introduction – providing an overview and definition of the topic.
- ▶ Assessment of effects – detailing the likely effects on each topic arising from the potential activities that could take place during the following six stages of unconventional oil and gas exploration and production:
  - ▶ **Stage 1:** Non-intrusive exploration;
  - ▶ **Stage 2:** Exploration drilling and hydraulic fracturing;
  - ▶ **Stage 3:** Production development;
  - ▶ **Stage 4:** Production/operation/maintenance;
  - ▶ **Stage 5:** Decommissioning of wells;
  - ▶ **Stage 6:** Restoration and relinquishment.
- ▶ Mitigation measures – identifying potential measures to manage risks associated with unconventional oil and gas exploration and production activities at each stage of the project life cycle.
- ▶ Regulatory framework – providing a summary of the regulatory frameworks that are in place in the UK and Europe to manage the potential effects of unconventional oil and gas exploration and production activities.





# 1 Biodiversity

## 1.1 Introduction

Biodiversity in this context is defined by the **Convention on Biological Diversity**<sup>1,2</sup> as “*the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.*” Biodiversity is integral to the functioning of ecosystems and these, in turn, provide ‘ecosystem services’ which include food, flood management, pollination and the provision of clean air and water.

There are links between the effects on biodiversity and nature conservation topic and other topics in the assessment, including water, soil and geology, land use, and climate change.

## 1.2 Assessment of Effects

This section comprises of the review of the likely effects on biodiversity arising from unconventional oil and gas exploration and production activities. There are a total of six main stages of oil and gas exploration and production. **Table B1.1** presents a summary of the key stages of exploration, production and decommissioning.

Table B1.1 Unconventional Oil and Gas Exploration and Production Lifecycle and Key Activities

Stage	Activities
1	<p><b>Non-intrusive exploration</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Site identification, selection, characterisation;</li> <li>▶ Seismic surveys;</li> <li>▶ Securing of necessary development and operation permits</li> </ul>
2	<p><b>Exploration drilling and hydraulic fracturing</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Pad preparation road connections and baseline monitoring;</li> <li>▶ Well design and construction and completion;</li> <li>▶ Hydraulic fracturing;</li> <li>▶ Well testing including flaring.</li> </ul>

<sup>1</sup> United Nations (1992) *Convention on Biological Diversity*. Available from <http://www.cbd.int/doc/legal/cbd-en.pdf> [Accessed April 2015].

<sup>2</sup> The convention uses this definition to describe ‘biological diversity’ commonly taken to mean the same as biodiversity.

Table B1.1 (continued) Unconventional Oil and Gas Exploration and Production Lifecycle and Key Activities

Stage	Activities
3	<p><b>Production development</b>, including :</p> <ul style="list-style-type: none"> <li>▶ Pad preparation and baseline monitoring;</li> <li>▶ Facility construction and installation;</li> <li>▶ Well design construction and completion;</li> <li>▶ Hydraulic fracturing;</li> <li>▶ Well testing, possibly including flaring</li> <li>▶ Provision of pipeline connections</li> <li>▶ (Possibly) re-fracturing.</li> </ul>
4	<p><b>Production/operation/maintenance</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Gas/oil production;</li> <li>▶ Production and disposal of wastes/emissions;</li> <li>▶ Power generation, chemical use and reservoir monitoring;</li> <li>▶ Environmental monitoring and well integrity monitoring</li> </ul>
5	<p><b>Decommissioning of wells</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Well plugging and testing;</li> <li>▶ Site equipment removal;</li> <li>▶ Environmental monitoring and well integrity monitoring.</li> </ul>
6	<p><b>Site restoration and relinquishment</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Pre-relinquishment survey and inspection;</li> <li>▶ Site restoration and reclamation.</li> </ul>

Note: Exploration wells most usually move from Stage 2 to Stage 4, though some may be used for long-term production testing and some may be retained and their sites redeveloped as a production project. For the purposes of this review, the appraisal stage (a term commonly used in industry) spans Stages 2 and 3.

The following pressures and risks in respect of biodiversity and nature conservation that are particularly relevant to unconventional onshore oil and gas exploration and production include<sup>3,4</sup>:

- ▶ Direct impacts on habitats and species including:
  - ▶ Habitat destruction and fragmentation; and
  - ▶ Disruption of animal behaviour e.g. feeding patterns and breeding.
- ▶ Water abstraction on or off-site;

<sup>3</sup> DECC (2013) *Strategic Environmental Assessment for Further Onshore Oil and Gas Licensing: Environmental Report*. Available from [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/273997/DECC\\_SEA\\_Environmental\\_Report.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/273997/DECC_SEA_Environmental_Report.pdf) [Accessed April 2015].

<sup>4</sup> Tyndall Centre for Climate Change Research (2011) *Shale gas: a provisional assessment of climate change and environmental impacts*. Available from [http://www.tyndall.ac.uk/sites/default/files/tyndall-coop\\_shale\\_gas\\_report\\_final.pdf](http://www.tyndall.ac.uk/sites/default/files/tyndall-coop_shale_gas_report_final.pdf) [Accessed April 2015].

- ▶ Wastewater storage, treatment and discharge;
- ▶ Impacts arising during construction:
  - ▶ noise/light pollution during well drilling/completion;
  - ▶ flaring/venting; and
  - ▶ local traffic impacts.
- ▶ Atmospheric pollution (acid precipitation, nitrogen deposition);
- ▶ Contamination of groundwater by fracturing fluids/mobilised contaminants arising from:
  - ▶ wellbore/casing failure; and
  - ▶ subsurface migration.
- ▶ Pollution of land and surface water (and potentially groundwater via surface route) arising from:
  - ▶ spillage of fracturing additives; and
  - ▶ spillage/tank rupture/storm water overflow from liquid waste storage.
- ▶ Indirect and cumulative effects associated with the above, including climate change and the ability of habitats and species to respond to changes.

### Non-intrusive Exploration

The activities associated with this stage of the unconventional oil and gas exploration and production lifecycle would comprise: site identification, selection and characterisation and the securing of regulator approval would be expected to be largely desk-based and in consequence, no significant effects on biodiversity would be anticipated from these activities.

There is potential for disturbance effects associated with seismic testing, particularly in the breeding season or for vulnerable species. Vibroseis is a common method of seismic survey and typically involves 3-5 large truck mounted vibrator units which sub-sonically vibrate the ground while a number of support vehicles record the returning shock waves for analysis. An alternative to the use of vehicles are surface and buried seismic arrays which can be extended if exploration activities deem it justified on the basis of prospectivity. Whilst there is a considerable body of research in respect of potential effects arising from seismic surveys in the marine environment, there is no known evidence of onshore surveys resulting in adverse impacts on biodiversity. The literature reviewed as part of this study does not identify seismic surveys themselves as representing a significant risk to ecology, although associated vehicle movements and/or the installation of the arrays may result in short term disturbance/habitat loss.

As highlighted in the initial 2010 Environmental Report<sup>5</sup> on the 14<sup>th</sup> UK onshore oil and gas round, surveys tend to be spatially restricted due to the requirement for roads or other hard surfaces accessible by vehicle. Where roads have to be constructed to facilitate access to sites, adverse effects could include habitat loss, disturbance and the pollution and siltation of water bodies, particularly where new roads are of a significant length. However, any new access road would be temporary with land restored following completion of the surveys. Where shot-hole techniques are utilised (which involve the use of explosions as a source of seismic energy), the requirement for large vehicular access would be likely to be reduced (although the potential for disturbance to ecology arising from the survey itself may be increased) whilst it would be expected that shot holes would be infilled after use.

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<sup>5</sup> DECC (2010) Strategic Environmental Assessment for a 14th and Subsequent Onshore Oil & Gas Licensing Rounds: Environmental Report. Available from [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/66721/onshore-er.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/66721/onshore-er.pdf) [Accessed April 2015].

## Exploration drilling and hydraulic fracturing

Impacts on biodiversity from this phase can arise from two separate operations: preparation for, and construction of, the well pad(s); and subsequently exploratory activities involving drilling, hydraulic fracturing, testing and flaring.

The infrastructure required for the drilling and subsequent hydraulic fracturing of a typical 1.5-km-deep shale gas well consists of: a raised gravel pad occupying 1-2ha laid over an impermeable geotextile membrane; a stormwater system for capturing flowback water; new roads; compressor stations for pumping natural gas; and pipelines. Well pad construction could result in the loss and/or fragmentation of habitat, the effects being direct (such as loss to the construction of drilling pads and access roads, fencing of compounds and degradation of habitats due to water abstraction) or indirect (such as disturbance from noise, human presence and light pollution and the introduction of invasive species)<sup>6</sup>. The nature of potential direct and indirect effects on biodiversity associated with well pad construction would be similar to conventional oil and gas construction activity as well as other types of development (particularly where this involves the development of greenfield land) although the magnitude of effect may be greater owing to the differences in the scale of land take and intensity of activity.

The effects of habitat loss and fragmentation are in the relatively early stages of research, but a review of studies conducted in Pennsylvania<sup>7</sup> identified forest patch reduction of around 10%, and a consequent increase in edge (as opposed to core) habitats associated with road construction, in turn potentially influencing community structure (i.e. the composition and abundance of species occupying the same geographical area and in a particular time). Habitat loss and fragmentation has particular consequences for fauna and flora which occupy specific niches and/or have limited geographic ranges, and it has been observed that industrial habitats generated by shale gas development were more likely to support common species that are ecological generalists rather than species of conservation concern<sup>8</sup>. It has also been noted<sup>9</sup> that degradation of habitat quality through disturbance can also influence the distribution of species and result in effective habitat loss, even in the absence of complete destruction. Light pollution for example can create fragmentation by preventing animals from accessing suitable habitat thereby increasing the risk of local extinctions and reduced genetic diversity, as well as influencing the feeding behaviour of light-sensitive species such as bats<sup>10</sup>.

A key issue associated with well-pad construction which could affect habitat integrity is cumulative land take<sup>11</sup>. This reflects the need for a compound to accommodate the well pad and associated equipment which includes pits, impoundments, tanks, hydraulic fracturing equipment, reduced emission completion equipment, dehydrators and production equipment such as separators, brine tanks. The effects of shale gas production on habitat fragmentation and degradation is the subject of ongoing research in the United States of America where, for example, there is evidence that generalist species are replacing specialist ones following habitat change<sup>12</sup>. There would also be construction of pipelines although these could be buried to allow land to return to beneficial uses<sup>13</sup>.

Typical land-take for a drilling pad and associated compound is approximately 1-2 hectares (ha) during the exploratory drilling and hydraulic fracturing stage (compared to 1ha for conventional drilling), reflecting the need to accommodate the equipment and storage tanks/pits, together with chemical additives and waste water. The effects of habitat loss, individually and cumulatively, are issues of concern, but a lack of clear evidence to date means that their overall significance cannot be fully assessed<sup>14</sup>. Disturbance effects could be significant for sensitive habitats and species or during the breeding season particularly where they are

<sup>6</sup> AEA (2012) *Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe* p.250, Table A6.2 and section 2.4.4. Available from <http://ec.europa.eu/environment/integration/energy/pdf/fracking%20study.pdf> [Accessed April 2015].

<sup>7</sup> Moore, V., Beresford, A., & Gove, B. (2014) *Hydraulic fracturing for shale gas in the UK: Examining the evidence for potential environmental impacts*. UK: RSPB p.26. Available from <http://www.rspb.org.uk/forprofessionals/policy/climatechange/action/ukenergy/fit-to-frack.aspx> [Accessed April 2015].

<sup>8</sup> Gillen, J.L. and Kiviat, E. (2012) *Hydraulic Fracturing Threats to Species with Restricted Geographic Ranges in the Eastern United States*. *Environmental Practice*, 14: 320–331. doi: 10.1017/S1466046612000361. Available from <http://hudsonia.org/wp-content/uploads/2013/03/GillenKiviatFracking.pdf> [Accessed April 2015].

<sup>9</sup> See Moore, V., Beresford, A., & Gove, B. (2014) p.27.

<sup>10</sup> See Moore, V., Beresford, A., & Gove, B. (2014) p.27 and p.36 case study on bat behaviour.

<sup>11</sup> See Moore, V., Beresford, A., & Gove, B. (2014).

<sup>12</sup> See Moore, V., Beresford, A., & Gove, B. (2014) p.26-27.

<sup>13</sup> See AEA (2012) Section 2.4.3.

<sup>14</sup> See AEA (2012) p.x.

associated with the intensity of surface activity, such as during the well drilling and fracturing phase, involving considerable heavy truck traffic with associated noise and air pollution<sup>15</sup>. It has been estimated<sup>16</sup> that the construction of a single well pad will require between 4,300 and 6,600 truck trips for the transportation of equipment, fluid, sand and other materials during the drilling, completion and hydraulic fracturing stages.

In order to monitor the effects of exploratory drilling, a network of surface and buried seismic arrays is typically used, providing data on the location, extent and direction of the fractures that occur within the rock arising from hydraulic fracturing<sup>17</sup>. Surface arrays require shallow pits some 0.8m deep covered by a manhole cover, each with a small junction box (1m square, 50cm deep) with an estimated time of construction 1-2 days. Each manhole cover is surrounded by a post and rail fence. Buried arrays will be drilled boreholes, say up to 100m deep drilled by a truck mounted rig, capped with concrete pad and an inspection collar, requiring around 4 days to install. The Cuadrilla site in Lancashire, UK proposes a network of 80 buried seismic arrays and 10 surface arrays arranged over 25km<sup>2</sup> area<sup>18</sup>. As a consequence, localised and short term disturbance will extend beyond the notional 3 ha of the pad and is could require a walkover ecology survey<sup>19</sup> of each location to identify potential significant effects on particular habitats or species. Whilst these are unlikely because of the small range of the individual operations, a precautionary approach to potential indirect effects on sensitive species (such as through traffic movements or human activity generally) has been deemed necessary in some exploratory work<sup>20</sup>. Pairs of groundwater monitoring boreholes are also drilled in the immediate vicinity of the well pad<sup>21</sup>, and as such any effects will be part of well pad construction.

Drilling associated with both conventional and unconventional oil and gas exploration and production may cause disturbance to ecological receptors. The impact of noise disturbance on biodiversity associated with unconventional oil and gas drilling activity has recently been identified<sup>22</sup> as an issue of particular significance, reflecting the fact that the drilling of wells from a well pad may take a number of years with each well typically taking 3-4 months of 24 hours/day drilling (the duration will depend on the underlying geology, well depth, the length and angle of the well, and any problems encountered). Diesel compressors, for example, generate low frequency noise which can affect animal physiology and behaviour, the effects of which can be inferred from studies relating to road traffic and military operations<sup>23</sup>. Studies in Colorado<sup>24</sup>, have found that the sound of 64 compressors outside a protected area resulted in an average 34.8-decibel (dBA) elevation above typical ambient sound within the protected areas, whilst nearest to the highest density of compressors, sound levels increased by a mean of 56.8 dBA above ambient conditions. Particular impacts are to be expected on species which are sensitive to disturbance, such as breeding birds, where studies of the impacts of traffic noise<sup>25</sup> found that along a gradient of disturbance, species richness consistently decreased as ambient noise increased. Increased ambient noise can be associated with reductions in the detectability of territorial calls and consequent have implications for the establishment or holding of territories, the ability to attract mates and maintain pair bonds, and ultimately on breeding success<sup>26</sup>.

Additional identified impacts include the potential introduction of invasive species (plants, animals and micro-organisms) associated with the importation of water and construction materials on to the site. The specific sensitivity of the receiving habitats and associated species will determine these effects, although there appears to be an absence of research on this issue. Notwithstanding, the risk of invasive species transfer

<sup>15</sup> EC JRC (2012) *Shale Gas for Europe – Main Environmental and Social Considerations: A Literature Review* p.25. Available from <https://ec.europa.eu/jrc/sites/default/files/lbna25498enn.pdf> [Accessed April 2015].

<sup>16</sup> Broderick J. *et al* (2011) *Shale gas: an updated assessment of environmental and climate change impacts*. Tyndall Centre for Climate Change Research, University of Manchester (Table 11). Available from [http://www.tyndall.ac.uk/sites/default/files/coop\\_shale\\_gas\\_report\\_update\\_v3.10.pdf](http://www.tyndall.ac.uk/sites/default/files/coop_shale_gas_report_update_v3.10.pdf) [Accessed April 2015].

<sup>17</sup> Cuadrilla Bowland Ltd (2014) *Temporary Shale Gas Exploration, Preston New Road, Lancashire: Environmental Statement* pp.32-35. Available from [http://www.cuadrillaresources.com/wp-content/uploads/2014/07/PNR\\_ES\\_Vol1\\_Environmental\\_Statement.pdf](http://www.cuadrillaresources.com/wp-content/uploads/2014/07/PNR_ES_Vol1_Environmental_Statement.pdf) [Accessed April 2015].

<sup>18</sup> See: Cuadrilla Bowland Ltd (2014) pp.32-35.

<sup>19</sup> See: Cuadrilla Bowland Ltd (2014) pp.189.

<sup>20</sup> See: Cuadrilla Bowland Ltd (2014) Section 7 p.228 et seq.

<sup>21</sup> See: Cuadrilla Bowland Ltd (2014) p. 35.

<sup>22</sup> See Citation: Moore, V., Beresford, A., & Gove, B. (2014) p.32.

<sup>23</sup> See Citation: Moore, V., Beresford, A., & Gove, B. (2014) p.32/33.

<sup>24</sup> Cited in Moore, V., Beresford, A., & Gove, B. (2014) p.32.

<sup>25</sup> Cited in Moore, V., Beresford, A., & Gove, B. (2014) p.32.

<sup>26</sup> Moore, V., Beresford, A., & Gove, B. (2014) p.32.

would be similar to other forms of development and particularly those involving the importation of water (for example, activity involving the transfer of untreated water).

According to the sensitivity of a site, restoration to its original state may not be possible following cessation of drilling activity.

During both conventional and unconventional onshore oil and gas exploration operations, the accidental release of substances such as diesel and drilling fluids, silt-laden run-off and the deposition of pollutants associated with transport movements could also negatively affect biodiversity<sup>27</sup>. With specific regard to unconventional oil and gas exploration, potentially polluting substances will also include hydraulic fracturing fluids. At this stage, the risks posed by sediment runoff into streams and potential contamination of streams from accidental spills should be considered, in order to minimise the risk of impacts at a later stage in the process<sup>28</sup>. Contamination of surface water or shallow groundwater by drilling and fracturing fluids poses risks to animal and human health, associated with elevated concentrations of heavy metals and total dissolved solids, requiring specialised wastewater treatment to remove<sup>29,30,31</sup> (see also section below on the frequency and severity of pollution events during production).

## Production Development

There could be a range of direct effects on biodiversity associated with production development activity, including habitat loss (from the land take for the larger production pad), severance (associated with road and pipeline construction, for example) and species disturbance including noise, human activity and light pollution which could affect sensitive species, particularly during the breeding season. A typical unconventional well pad (containing one well) would be extended to approximately 3ha (compared to 1.9ha per pad for conventional drilling) during production. However, multi-well pads are now widely used, where 6-10 wells are accommodated on a single pad enabling a single multistage horizontal well pad to access approximately 250 hectares of shale gas play, compared to approximately 15 hectares for a vertical well pad. Assuming 3 hectares per multi-well pad, this suggests that approximately 1.2% of the land above a productive shale gas reservoir may need to be used to fully exploit the reservoir, or more if other indirect land-uses (e.g. central storage facilities and pipelines) are taken into account<sup>32</sup>. Research from the United States<sup>33</sup> suggests that the indirect effects of well-pad establishment extend to an additional 2.4ha for every hectare of well pad area, or an additional 9ha per well pad.

There could be localised disturbance effects, resulting from traffic movements<sup>34</sup> and associated pollution<sup>35</sup>, although the precise impacts are uncertain and dependent upon mitigation such as routing of traffic.

The accidental release of pollutants could also affect both habitats and species (see above).

Water used during the fracturing process could potentially affect habitats and species especially during times of water stress, although within the UK, this will be subject to assessment by the water companies and Environment Agency (or Natural Resources Wales or SEPA) controls (depending on the location of the pads). Risks associated with the introduction of invasive species through water carried to the site, for example have been identified<sup>36</sup>.

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<sup>27</sup> See AEA (2012) section 2.4.4.

<sup>28</sup> Entekin S, Evans-White M, Johnson B and Hagenbuch E (2011) *Rapid expansion of natural gas development poses a threat to surface waters*, Front Ecol Environ 2011; 9(9): 503–511 p.8. Available from <http://www.esajournals.org/doi/abs/10.1890/110053> [Accessed April 2015].

<sup>29</sup> See Moore, V., Beresford, A., & Gove, B. (2014) p.39.

<sup>30</sup> See Tyndall Centre for Climate Change Research (2011) para 4.2.2.

<sup>31</sup> See: AEA (2012) Appendix 6.

<sup>32</sup> See AEA (2012) section 2.4.3.

<sup>33</sup> See Nature Conservancy (2011) "*Pennsylvania Energy Impacts Assessment Report 1: Marcellus Shale Natural Gas and Wind*," available via [http://www.nature.org/media/pa/pa\\_energy\\_assessment\\_report.pdf](http://www.nature.org/media/pa/pa_energy_assessment_report.pdf) p.18 reported in AEA (2012) p.32/33

<sup>34</sup> See: IOD (2012) *Getting Shale Gas Working*, Table 34 p.117. Available from <http://www.iod.com/influencing/policy-papers/infrastructure/infrastructure-for-business-getting-shale-gas-working> [Accessed April 2015].

<sup>35</sup> See: AEA (2012) p.viii.

<sup>36</sup> See AEA (2012) Appendix 6.



## Production/operation/maintenance

Assuming that all operational activities would take place within the already identified site area, there would be no additional land take and hence direct effects on biodiversity. However, there would be the potential for continued disturbance and/or displacement as a result of operational activities, including noise, traffic movements<sup>37</sup>, human activity and light pollution which could affect sensitive species (such as bats)<sup>38</sup>, particularly during the breeding season. The accidental release of pollutants, including untreated flowback water from refracturing could also affect both habitats and species<sup>39</sup>. The potential effects are likely to be locationally dependent, with sensitive habitats and species at particular risk. Research on biodiversity impacts associated with operational activities such as noise and light pollution and traffic movements cited above is applicable to this stage of production.

Theoretically, indirect water pollution could occur<sup>40</sup> through the migration of contaminants from the target fracture formation through subsurface pathways including: the outside of the wellbore itself; other wellbores (such as incomplete, poorly constructed, or older/poorly plugged wellbores); fractures created during the hydraulic fracturing process; or natural cracks, fissures and interconnected pore spaces. The likelihood of such effects is highly uncertain given the distances between shale gas formations and groundwater. For example, modelling<sup>41</sup> of fracture pathways within the Marcellus shale formation across Pennsylvania, New York and West Virginia suggests that there is *“substantial geologic evidence that natural vertical flow drives contaminants, mostly brine, to near the surface from deep evaporite sources. Interpretative modelling shows that advective transport could require up to tens of thousands of years to move contaminants to the surface, but also that fracking the shale could reduce that transport time to tens or hundreds of years. Conductive faults or fracture zones, as found throughout the Marcellus shale region, could reduce the travel time further.”* However, within the UK, the migration of fractures such that they would cause contamination of aquifers has been assessed<sup>42</sup> as being of low risk, with fracking typically occurring 2km to 3km below the surface and the average drinking water aquifer being located roughly 300m below the surface. By contrast *“it is more likely that any pollution would come from drilling down through rock containing methane and where the cement or steel well casing failed.”* This is corroborated by evaluation<sup>43</sup> of operational impacts associated with Marcellus Shale drilling where it was concluded that: *“Water-supply contamination from so-called stray gas occurs more often from failures in well design and construction, breaches in spent hydraulic-fracturing water-containment ponds, and spills of leftover natural gas liquids used in drilling. Where groundwater has been impacted ... the issue stems not from hydraulic fracturing per se, but poorly formulated cement and improperly designed wells.”*

Additional abstraction of water to supply wells could affect wetland ecosystems through the lowering of groundwater levels, particularly in times of water stress.<sup>44</sup>

The incidence of environmental pollution associated with drilling and production activity in the United States of America is reported<sup>45</sup> to be declining. A survey of events between 2008 and 2011 in Pennsylvania where some 3,533 wells have been drilled from over 100 drilling rigs, identified that where half of all wells involved some level of environmental pollution, this had declined to one fifth by 2011. Of 845 incidents that caused measurable amounts of pollution, 820 (97%) were classified as non-major and 25 (0.3%) involved major impacts to air, water and land resources. Of all the pollution events, 38.8% involved site restoration, 30.5% spills contaminating water, 17.6% non-major land spills and 10.1% involved cement and casing problems. Of these incidents, some 3% created major problems for the environment, 1.1% from major land spills, 0.9%

<sup>37</sup> See: IOD (2012) *Getting Shale Gas Working* Table 34 p.117.

<sup>38</sup> See: Cuadrilla Bowland Ltd (2014) and Moore, V., Beresford, A., & Gove, B. (2014) p.36 case study on bats.

<sup>39</sup> See: AEA (2012) Appendix 6.

<sup>40</sup> Broderick J. *et al* (2011) p.81-86.

<sup>41</sup> Myers T. (2012) *Potential Contaminant Pathways from Hydraulically Fractured Shale to Aquifers*. Available from <http://nofracking.com/static/media/PDF/Fracking-Aquifers.pdf> [Accessed April 2015].

<sup>42</sup> Davies R. *et al* (2014) *Can fracking cause contamination of drinking water?* Available from <https://www.dur.ac.uk/~/HydraulicfracturesResearchBrief.docx> [Accessed April 2015].

<sup>43</sup> Considine T. *et al* (2012) *Environmental Impacts during Marcellus Shale Gas Drilling: Causes, Impacts and Remedies*. Shale Resources and Society Institute p.8. Available from <http://cce.cornell.edu/EnergyClimateChange/NaturalGasDev/Documents/UBSRSI-Environmental%20Impact%20Report%202012.pdf> [Accessed April 2015].

<sup>44</sup> Tyndall Centre for Climate Change Research (2011) *Shale gas: a provisional assessment of climate change and environmental impacts* p.59. Available from [http://www.tyndall.ac.uk/sites/default/files/tyndall-coop\\_shale\\_gas\\_report\\_final.pdf](http://www.tyndall.ac.uk/sites/default/files/tyndall-coop_shale_gas_report_final.pdf) [Accessed April 2015].

<sup>45</sup> Considine T. *et al* (2012) *Environmental Impacts during Marcellus Shale Gas Drilling: Causes, Impacts and Remedies*. Shale Resources and Society Institute p.19/p.30. Available from <http://cce.cornell.edu/EnergyClimateChange/NaturalGasDev/Documents/UBSRSI-Environmental%20Impact%20Report%202012.pdf> [Accessed April 2015].

involving major water contamination, 0.5% from blow-outs and venting, 0.2% involving major site restoration problems and 0.2% from gas migration.

### Decommissioning of wells

All activities associated with decommissioning would take place within the existing site area and therefore no further effects on biodiversity are anticipated.

### Site restoration and relinquishment

All activities associated with site restoration would take place within the existing site area and therefore no further effects on biodiversity are anticipated. Following closure, it is assumed that the site would be restored to as near its preconstruction condition as possible, although this may not be possible, particularly for sites in sensitive areas. Over a wide area, there could be a significant loss or fragmentation of habitat depending on the number and spacing of well pads, but generally there is an absence of research on biodiversity impacts and risks following abandonment<sup>46</sup>.

## 1.3 Mitigation Measures

The following section sets out the potential mitigation measures available at each stage of the project life cycle. All measures should be part of a Biodiversity Mitigation Strategy (BMS) which details generic and more specific proposals for addressing identified impacts, with implementation overseen by an Ecological Clerk of Works<sup>47</sup>. Typical measures<sup>48</sup> include:

- ▶ Pre-construction checks for protected species.
- ▶ Programming of site/vegetation clearance to avoid disruption to ground nesting birds.
- ▶ Ecological pre-start checks prior to each new phase of the project (e.g. drilling, fracturing, initial flow testing, extended flow testing, decommissioning).
- ▶ Briefings and training for all site personnel prior to construction and each phase of the project.
- ▶ Regular compliance checks undertaken by the Ecological Clerk of Works.
- ▶ Yearly re-assessment of site vegetation to determine species use/presence.
- ▶ Use of buffer zones where the works and access routes are in close proximity to sensitive habitats.
- ▶ Application of specific measures to limit pollution of air and water courses such as through sediment polluted water.
- ▶ Further specific measures relating to key habitats and species as required, including habitat creation if required.

### Non-intrusive Exploration

Sites selected should be of low biodiversity value, and the presence of any sensitive species and potential pollutant pathways identified through desk-based assessment, walk-over surveys, and detailed species-specific surveys<sup>49</sup>. This could lead to the preparation of a staged approach to the identification and mitigation of impacts for specific species as illustrated in **Table B1.2**<sup>50</sup>.

<sup>46</sup> See: AEA (2012) p.69.

<sup>47</sup> See: Cuadrilla Bowland Ltd (2014) p.252.

<sup>48</sup> See: Cuadrilla Bowland Ltd 2014) pp.252/253.

<sup>49</sup> See: AEA (2012) p.283-285 Table A7.2.

<sup>50</sup> Based on Moore, V., Beresford, A., & Gove, B. (2014) p.33.

Table B1.2 Identification of Requirements and Limitations Associated with Sensitive Species

Step	Description	Requirements	Knowledge Limitations
1	Identify species sensitive to disturbance from fracking activities	Objective criteria for species selection, ideally based on known responses to fracking activity, but could be based on responses to other forms of disturbance.	Potential impacts on species may have to be inferred from their response to other forms of disturbance, but for many species, disturbance impacts are unknown
2	Map the distribution of sensitive species	Detailed distribution data for sensitive species, including foraging areas.	Detailed distribution data are lacking for many species, and knowledge of foraging areas is poor.
3	Buffer mapped distributions by disturbance distances, categorised as high or medium sensitivity	Species-specific disturbance distances and knowledge of the likely scale of the disturbance impact (high or medium).	Specific data on disturbance distances for sensitive species or the severity of the impacts. Consideration of the sources of, and interaction between, direct and indirect disturbance (construction noise, traffic, lighting, human activity) can inform the setting and appropriate distances and levels for some species.

Site design and layout should retain or minimise loss of any valuable habitats or species whilst avoiding habitat fragmentation, particularly associated with road, rail and pipeline infrastructure. Opportunities for habitat creation and enhancement should be identified for implementation during construction, operation and decommissioning phases.

Risks associated with each stage of the operation should be identified and management procedures put in place to address these.

### Exploration drilling and hydraulic fracturing

The mitigation considerations identified for site investigation apply as well to exploration drilling and hydraulic fracturing. The timing of activities (seasonally and project phasing) should also be considered, as should risks associated with the discharge of pollutants which could damage local and distant aquatic environments. These should be identified and addressed in the risk management plan identified in Stage 1.

In addition to the generic measures identified in the Biodiversity Mitigation Strategy, mitigation measures should respond to impacts identified, such as<sup>51</sup>:

- ▶ Loss of vegetation - replacement through boundary planting, using locally native species, and the preparation of a management plan to ensure their success.
- ▶ Loss of foraging habitat and connectivity and species disturbance (such as through the effects of lighting on bats) – lighting to be directed onto site equipment only, levels of brightness are as low as safely possible, upward lighting minimised to avoid light pollution and height limits applied to lighting columns to reduce light spillage. Species monitoring should be employed to assess changes in the levels of activity.
- ▶ Loss of habitat for feeding and nesting/breeding birds and disturbance – off-site planting to compensate for habitat loss in areas unlikely to be disturbed by vehicle and personnel movements. In addition, habitat management to favour animals displaced by operations could be required<sup>52</sup>.

<sup>51</sup> See: Cuadrilla Bowland Ltd (2014) pp.255-261.

<sup>52</sup> See: Cuadrilla Bowland Ltd (2014) p.261.

- ▶ Disturbance effects - If construction occurs with the breeding season, a detailed Method Statement on measures to minimise potential disturbance impacts should be prepared prior to works commencing. In addition there should be attention to site screening, lighting control (as specified above) and minimisation of noise disturbance (associated with 24-hour operation) such as through bunding (typically of 2-3m) and 'soft start ups' where machinery are started up one by one to gradual work up to full activity levels. Pre-construction training of personnel will be required, as will regular compliance checks undertaken by the Ecological Clerk of Works.

Detailed protocols and management measures relating to the above mitigation measures have been established in the North East United States<sup>53</sup> and concern:

- ▶ Reducing Direct Impacts at Individual Well Sites:
  - ▶ Require multiple wells on single pads wherever possible;
  - ▶ Design well pads to fit the available landscape and minimize tree removal;
  - ▶ Require "soft" edges around forest clearings by either maintaining existing shrub areas, planting shrubs, or allowing shrub areas to grow;
  - ▶ Limit mowing to one cutting per year or less after the construction phase of well pads is completed. Mowing would not occur during the nesting season for grassland birds;
  - ▶ When well pads are placed in large patches of grassland habitat (greater than 12 ha) construction and drilling activities are prohibited during grassland bird nesting season;
  - ▶ Require lighting used at wellpads to shine downward during bird migration periods;
  - ▶ Limit the total area of disturbed ground, number of well pads, and especially, the linear distance of roads, where practicable;
  - ▶ Design roads to lessen impacts, including two-track roads and limiting canopy gaps;
  - ▶ Require roads, water lines, and well pads to follow existing road networks and be located as close as possible to existing road networks to minimize disturbance; and
  - ▶ Require reclamation of non-productive, plugged, and abandoned wells, well pads, roads and other infrastructure areas.
- ▶ Reducing Indirect and Cumulative Impacts of Habitat Fragmentation:
  - ▶ Preserve existing blocks of the critically important grassland and interior forest habitats identified in Grassland and Forest Focus Areas by avoiding site disturbance (wellpad construction) in those areas.
- ▶ Monitoring Changes in Habitat:
  - ▶ Conduct pre-development surveys of plants and animals to establish baseline reference data for future comparison;
  - ▶ Monitor the effects of disturbance as active development proceeds and for a minimum of two years following well completion. Practice adaptive management as previously unknown effects are documented; and
  - ▶ Conduct test plot studies to develop more effective re-vegetation practices. Variables might include slope, aspect, soil preparation, soil amendments, irrigation, and seed mix composition.

Where specific risks have been identified, such as a sensitive species, then a detailed mitigation plan will be required. For example, an ecological assessment of the potential effects development on feeding grounds

<sup>53</sup> New York State Department of Environmental Conservation (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, September 2011. Available from [http://www.dec.ny.gov/docs/materials\\_minerals\\_pdf/rdsgeisch70911.pdf](http://www.dec.ny.gov/docs/materials_minerals_pdf/rdsgeisch70911.pdf) [Accessed April 2015].

for swans from an adjacent SPA/Ramsar sites demonstrated a functional link between the SPA and land in the vicinity of the development site<sup>54</sup>. A mitigation strategy has been proposed for the time the birds are in residence (October – March) entailing:

- ▶ screening of the compound to prevent disturbance;
- ▶ active management of the feeding grounds in the vicinity of the compound including supplementary feeding;
- ▶ minimisation of light spillage;
- ▶ noise compliance checks; and
- ▶ minimisation of vehicle movements.

Potential risks associated with the introduction and spread of invasive species, and by implication encourage the restoration of native vegetation, should be set out in an invasive species mitigation plan. Measures could include<sup>55</sup>:

- ▶ Prior to any ground disturbance, any invasive plant species encountered at the site should be stripped and removed;
- ▶ All fill and/or construction material from offsite locations should be inspected for invasive species and should only be utilized if no invasive species are found growing in or adjacent to the fill/material source;
- ▶ Only certified weed-free straw should be utilised for erosion control (of particular relevance to UK and Europe);
- ▶ All trucks, machinery and equipment to be checked prior to entry and exit of the project site;
- ▶ All machinery and equipment to be washed with high pressure hoses and hot water prior to delivery to the project site;
- ▶ Run-off resulting from washing operations should not be allowed to directly enter any water bodies or wetlands;
- ▶ Loose plant and soil material that has been removed from clothing, boots and equipment, or generated from cleaning operations would be destroyed or appropriately disposed of off-site.
- ▶ Water should not be transferred from one water body to another;
- ▶ Any top soil brought to the site for reclamation activities should be obtained from a source known to be free of invasive species;
- ▶ Native vegetation should be re-established and weed-free mulch should be used on bare surfaces to minimise weed germination;
- ▶ Only native (non-invasive) seeds or plant material should be used for re-vegetation;
- ▶ All seed should be from local sources to the extent possible;
- ▶ Re-vegetation should occur as quickly as possible at each project site;
- ▶ The site should be monitored for new occurrences of invasive plant species following partial reclamation; and

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<sup>54</sup> Ecology Services Ltd for Cuadrilla Resources Ltd (2013) *Impact Assessment and Method Statement – Site at Anna’s Road, Westby Lancs*. Available from [http://planningregister.lancashire.gov.uk/Attachments/6193/Annas\\_Rd\\_MS\\_10-2-13\\_final\\_comp.pdf](http://planningregister.lancashire.gov.uk/Attachments/6193/Annas_Rd_MS_10-2-13_final_comp.pdf) [Accessed April 2015].

<sup>55</sup> New York State DEC 2011 PR (p7-88 to 7-94) New York State Department of Environmental Conservation (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, September 2011 cited in AEA (2012) p.173/174.

- ▶ Any new invasive species occurrences found at the project location should be removed and disposed of appropriately.

Managing the potential impacts of invasive species is related to minimising the impacts on biodiversity associated with water use, particularly related to the storage and movement of water. A variety of mitigation measures can be considered<sup>56</sup>, including:

- ▶ For moving fresh water between sites and/or discharges, transport unused fresh water via truck or pipeline to other drilling locations where it can be discharged into tanks or for subsequent use; and
- ▶ If fresh water cannot be used at another drilling location, dispose of unused fresh water over land (not in surface water or in manner that drains directly to surface water), preferably in the same drainage area as collected, and using appropriate erosion control measures.
- ▶ For vehicles and equipment used to withdraw and transport fresh water:
  - ▶ drain all hoses and equipment at collection site after use; and
  - ▶ clean all mud, vegetation, organisms and debris and dispose on site if the contaminants originated at site and dispose of properly.
- ▶ Before moving to another water body, decontaminate equipment that has come in contact with surface water using appropriate protocols (pressure wash with hot water at contact point for 3 minutes or disinfect with 200 ppm chlorine for 10 minutes); keep disinfection solution from entering surface waters.

## Production Development

The mitigation measures identified for site investigation and exploration should be continued as appropriate. In addition, the effects of production development activities should be closely monitored for adverse and cumulative impacts, particularly under the high activity scenario. The timing of activities should also be considered, as should risks associated with the discharge of pollutants. It may be necessary to establish a buffer zone around protected areas, the size of which relates to its character. Habitat creation and/or enhancement should be progressed as appropriate.

## Production/operation/maintenance

The potential impacts of production activities should be closely monitored for potential adverse and cumulative impacts such as disturbance effects of operations and potential risks associated with the accidental discharge of pollutants such as fracturing fluids and untreated flowback water stored on site. This is particularly the case where there are likely to be concentrations of well pads in a locality. Specific measures on risk management should include: the implementation of already prepared plans to monitor impacts on sensitive species (both on-site and through vehicle movements) and accident prevention measures relating to the use and storage of material.<sup>57</sup>

## Decommissioning of wells

Prior to site restoration, habitats and species surveys should be undertaken to determine biodiversity value and opportunities for protection and enhancement in consultation with interested organisations. Site management plans might be appropriate, particularly where opportunities for enhancement have been identified. The Biodiversity Mitigation Strategy identified above should guide the application of any measures to protect biodiversity at this stage, including the transition to site restoration.

## Site restoration and relinquishment

As for decommissioning.

<sup>56</sup> New York State DEC 2011 PR (p7-97) cited in AEA (2012) p.262/263.

<sup>57</sup> See: AEA (2012) p.129-138.



## 1.4 Summary of Effects and Mitigation

The effects of unconventional oil and gas activity on biodiversity interests are considered to be combinations of both neutral and negative in character, according to the stages and scale of operation, where the risks of the accidental release of pollutants, for example, are greater by virtue of the scale of activity. There could be negative effects associated with exploration drilling, well pad construction and production activity, related to the direct effects of habitat loss and also indirect effects associated with noise, human activity and light pollution. Other stages of the process are likely to produce no overall effect, assuming that suitable knowledge of habitats and species exists to avoid or mitigate any immediate impacts. The following mitigation is recommended:

- ▶ **Site investigation:** Sites selected should be of low biodiversity value, and the presence of any sensitive species identified through desk-based assessment, walk-over surveys, and detailed species-specific surveys. Site design and layout should retain or minimise loss of any valuable habitats or species whilst avoiding habitat fragmentation, particularly associated with road, rail and pipeline infrastructure. Opportunities for habitat creation and enhancement should be identified for implementation during construction, operation and decommissioning phases.
- ▶ **Site Construction:** The mitigation measures identified for site investigation and exploration should be continued as appropriate. In addition, the effects of production development activities should be closely monitored for adverse and cumulative impacts, particularly under the high activity scenario. The timing of activities should also be considered, as should risks associated with the discharge of pollutants. It may be necessary to establish a buffer zone around protected areas, the size of which relates to its character. Habitat creation and/or enhancement should be progressed as appropriate. These should be set out as part of a Biodiversity Management Strategy prepared to address matters relating to the development, operation and decommissioning of the site.
- ▶ **Site production:** The effects of production activities should be closely monitored for adverse and cumulative impacts, particularly under the high activity scenario. The timing of activities should also be considered, as should risks associated with the discharge of pollutants.
- ▶ **Site Decommissioning:** Prior to site restoration, habitats and species surveys should be undertaken to determine biodiversity value and opportunities for protection and enhancement in consultation with interested organisations. A site management plan might be appropriate.

## 1.5 Regulatory Framework

### International/European

The UK is a signatory (along with another 189 parties) to the **Convention on Biological Diversity**, Nagoya, Japan, 2010 which sets out a conservation plan to protect global biodiversity, and an international treaty to establish a fair and equitable system to enable nations to co-operate in accessing and sharing the benefits of genetic resources. The new global vision is: 'By 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people.' The parties also agreed a shorter-term ambition to 'Take effective and urgent action to halt the loss of biodiversity, [so] that by 2020 ecosystems are resilient and continue to provide essential services, thereby securing the planet's variety of life, and contributing to human well-being, and poverty eradication'.

In March 2010, the European Union (EU) agreed to **an EU vision and 2020 mission for biodiversity:**

- ▶ By 2050, EU biodiversity and the ecosystem services it provides – its natural capital – are protected, valued and appropriately restored for biodiversity's intrinsic value and for their essential contribution to human wellbeing and economic prosperity, and so that catastrophic changes caused by the loss of biodiversity are avoided; and

- ▶ Halt the loss of biodiversity and the degradation of ecosystem services in the EU by 2020, and restore them insofar as is feasible, while stepping up the EU contribution to averting global biodiversity loss.

The European Commission adopted a new **EU Biodiversity strategy** to help meet this goal. The strategy provides a framework for action over the next decade and covers the following key areas:

- ▶ Conserving and restoring nature;
- ▶ Maintaining and enhancing ecosystems and their services;
- ▶ Ensuring the sustainability of agriculture, forestry and fisheries;
- ▶ Combating invasive alien species; and
- ▶ Addressing the global biodiversity crisis.

There are a number of EU Directives focusing on various types of wildlife and habitat that provide a framework for national action and international co-operation for conservation on land and in the sea. In particular the Directive 92/43/EEC on the conservation of natural habitat and of wild fauna and flora (the "**Habitat Directive**") and Directive 2009/147/EC on the conservation of wild birds (the "**Wild Bird Directive**") include measures to maintain or restore important natural habitats and species including through the designation of Special Areas of Conservation (SACs) and Special Protection Areas (SPAs). These Directives are transposed into British law through a number of regulations and planning policy documents. These are transposed into general pieces of law, such as the Environmental Code in France and Sweden, or general pieces of law in the field of environmental protection, such as the Act on Access to Environmental Information and its Protection, Participation of the Society in Environmental Protection and Environmental Impact Assessment in Poland or the Federal Nature Conservation Act in Germany. Specific implementing pieces of legislation implement specific aspects of wild life protection measures, such as the Order for obtaining derogations to the preservation measures in France, etc.

Activities in Natura 2000 protected areas require a prior assessment procedure in Poland, France and Sweden.

Under the Polish Act on Natura Protection, "any plan or project not directly connected with or necessary for the management of the Natura 2000 protected site but likely to have a significant effect on it is subject to an assessment procedure". During this assessment, the competent authority verifies whether the plan or project "would not adversely affect the site at stake". In case it would and there is a lack of alternative solution, a plan or project can be authorised "for imperative reasons overriding public interest only" and provided that "compensatory measures" are taken and the Commission must be informed. For the sites hosting priority natural habitat types and/or priority species, the law forbids any considerations to carry with the plan or project other than those relating to human health or public safety, to beneficial consequences of primary importance for the environment or other imperative reasons of overriding public interest after obtaining an opinion from the Commission. As a general rule of thumb, assessment of the impact on a Natura 2000 area is part of the E.I.A. The General and Regional Directorate for Environmental Protection are the competent bodies. The Directorate assesses the proposed project, including in particular the verification of the environmental impact report for the project, the acquisition of the opinions and approvals required by the Act, ensuring the possibility of public participation in the procedure. The authority is responsible for carrying out the correct procedure and decides about a possible necessity of imposing the appropriate Natura 2000 assessment obligation on the investor.

In France, the Prefects determine in advance the operations being capable to significantly affect the Natura 2000 protected areas, under the form of a decree, after consultation of the Conseil Scientifique Régional du Patrimoine Naturel and the Commission Départementale de la Nature, des Paysages et des Sites. Applicants must file an application form to the Prefect. A public inquiry is conducted. The Prefect takes a decision within two months.

In Sweden, a permit may be granted only if the operations: (i) do not harm the habitat in the protected area; and (ii) do not disturb the protected species in such a way that it affects the preservation of the species in the area. During the application procedures for exploration authorisations, the Swedish Mining Inspectorate informs the applicant about the protected areas before granting an authorisation covering these areas. The

Inspectorate furthermore informs the applicant about the consequences for the coming exploration/exploitation work. The information is provided to the Inspectorate by the CAB and the concerned municipalities. With a view of starting exploration activities, the CAB or the concerned municipalities can grant permits and/or foresee exceptions from local nature preserve regulations (municipality) and the national Natura 2000 regulations (CAB). During the procedure for obtaining an exploitation concession, the Mining Inspectorate cannot grant a concession if nature preservation provisions and/or Natura 2000-regulations are not complied with. Binding opinions on this are provided by the concerned municipalities (local nature preserve regulations) and/or the CAB (national Natura 2000-regulations). If the Mining Inspectorate disagrees with this opinion, the concession must be tried by the Government. Verification of the Natura 2000 conditions also can happen under the overall procedure leading to the grant of an environmental permit. The issue of a separate permit only may arise, when the impact of the foreseen activities on the protected site is significant. The Inspectorate confirms that, as a general principle, in Sweden, no drilling activities are allowed in Natura 2000 and nature preserve areas.

In Germany, no specific permit is required but, as a general rule, avoidable environmental interventions are prohibited whereas unavoidable ones require compensation, namely compensation measures locally ("Ausgleichsmassnahme") or contingency measures elsewhere ("Ersatzmassnahme"). The Federal Mining Act requires a weighing of the exploration or production activities with public interests. In the Land of North Rhine Westphalia, the Ministry of Environment and the mining lower authority are the competent supervisory authorities.

The **Marine Strategy Framework Directive (2008/56/EC)** requires Member States to develop a marine strategy, including determining Good Environmental Status (GES) for their marine waters, and designing and implementing programmes of measures aimed at achieving it by 2020, using an ecosystem approach to marine management. It takes account both of socioeconomic factors and the cost of taking action in relation to the scale of the risk to the marine environment.

Under the **Ramsar Convention**, wetlands of international importance are designated as Ramsar Sites. As a matter of policy, Ramsar sites in England are protected as European sites. The vast majority are also classified as SPAs and all terrestrial Ramsar sites in England are notified as Sites of Special Scientific Interest (SSSIs).

## UK

**The Wildlife and Countryside Act (1981)** is the main UK legislation relating to the protection of named animal and plant species includes legislation relating to the UK network of nationally protected wildlife areas: Site of Special Scientific Interest (SSSIs<sup>58</sup>). Under this Act, Natural England now has responsibility for identifying and protecting the SSSIs in England. The **Countryside and Rights of Way Act (2000)** (CROW) strengthens the powers of Natural England to protect and manage SSSIs. The CROW Act improves the legislation for protecting and managing SSSIs so that:

- ▶ Natural England can change existing SSSIs to take account of natural changes or new information;
- ▶ All public bodies have a duty to further the conservation and enhancement of SSSIs;
- ▶ Neglected or mismanaged sites can be brought into favourable management; and
- ▶ New offences and heavier penalties now apply to people who illegally damage SSSIs.

The **UK Biodiversity Action Plan (1994)** was the UK Government's response to signing the Convention on Biological Diversity (CBD) at the 1992 Rio Earth Summit. The CBD called for the development and enforcement of national strategies and associated action plans to identify, conserve and protect existing biological diversity, and to enhance it wherever possible. The UK Biodiversity Action Plan was then established to conserve and enhance biodiversity in the UK through the use of Habitats and Species Action Plans to help the most threatened species and habitats to recover and to contribute to the conservation of

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<sup>58</sup> As amended by the *Countryside and Rights of Way (CROW) Act 2000* and the *Natural Environment and Rural Communities (NERC) Act 2006*

global biodiversity. In 2002 world leaders agreed in Johannesburg on the urgent need to reduce the rate of loss of biodiversity by 2010, and in 2007 they recognised the need to take action to mitigate the impacts of climate change following the 2005 Millennium Ecosystem Assessment.

Since the publication in 2007 of *Conserving Biodiversity – the UK approach*, the context in which the Convention on Biological Diversity (CBD) is implemented in the UK has changed. Strategic thinking in all the four countries (England, Northern Ireland, Scotland and Wales) has pursued a direction away from a piecemeal approach dealing with different aspects of biodiversity and the environment separately, towards a new focus on managing the environment as a whole, with the true economic and societal value of nature properly acknowledged and taken into account in decision-making in all relevant sectors. In October 2010, 192 governments and the European Union agreed the **Strategic Plan for Biodiversity 2011-2020**, with its 5 strategic goals and 20 new global 'Aichi' targets sets a new global vision and direction. The resulting **UK Biodiversity Framework** is designed to identify the activities needed to galvanise and complement country strategies, in pursuit of the Aichi targets. As such it is an important framework that is owned, governed and implemented by the four countries, assisted by Defra and JNCC in their UK co-ordination capacities. Although differing in details and approach, the four UK countries have published strategies which promote the same principles and address the same global targets: joining-up our approach to biodiversity across sectors; and identifying, valuing and protecting our 'Natural Capital' to protect national well-being now and in the future.

The purpose of this **UK Biodiversity Framework**<sup>59</sup> is to set a broad enabling structure for action across the UK between now and 2020:

- ▶ To set out a shared vision and priorities for UK-scale activities, in a framework jointly owned by the four countries, and to which their own strategies will contribute;
- ▶ To identify priority work at a UK level which will be needed to help deliver the Aichi targets and the EU Biodiversity Strategy;
- ▶ To facilitate the aggregation and collation of information on activity and outcomes across all countries of the UK, where the four countries agree this will bring benefits compared to individual country work; and
- ▶ To streamline governance arrangements for UK-scale activity.

The **Conservation of Habitats and Species Regulations (2010)** requires that sites of importance to habitats or species are to be designated and any impact on such sites or species must be considered in regards to planning permission applications.

The **Environmental Protection Act (1990)** sets out key statutory requirements for the UK regarding environmental protection (including waste and nature conservation).

Section 50 of the **Infrastructure Act 2015** inserts an amendment to the Petroleum Act 1998 regarding safeguards for onshore hydraulic fracturing. These include a commitment that "hydraulic fracturing will not take place within other protected areas", which will be defined in regulations issued by the Secretary of State for Energy and Climate Change. It is noted however, that in the originally proposed amendment at the third reading of the Bill, protected areas included:

- ▶ Special areas of conservation under the Conservation (Natural Habitats, &c) Regulations 1994;
- ▶ Special protection areas under the Wildlife and Countryside Act 1981;
- ▶ Sites of special scientific interest under the Wildlife and Countryside Act 1981;
- ▶ National parks under the National Parks and Access to the Countryside Act 1949;
- ▶ The Broads under the Norfolk and Suffolk Broads Act 1988; and
- ▶ Areas of outstanding natural beauty under the Countryside and Rights of Way Act 2000.

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<sup>59</sup> JNCC and Defra (2012) *UK Post-2010 Biodiversity Framework*. Available from [http://jncc.defra.gov.uk/pdf/UK\\_Post2010\\_Bio-Fwork.pdf](http://jncc.defra.gov.uk/pdf/UK_Post2010_Bio-Fwork.pdf) [Accessed April 2015].

The **Marine and Coastal Access Act (2009)** sets out a number of measures including the establishment of Marine Conservation Zones (MCZs) and Marine Spatial Plans.

The **Marine Strategy Regulations 2010** transposes the Marine Strategy Framework Directive (2008/56/EC) into UK law. It requires member states to:

- ▶ Provide an assessment of the current state of their seas by July 2012;
- ▶ Provide a set of detailed characteristics of what good environmental status means for their waters, and associated targets and indicators, by July 2012;
- ▶ Establish a monitoring programme to measure progress by July 2014; and
- ▶ Establish a programme of measures for achieving good environmental status by 2016.

The UK Marine Strategy Part One addresses the first two of these requirements. Future consultation<sup>60</sup> is planned on:

- ▶ Proposals for the UK monitoring programmes for good environmental status (Autumn 2013); and
- ▶ UK programmes of measures for achieving good environmental status (Autumn 2014).

The **National Parks and Access to the Countryside Act (1949)** aims to conserve and protect countryside and National Parks through legislation.

The **Overarching National Policy Statement (NPS) for Energy (EN-1)** sets out the Government's national policy against which proposals for major energy projects will be assessed and decided on by the National Infrastructure Directorate (NID) within the Planning Inspectorate. The NPS identifies a range of generic impacts that may arise from energy development and associated policy including in respect of biodiversity. The **National Policy Statement for Gas Supply Infrastructure and Gas and Oil Pipelines (EN-4)** provides the primary basis for decisions on applications for gas supply infrastructure and gas and oil pipelines considered to be nationally significant in England and Wales.

## England

The **Natural Environment and Rural Communities (NERC) Act (2006)** establishes Natural England as the main body responsible for conserving, enhancing and managing England's natural environment. It also covers biodiversity, pesticides harmful to wildlife and the protection of birds.

The **Natural Environment White Paper (2011)** recognises that nationally, the fragmentation of natural environments is driving continuing threats to biodiversity. It sets out the Government's policy intent to:

- ▶ Improve the quality of the natural environment across England;
- ▶ Move to a net gain in the value of nature;
- ▶ Arrest the decline in habitats and species and the degradation of landscapes;
- ▶ Protect priority habitats;
- ▶ Safeguard vulnerable non-renewable resources for future generations;
- ▶ Support natural systems to function more effectively in town, in the country and at sea; and
- ▶ Create an ecological network which is resilient to changing pressures.

By 2020, the Government wants to achieve an overall improvement in the status of the UK's wildlife including no net loss of priority habitat and an increase of at least 200,000 hectares in the overall extent of priority habitats. Under the White Paper, the Government has also put in place a clear institutional framework to

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<sup>60</sup>Defra (2015) *Implementing the Marine Strategy Framework Directive*. Available from <https://www.gov.uk/government/policies/protecting-and-sustainably-using-the-marine-environment/supporting-pages/implementing-the-marine-strategy-framework-directive> [Accessed April 2015].



support nature restoration which includes Local Nature Partnerships creating new Nature Improvement Areas (NIAs).

***Biodiversity 2020: A strategy for England's wildlife and ecosystem (2011)*** is a new biodiversity strategy for England that builds on the Natural Environment White Paper and provides a comprehensive picture of the Government is implementing the international and EU commitments. It sets out the strategic direction for biodiversity policy for the next decade on land (including rivers and lakes) and at sea. The Strategy has as its mission to halt overall biodiversity loss, support healthy well-functioning ecosystems, and establish coherent ecological networks, with more and better places for nature for the benefit of wildlife and people.

The ***National Planning Policy Framework (NPPF) (2012)*** replaces the majority of previously used planning policy including Planning Policy Statement 9 on Biodiversity and Geological Conservation. The NPPF includes key policies to ensure the planning system contributes to and enhances the natural and local environment by:

- ▶ Protecting and enhancing valued landscapes, geological conservation interests and soils;
- ▶ Recognising the wider benefits of ecosystem services;
- ▶ Minimising impacts on biodiversity and providing net gains in biodiversity where possible, contributing to the Government's commitment to halt the overall decline in biodiversity, including by establishing coherent ecological networks that are more resilient to current and future pressures;
- ▶ Preventing both new and existing development from contributing to or being put at unacceptable risk from, or being adversely affected by unacceptable levels of soil, air, water or noise pollution or land instability; and
- ▶ Remediating and mitigating despoiled, degraded, derelict, contaminated and unstable land, where appropriate.

The Framework states that, when preparing plans to meet development needs, the aim should be to minimise pollution and other adverse effects on the local and natural environment. Local planning authorities are expected to set criteria based policies against which proposals for any development on or affecting protected wildlife or geodiversity or landscape areas will be judged. In doing so they must take into account the policies in the Framework including those which set out the circumstances where in order to conserve and enhance biodiversity planning permission should be refused.



## 2 Land Use, Geology and Soils

### 2.1 Introduction

Land use in this context is concerned with the effective use of land, i.e. by encouraging the reuse of land that has been previously developed (brownfield land) as well promoting sustainable patterns of land use, e.g. in relation to the protection of open spaces and green infrastructure. Geology and soils is also concerned with subsurface issues related to the effects of hydrological fracturing as well as the potential contamination of soils and high quality agricultural land.

There are links between the land use, geology and soil topic and other topics in the study, including waste.

### 2.2 Assessment of Effects

This section comprises of the review of the likely effects on land use and geology arising from unconventional oil and gas exploration and production activities. **Table B2.1** presents a summary of the key stages of exploration, production and decommissioning.

Table B2.1 Unconventional Oil and Gas Exploration and Production Lifecycle and Key Activities

Stage	Activities
1	<p><b>Non-intrusive exploration</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Site identification, selection, characterisation;</li> <li>▶ Seismic surveys;</li> <li>▶ Securing of necessary development and operation permits.</li> </ul>
2	<p><b>Exploration drilling and hydraulic fracturing</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Pad preparation road connections and baseline monitoring;</li> <li>▶ Well design and construction and completion;</li> <li>▶ Hydraulic fracturing;</li> <li>▶ Well testing including flaring.</li> </ul>
3	<p><b>Production development</b>, including :</p> <ul style="list-style-type: none"> <li>▶ Pad preparation and baseline monitoring;</li> <li>▶ Facility construction and installation;</li> <li>▶ Well design construction and completion;</li> <li>▶ Hydraulic fracturing;</li> <li>▶ Well testing, possibly including flaring</li> <li>▶ Provision of pipeline connections</li> <li>▶ (Possibly) re-fracturing.</li> </ul>

Table B2.1 (continued) Unconventional Oil and Gas Exploration and Production Lifecycle and Key Activities

Stage	Activities
4	<b>Production/operation/maintenance</b> , including: <ul style="list-style-type: none"> <li>▶ Gas/oil production;</li> <li>▶ Production and disposal of wastes/emissions;</li> <li>▶ Power generation, chemical use and reservoir monitoring;</li> <li>▶ Environmental monitoring and well integrity monitoring.</li> </ul>
5	<b>Decommissioning of wells</b> , including: <ul style="list-style-type: none"> <li>▶ Well plugging and testing;</li> <li>▶ Site equipment removal;</li> <li>▶ Environmental monitoring and well integrity monitoring.</li> </ul>
6	<b>Site restoration and relinquishment</b> , including: <ul style="list-style-type: none"> <li>▶ Pre-relinquishment survey and inspection;</li> <li>▶ Site restoration and reclamation.</li> </ul>

Note: Exploration wells most usually move from Stage 2 to Stage 4, though some may be used for long-term production testing and some may be retained and their sites redeveloped as a production project. For the purposes of this review, the appraisal stage (a term commonly used in industry) spans Stages 2 and 3.

The principal effects are anticipated to be:

- ▶ Land-take associated with exploration drilling and hydraulic fracturing, amounting to around 3ha pad. Further land-take would be required for access roads and pipework. Cumulatively, there could be significant effects in a locality, which could influence farming viability for some landholdings.
- ▶ Compaction of soils associated with the well-pad, with negative effects on high quality land.
- ▶ Potential for induced seismicity associated with fracturing activity, although the risk is judged to be low.
- ▶ Potential for the disturbance of contaminated land through construction and drilling activities and contamination by spillage during exploration production phases.

Potential mitigation measures include:

- ▶ Appropriate site selection to avoid sensitive areas;
- ▶ Use of larger drilling pads to accommodate multiple wells thereby reducing overall land-take;
- ▶ Attention to the potential for induced seismicity associated with fracturing though the use of detailed modelling and monitoring protocols;
- ▶ Controlled waste disposal; and
- ▶ Erosion control and land restoration.

### Non-intrusive Exploration

Stage 1 of the oil and gas exploration and production lifecycle comprises non-intrusive activities. Site identification, selection and characterisation and the securing of regulator approval would be expected to be

largely desk-based and in consequence, no effects on land use, geology or soils would be anticipated from these activities.

Vibroseis is a common method of seismic survey and typically involves 3-5 large truck based vibrator units which sub-sonically vibrate the ground while a number of support vehicles record the returning shock waves for analysis. Surveys tend to be spatially restricted due to the requirement for roads or other hard surfaces accessible by vehicle. Where existing roads and/or hard surfaces are utilised, any effects on land use, geology or soils would be negligible and in this context, it should be noted that vibroseis would generally be regarded in the UK as a permitted development. There may, however, be a requirement for the temporary construction of new roads to facilitate access to sites. This could result in the loss of greenfield land and soils and may obstruct the use of land (e.g. for agricultural use). Where soils are high agricultural quality these effects may be more severe.

There is also the potential for seismic surveys to affect geologically sensitive areas. Notwithstanding, the area of land lost to development would be expected to be small and any adverse effects would be temporary with land restored following the completion of surveys.

Where shot-hole techniques are utilised (which involve the use of explosions as a source of seismic energy), the requirement for large vehicular access would be likely to be reduced whilst it would be expected that shot holes would be infilled after use.

### Exploration drilling and hydraulic fracturing

Typical land-take for a drilling pad and associated compound is approximately 1-2 hectares (ha) for high volume hydraulic fracturing during the fracturing, compared to 1 ha per pad for conventional drilling<sup>1</sup> reflecting the needed to accommodate the equipment and storage tanks/pits, together with chemical additives and waste water.

Land take associated with the exploration stage requires the clearance of vegetation through stripping and stockpiling of topsoil, then placing a layer of crushed stone or gravel over geotextile fabric. In addition, erosion and sediment control structures are required around the site and lined pits to a capacity of around 30,000m<sup>3</sup> for the retention of drilling fluid and freshwater<sup>2</sup> (although these are not permitted in the UK where all waste fluids are to be held in tankers and freshwater will be sourced either from mains pipes, licensed abstraction or tankered in).

Over the pad area, disruption of soil layers and compaction may have a negative effect in terms of soil function and processes, although these impacts are generally shared with other large construction projects and particularly those located on greenfield sites. It is anticipated that sites would be restored following either completion of exploration drilling or decommissioning of wells such that effects would be reduced in longer term (i.e. following exploratory drilling or beyond the site restoration stage, depending on whether a site is taken forward to the production stage). Where development is located on land that is of high agricultural quality, or in other sensitive areas, effects could be more significant and permanent particularly if the nature of the sensitive area inhibits full site restoration<sup>3</sup> or where development takes place in areas of intensive agriculture. Drilling activity over a wide area, where multiple installations are employed, could result in significant cumulative land-take<sup>4</sup> and has the potential to disrupt the operation of farming businesses through severance of land holdings, for example, although the overall potential impact and opportunities for mitigation will be a function of their size and nature of the business. Generally, larger farms will have greater capacity to absorb impacts and be less sensitive to change, although detailed survey would be required<sup>5</sup>.

<sup>1</sup> New York State Department of Environmental Conservation (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, September 2011* cited in AEA (2012) section 2.4.3 p.31.

<sup>2</sup> AEA (2012) *Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe* p.250, Table A6.2 and section 2.4.4. Available from <http://ec.europa.eu/environment/integration/energy/pdf/fracking%20study.pdf> [Accessed April 2015].

<sup>3</sup> See AEA (2012) p.31.

<sup>4</sup> See AEA (2012) p.vii.

<sup>5</sup> See Cuadrilla Bowland Ltd (2014) *Temporary Shale Gas Exploration, Preston New Road, Lancashire: Environmental Statement* p.382. Available from [http://www.cuadrillaresources.com/wp-content/uploads/2014/07/PNR\\_ES\\_Vol1\\_Environmental\\_Statement.pdf](http://www.cuadrillaresources.com/wp-content/uploads/2014/07/PNR_ES_Vol1_Environmental_Statement.pdf) [Accessed April 2015].

There is the potential for construction activities and exploratory drilling to cause disturbance to contaminated sites which could result in pollution pathways being created or re-opened for existing ground contamination. However, the risk of any such effect occurring cannot be fully established until such time that sites have been identified. Further, it is anticipated that ground contamination surveys would be undertaken prior to development in order to identify the potential risk of disturbance and appropriate mitigation, in accordance with the Contaminated Land Regulations and taking into account appropriate guidance.

As with other types of construction activity, there is a small risk of land contamination from, for example, accidental spillage associated with oil and gas exploration. With specific regard to unconventional oil and gas exploration, potentially polluting substances will also include hydraulic fracturing fluids. It would be expected that any potential contamination would be sufficiently mitigated by following best practice guidance and through the use of a Construction Environmental Management Plan (CEMP). However, it would not allow for accidental or unforeseen discharges.

Pad preparation and the drilling of boreholes may affect land stability, geomorphology and/or soil erosion rates, on- or off-site. The type/magnitude of the effects will depend on the geology and physical nature of the area and effects may be particularly adverse where activities are undertaken within or in close proximity to sensitive geological areas. Within the UK, the risk of potential impacts on geologically sensitive sites/areas would be fully considered as part of the planning application process and in accordance with national planning policy and guidance including that specifically relating to onshore oil and gas (DCLG, 2014<sup>6</sup>). Further, the potential for significant negative effects would be identified as part of the Environmental Impact Assessment (EIA) process (where appropriate).

On 1<sup>st</sup> April 2011, the Blackpool area in North West England experienced seismicity of magnitude 2.3 M<sub>L</sub> shortly after Cuadrilla Resources hydraulically fractured a well at its Preese Hall site. Seismicity of magnitude 1.5 M<sub>L</sub> occurred on 27<sup>th</sup> May 2011 following renewed fracturing of the same well. Hydraulic fracturing was subsequently suspended. Cuadrilla Resources commissioned a set of reports to investigate the cause of seismicity and DECC subsequently commissioned an independent review of these reports, which was published for public comment<sup>7</sup>. This research confirms that the observed seismicity was induced by hydraulic fracturing, most probably through the injection of fluid into a nearby, but unidentified, pre-stressed fault.

The independent review<sup>8</sup> concluded, however, that the maximum magnitude of induced seismicity arising from hydraulic fracturing operations in that area would be not greater than M<sub>L</sub>=3 which, according to the European Macroseismic Scale, would be equivalent to a passing truck, being felt by few people and resulting in negligible, if any, surface effects. In this context, Davies *et al*<sup>9</sup> state that, when compared with other sources of induced seismicity such as mining and reservoir impoundment, “*hydraulic fracturing has been, to date, a relatively benign mechanism. It is possible that fault reactivation by hydraulic fracturing might cause induced seismicity larger than that recorded to date, but a fuller understanding of shale geology can mitigate against this risk*” and that the likelihood of hydraulic fracturing “*causing felt seismicity (M>3) is very small*”. Similarly, the AEA (2012)<sup>10</sup> conclude that: “*In view of these evaluations and the low frequency of reported incidents, it is judged that the frequency of significant seismic events is “rare” and the potential significance of this impact is “slight.” Multiple development could increase the risk of seismic events due to one operation affecting the well integrity of a separate operation, although in view of the low frequency of the reported events and the established measures for monitoring well integrity, the risks are judged to remain low.*”

This conclusion has been corroborated by recent research<sup>11</sup> which observes that: “The development of a fracture network of this size [c.600m] in one single tensile rupture would correspond to an induced

<sup>6</sup> Department for Communities and Local Government (DCLG) (2014) *Planning Practice Guidance*. Available from <http://planningguidance.planningportal.gov.uk/blog/policy/achieving-sustainable-development/delivering-sustainable-development/13-facilitating-the-sustainable-use-of-minerals/> [Accessed April 2015].

<sup>7</sup> Green C., Styles P.; Baptie B. (2012) *Preese Hall Shale Gas Fracturing Review and Recommendations for Induced Seismic Mitigation*. Available from [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/15745/5075-preese-hall-shale-gas-fracturing-review.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/15745/5075-preese-hall-shale-gas-fracturing-review.pdf) [Accessed April 2015].

<sup>8</sup> Green C., Styles P.; Baptie B. (2012).

<sup>9</sup> Davies, J.D. Foulgar, G., Bindley, A., Styles, P. (2013) *What size of earthquakes can be caused by fracking? DEI Briefing Note April 2013*. Durham University: Durham. Available from [https://www.dur.ac.uk/resources/dei/ResearchBrief\\_InducedSeismicity\\_final.pdf](https://www.dur.ac.uk/resources/dei/ResearchBrief_InducedSeismicity_final.pdf) [Accessed April 2015].

<sup>10</sup> See AEA (2012) p.54.

<sup>11</sup> Westaway R. & Younger P. (2014) *Quantification of potential macroseismic effects of the induced seismicity that might result from hydraulic fracturing for shale gas exploitation in the UK*, Quarterly Journal of Engineering Geology and Hydrogeology (forthcoming -

earthquake c. magnitude 3.6, although the probability of this happening is very low. Events of this size ... might be sufficient to cause minor damage to property, such as cracked plaster; however, such occurrences, if they ever occur, will be infrequent.” The research goes into to reflect on the potential for compensation arrangements in the UK: “If any such incidents do occur, they could be readily handled under a system of compensation similar to that operated by the Coal Authority for mining subsidence, or that operated by the Royal Air Force to compensate for the effects of sonic booms. The data to operate such a system will be available, as seismic monitoring of ‘fracking’ is essential both to follow the progression of the process in the interests of the developer, and also to demonstrate compliance with any regulatory framework. There is thus no scientific reason why seismicity induced by shale gas ‘fracking’ should not be regulated in a manner analogous to the way in which quarry blasting has been successfully and uncontroversially regulated in the UK for decades.”

In addition to the UK, induced seismicity associated with hydraulic fracturing has been identified in two other shale gas fields located in the USA and Canada. Hydraulic fracturing for shale gas in these three fields is known to have induced 79 seismic events with a magnitude >1. The largest of these was an earthquake of magnitude 3.8 M<sub>L</sub>, which occurred in the Horn River Basin of British Columbia, Canada<sup>12</sup>. It was felt, but caused no recorded damage. An earlier review of operating experience in the NE United States<sup>13</sup> concluded that such induced seismic activity is only detectable at the surface by the use of sensitive equipment and the magnitude can be minimised by avoiding pre-existing faults.

In the context of the Preese Hall site, the independent review<sup>14</sup> concluded that, with appropriate mitigation (which included geological surveys to characterise stresses and identify faults and use of sensitive fracture monitoring equipment), shale gas exploration activities could be allowed to restart. New controls based on expert advice<sup>15,16</sup> to be implemented by DECC<sup>17</sup>, include the requirement for operators to:

- ▶ Conduct a prior review of information on seismic risks and the existence of faults;
- ▶ Submit to DECC a hydraulic fracturing plan showing how any seismic risks are to be addressed;
- ▶ Carry out seismic monitoring before, during and after hydraulic fracturing; and
- ▶ Implement a “traffic light” system which will be used to identify unusual seismic activity requiring reassessment, or halting, of operations. In the context of the traffic lights:
  - ▶ ‘Green’ would mean magnitude of 0 M<sub>L</sub> which would mean injection could proceed as planned;
  - ▶ ‘Amber’ would mean a magnitude of between 0 to 0.5 M<sub>L</sub> would mean that injection could proceed with caution, possibly at reduced rates and that monitoring is intensified; and
  - ▶ ‘Red’ is defined as a magnitude 0.5 M<sub>L</sub> or higher, where injection is suspended immediately and the pressure of fluid in the well is also reduced immediately.

The level of 0.5 M<sub>L</sub> is well below what could be felt at the surface. For comparison, it is within the range of normal background noise caused by vehicles, trains and farming activities. However, it is above the level expected from normal fracking operations and so serves as early warning of the possibility of larger tremors.

For the first few operations, DECC will also have an independent expert on site to observe the operator’s conformance to the protocols established by DECC and to monitor the operator’s interpretation of data. This

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published online November 11, 2014, doi:10.1144/qjegh2014-011). Available from <http://qjegh.geoscienceworld.org/content/early/2014/10/29/qjegh2014-011.full.pdf+html> [Accessed April 2015].

<sup>12</sup> Durham Energy Institute (2013).

<sup>13</sup> New York State Department of Environmental Conservation (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, September 2011 p.6-321. Available from [http://www.dec.ny.gov/docs/materials\\_minerals\\_pdf/rdsgeisch6b0911.pdf](http://www.dec.ny.gov/docs/materials_minerals_pdf/rdsgeisch6b0911.pdf) [Accessed April 2015].

<sup>14</sup> Westaway R. & Younger P. (2014).

<sup>15</sup> The Royal Society & The Royal Academy of Engineering (2012) *Shale gas extraction in the UK: a review of hydraulic fracturing*. Available from <http://www.raeng.org.uk/publications/reports/shale-gas-extraction-in-the-uk> [Accessed April 2015].

<sup>16</sup> See also House of Commons (2013) *Shale Gas and Fracking standard note*. Available from <http://www.parliament.uk/business/publications/research/briefing-papers/SN06073/shale-gas-and-fracking> [Accessed April 2015].

<sup>17</sup> DECC (2014) *Fracking UK Shale: Understanding Earthquake Risk*. Available from [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/283837/Seismic\\_v3.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/283837/Seismic_v3.pdf) [Accessed April 2015].



will enable any lessons learned to be put into effect. These revised requirements have prompted the specification of detailed protocols for submission with Environmental Statements<sup>18</sup>. The Environmental Statement accompanying an application for exploration in Lancashire UK<sup>19</sup>, for example, includes a review of issues and responses to induced seismicity associated with fracturing activity to determine the viability of production.

There is the potential for construction activities and drilling to cause disturbance to contaminated sites which could result in pollution pathways being created or re-opened for existing ground contamination. However, the risk of any such effect occurring cannot be fully established until such time that sites have been identified. Further, it is anticipated that ground contamination surveys would be undertaken prior to development in order to identify the potential risk of disturbance and appropriate mitigation, in accordance with the Contaminated Land Regulations and taking into account appropriate guidance. There is also a small risk of land contamination from, for example, accidental spillage including of fracturing fluid or from well blow outs. However, an expert review<sup>20</sup> of hydraulic fracturing highlights that the impact of spills could be mitigated using established best practices such as bunding and use of non-hazardous chemicals whilst the probability of well failure is low. The issue is expanded on in **Appendix B3: Water**.

Like conventional oil and gas exploration, a potential source of soil and land contamination is likely to be drilling wastes, although the volume of arisings from unconventional oil and gas drilling activities (and, therefore, the risk of contamination) would be likely to be greater, commensurate with increased well depth. In England, drilling wastes are covered under section 1, 'wastes resulting from exploration, mining, quarrying, and physical and chemical treatment of minerals' in schedule 1 of the List of Wastes (England) Regulations 2005, implemented following the adoption of the Waste Directive (67/548/EEC) and after the List of Wastes Decision (2000/532/EC). Those wastes in the list relevant to drill cuttings and which are considered hazardous include:

- ▶ Oil-containing drilling muds and wastes (waste: 01 05 05); and
- ▶ Drilling muds and other drilling wastes containing dangerous substances (waste: 01 05 06).

Drilling muds and cuttings are the by-product of well drilling, and consist of a mixture of rock fragments and muds which may be oil or water-based. The latter usually contains biodegradable compounds whereas the former may contain compounds which resist degradation and would result in contamination if not appropriately managed (i.e. are hazardous wastes). Cuttings may be moved offsite and disposed of at a licensed landfill site or disposed of onsite if appropriate. The Environmental Protection (Duty of Care) Regulations will require operators to take suitable steps to manage such waste and provide appropriate information to any third party operator who may transport and/or dispose of the material elsewhere. In England, the requirements of the Landfill Regulations 2002 (and subsequent amendments) will need to be met, including the waste acceptance criteria, and under the Water Framework Directive it would also need to be demonstrated that water resources could not be contaminated by disposal of mud and cuttings. Regulatory controls under existing legislation will therefore effectively minimise and mitigate potential effects.

Like any large development, pad construction and associated land take could affect both existing land uses on site (e.g. agriculture) and those adjacent/in close proximity, particularly where they are sensitive to construction activity (e.g. residential areas). Works may also have a positive effect on this aspect of the objective where development utilises previously developed land. At this stage it is not known whether development would take place on previously developed or greenfield land nor what land uses may be affected. Further, it is anticipated that sites would be restored following either completion of exploration drilling or decommissioning of wells such that any adverse effects would be reduced in longer term (i.e. following exploratory drilling or beyond the site restoration stage, depending on whether a site is taken forward to the production stage).

Overall, it is considered that Stage 2 of the oil and gas exploration and production lifecycle carries moderate impacts, although cumulatively these could be high. This principally reflects the likelihood that there would be

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<sup>18</sup> See: Cuadrilla Bowland Ltd (2014) p.332.

<sup>19</sup> See: Cuadrilla Bowland Ltd (2014).

<sup>20</sup> The Royal Society & The Royal Academy of Engineering (2012).



some (albeit small scale) loss of greenfield land associated with pad preparation and the assumption that, under normal operating conditions, the risk of land contamination would be low.

## Production Development

The range and type of effects associated with Stage 3 of the unconventional oil and gas exploration and production lifecycle would be similar to those identified under Stage 2. The area of land take required per well pad would be greater than that associated with the exploratory drilling stage reflecting the need for additional infrastructure such as storage tanks and on-site pipelines. During this stage, land take would equate to around 3ha (which compares to 1.9ha per pad for conventional drilling) with potentially further land-take required for pipework. Research from the United States of America<sup>21</sup> suggests that the indirect effects of well-pad establishment extend to an additional 2.4ha for every hectare of well pad area, or an additional 9ha per well pad.

Where initial exploration drilling has been successful, multi-well pads are now widely used, where 6-10 wells are accommodated on a single pad enabling a single multistage horizontal well pad to access approximately 250 hectares of shale gas play, compared to approximately 15 hectares for a vertical well pad. Assuming 3 hectares per multi-well pad, this suggests that approximately 1.2% of the land above a productive shale gas reservoir may need to be used to fully exploit the reservoir, or more if other indirect land-uses (e.g. central storage facilities and pipelines) are taken into account<sup>22</sup>.

Additional land take may also be required for road connections and the installation of pipelines required to transfer gas to the existing natural gas pipeline infrastructure or to a gas compressor facility. Works are likely to require further clearance of vegetation and loss of soil layers and compaction which may have a negative effect in terms of soil function and processes.

Additionally, following the completion of Stage 3, some land associated with development of the well pad and associated infrastructure (e.g. pipelines) may be returned to its previous use. Where development is located on land that is of high agricultural quality, or in other sensitive areas, effects could be more significant and permanent particularly if the nature of the sensitive area inhibits restoration.

During Stage 3 there would be a need for further hydraulic fracturing to stimulate the production of gas. As highlighted under the assessment of Stage 2, this process has the potential to cause induced seismicity although independent reviews<sup>23</sup> suggest that the risk of hydraulic fracturing causing felt seismicity ( $M > 3$ ) is very small.

As under Stage 2, well pad construction and associated land take could affect both existing land uses on site (e.g. agriculture) and those adjacent/in close proximity, particularly where they are sensitive to construction activity (e.g. residential areas). Works may also have a positive effect where development utilises previously developed land. Further, it is anticipated that sites would be restored following the decommissioning of wells such that any adverse effects would be reduced in longer term.

Overall, it is considered that Stage 3 of the unconventional oil and gas exploration and production lifecycle would have minor negative effects. As with Stage 2, this principally reflects the likelihood that there would be some loss of greenfield land associated with pad preparation and the assumption that, under normal operating conditions, the risk of land contamination would be low.

## Production/operation/maintenance

It is assumed that no additional land take would be required during the production, operation and maintenance stage and in consequence, associated effects on soils would be negligible.

During production, an operator may choose to re-fracture a well in order to increase the rate of gas production, if this is considered worthwhile from a commercial perspective<sup>24</sup>. Wells are likely to be re-

<sup>21</sup> See Nature Conservancy (2011) *Pennsylvania Energy Impacts Assessment Report 1: Marcellus Shale Natural Gas and Wind*, available via [http://www.nature.org/media/pa/pa\\_energy\\_assessment\\_report.pdf](http://www.nature.org/media/pa/pa_energy_assessment_report.pdf) p.18 reported in AEA (2012) p.32/33.

<sup>22</sup> AEA (2012) p.31.

<sup>23</sup> See footnotes 10, 11 and 14 above.

<sup>24</sup> Jacobs, T. (2014) *Renewing Mature Shale Wells Through Refracturing*. Available from <http://interraenergy.com/renewing-mature-shale-wells-through-refracturing/> [Accessed April 2015].

fractured infrequently (either once every five to 10 years or not at all, based on US experience<sup>25</sup>). For example, “wells in the Barnett Shale in the US typically benefit from refracturing within five years of completion though this figure can vary depending on the circumstances. At present, there is little refracturing activity in the Marcellus Shale. A lifetime of up to 40 years suggests that wells may be refractured between zero and four times during their operational lifetime.”<sup>26</sup>

However, a recent study from the United States<sup>27</sup> suggests that refracturing periods could be shortening in response to rising prices of oil and gas and the attendant desire to maximise production: “Operators are increasingly refracturing two to four years later to stimulate oil and gas production. Refracturing of 15 oil wells in the Bakken Shale yielded a 30% increase in estimated ultimate recovery. In the Barnett Shale, where natural gas production declines 3- to 5-fold within a few years, refracturing increased estimated ultimate recovery by 20%. As the price for oil or natural gas rises, refracturing will become increasingly common.”

There is a small risk of land contamination from, for example, accidental spillage including of fracturing fluid or from well blow outs. However, as noted under Stages 2 and 3, the impact of spills could be mitigated using established best practices such as bunding and use of non-hazardous chemicals whilst the probability of well failure is low<sup>28</sup>. Further, it is expected that monitoring of potential well failure would be undertaken during re-fracturing with measures implemented to address any issues identified. Research<sup>29</sup> into environmental pollution incidents in the NE United States found a declining rate over a three-year period. Between 2008 and 2011 in Pennsylvania where some 3,533 wells have been drilled from over 100 drilling rigs, identified that where half of all wells involved some level of environmental pollution, this had declined to one fifth by 2011. Of 845 incidents that caused measurable amounts of pollution, 820 (97%) were classified as non-major and 25 (0.3%) involved major impacts to air, water and land resources. Of all the pollution events, 38.8% involved site restoration, 30.5% spills contaminating water, 17.6% non-major land spills and 10.1% involved cement and casing problems. Of these incidents, some 3% created major problems for the environment, 1.1% from major land spills, and 0.9% involving major water contamination, 0.5% from blow-outs and venting, 0.2% involving major site restoration problems and 0.2% from gas migration.

As there would be no additional land take associated with this stage of the unconventional oil and gas exploration and production lifecycle, it is anticipated that any effects on land use would be very minor and limited to disturbance to those uses that are in close proximity to well pad sites and potentially sensitive to impacts arising from operational activities (e.g. emissions to air, noise and vibration).

Based on the assumption that there would be no additional land take during Stage 4 and that the risk of induced seismicity and land contamination from operational activities would be low, this stage has been assessed as having neutral effects on land use, geology and soils.

## Decommissioning of wells

The range and type effects associated with Stage 5 of the unconventional oil and gas production lifecycle are likely to be similar to those identified under conventional oil and gas production for this stage.

Decommissioning will require additional machinery, and potentially, construction compounds to facilitate the removal of site equipment. Associated works may require clearance of vegetation and loss of soil layers and compaction, potentially generating a negative effect in terms of soil function and processes. However, it is not expected that the area of land required to undertake decommissioning activities (beyond existing well pads) would be significant. In this respect, the AEA (2012:69) report for the European Commission states that the consequences for landtake would be “comparable with many other industrial and commercial land-

<sup>25</sup> Ricardo-AEA (2013) *Unconventional Gas in England: Description of infrastructure and future scenarios* p.17. Available from <http://www.ricardo-aea.com/cms/assets/Uploads/Misc-uploads/ED58661-scenarios030214v14.pdf> [Accessed April 2015].

<sup>26</sup> Ricardo-AEA (2013) pp.17/18.

<sup>27</sup> Jackson R. et al (2014) *The Environmental Costs and Benefits of Fracking* p.332 in: Annual Review of Environmental Resources 2014 39:327–62. Available from <http://sites.biology.duke.edu/jackson/arer2014.pdf> [Accessed April 2015].

<sup>28</sup> The Royal Society & The Royal Academy of Engineering (2012).

<sup>29</sup> Considine T. et al (2012) *Environmental Impacts during Marcellus Shale Gas Drilling: Causes, Impacts and Remedies*. Shale Resources and Society Institute p.19/p.30. Available from

<http://cce.cornell.edu/EnergyClimateChange/NaturalGasDev/Documents/UBSRSI-Environmental%20Impact%20Report%202012.pdf> [Accessed April 2015].

uses, and are of no more than minor significance". However, where development associated with decommissioning activities is located on land that is of high agricultural quality or in other sensitive areas, effects could be more significant and permanent particularly if the nature of the sensitive area inhibits full site restoration.

As with pad preparation (Stages 2 and 3), decommissioning may affect land stability, geomorphology and/or soil erosion rates, on- or off-site. The type/magnitude of the effects will depend on the geology and physical nature of the area and effects may be particularly adverse where activities are undertaken within or in close proximity to sensitive areas such as Geological Conservation Review sites in the UK. However, it is considered reasonable to assume that the risk of potential impacts on geologically sensitive sites/areas would be fully considered as part of the planning application process and in accordance with national planning policy and guidance. Further, the potential for significant negative effects would be identified as part of the Environmental Impact Assessment (EIA) process (where appropriate).

There is the potential for the construction of buildings and infrastructure associated with decommissioning to cause disturbance to contaminated land where this development takes place on an existing contaminated site. However, the risk of any such effect occurring cannot be fully established until such time that sites have been identified. Further, it is anticipated that ground contamination surveys would be undertaken prior to decommissioning in order to identify the potential risk of disturbance and appropriate mitigation, in accordance with the Contaminated Land Regulations and taking into account appropriate guidance.

During the decommissioning stage, there continues to be a small risk of land contamination from, for example, accidental spillage. However, it would be expected that any potential contamination would be sufficiently mitigated by following best practice guidance and through the use of a Construction Environmental Management Plan (CEMP). It should also be noted that the decommissioning of onshore wells and associated installations would be addressed through conditions in planning consents and through PPC authorisation, which requires that the site of an installation be returned to a satisfactory state on closure. Within the UK, permission to decommission onshore wells is also required from DECC under The Petroleum (Production) (Landward Areas) Regulations 1995 and would require submission and agreement in advance of a Cessation of Production (COP) report.

Decommissioning activities and associated land take (beyond the existing well pad) could affect both existing land uses on decommissioning development sites (e.g. agriculture) and those adjacent/in close proximity, particularly where they are sensitive to decommissioning activity (e.g. residential areas). However, disruption would be temporary (i.e. for the duration of decommissioning) with land expected to be restored on completion.

### Site restoration and relinquishment

For the purposes of this assessment it is assumed that all production facilities, infrastructure and hardstanding would be removed during the site restoration and relinquishment stage. Due to the need for invasive demolition techniques and land excavation there is the potential for adverse effects on land stability, geomorphology and/or soil erosion during this stage. Notwithstanding, it is anticipated that effects would be similar to site restoration associated with other forms of mineral extraction and would be unlikely to be significant.

It is expected that during site restoration work, land would be remediated and wells sealed thereby mitigating the potential long term risk of land contamination.

Long term effects (i.e. beyond site restoration) on land use, geology and soils associated with the decommissioning phase will depend largely on the end use of well pad sites and future soil quality (this would be determined on a site-by-site basis following discussions between the operator and the minerals planning authority, or equivalent). Within the England, paragraph 143 of the National Planning Policy Framework (DCLG 2012) promotes high quality restoration and aftercare "*including for agriculture (safeguarding the long term potential of best and most versatile agricultural land and conserving soil resources), geodiversity, biodiversity, native woodland, the historic environment and recreation*". It is expected that this stage of the unconventional oil and gas exploration and production lifecycle would have a positive effect on this objective by restoring, and potentially enhancing, soil quality and prospects for beneficial land use.

It should be noted that the AEA (2012) report highlights that it may not be possible to return entire sites to beneficial use due to, for example, concerns regarding public safety. The report states (at page 69) that over a wider area “*this could result in a significant loss of land, and/or fragmentation of land area such as an amenity or recreational facility, valuable farmland, or valuable natural habitat*”. This is considered further in respect of both low and high activity scenarios below.

## 2.3 Mitigation Measures

The following section sets out the potential mitigation measures available at each stage of the project life cycle.

### Non-intrusive Exploration

- ▶ Sites selected should be of low agricultural/geological value.

### Exploration drilling and hydraulic fracturing

Potential measures for consideration include<sup>30</sup>:

- ▶ Using larger drilling pads for multiple wells, increasing the spacing between wells. Well pad spacing at one pad per 5km<sup>2</sup> instead of 1 per 2.5km<sup>2</sup> reduces the total land disturbance from 30ha to 22.5ha per 2,500ha area.
- ▶ Site selection including in respect of access and avoidance of sensitive areas such as areas of high agricultural land value.
- ▶ Limiting the use of impoundments in favour of tanks.
- ▶ Erosion and run-off control using measures such as soil stabilisation, terracing, and sediment traps.
- ▶ Land restoration to an appropriate after-use.

Where necessary, sites should be carefully stripped of topsoils prior to construction works commencing to avoid damage. All soils should be handled in suitable conditions (e.g. dry weather) and the most appropriate method of soil handling should be used. Soils should be stored in allocated heaps and protected from erosion, contamination or degradation. Different soil types should be stored separately and the length of time soils are stored should be minimised where possible. Soil excavation and mounds should avoid compaction where possible by making use of appropriate wide tracked vehicles and avoiding working on soil when it is wet. Appropriate drainage systems should be utilised on site to reduce soil erosion.

Appropriate waste disposal should be undertaken to avoid potential local contamination (see also Waste topic) relating to likely sources such as<sup>31</sup>:

- ▶ Drilling mud and drill cuttings located in mud tanks;
- ▶ Sanitary waste collected in a sealed cess tank;
- ▶ Site drainage collect in ditches;
- ▶ General waster (paper, timber, scrap metal) collected in skips;
- ▶ Waste fluids collected in storage tanks and collected by licensed operators and disposed of at authorised locations.

Where possible, development should make best use of previously developed land.

<sup>30</sup> AEA (2012) Section 5.4.

<sup>31</sup> Cuadrilla Resources Ltd (2010) *Supporting Statement to the Planning Application for the Becconsall Hydrocarbon Exploration Site* p.14. Available from <http://planningregister.lancashire.gov.uk/Attachments/5520/Becconsall%202%20-%20Supporting%20Statement.pdf> [Accessed April 2015].

Careful consideration should be given during the site selection process to the avoidance of adverse impacts on sensitive land uses that may be affected by construction activity and drilling.

In respect of reducing the risks of induced seismicity, potential mitigation embedded as part of project proposals include<sup>32,33</sup>:

- ▶ Reviewing available information on geology, structure (including faults) and in situ stresses in the vicinity of the proposed site to avoid hydraulically fracturing into, or close to, existing critically stressed faults:
  - ▶ Competent authorities compile regional maps of underground resources.
  - ▶ Conduct 3D seismic survey to identify faults and fractures.
  - ▶ Sharing of information to ensure that all operators in a gas play are aware of risks and can therefore plan.
  - ▶ Establish national capability to address groundwater contamination arising from unconventional gas operations. In the case of transboundary aquifers, joint capability established.
  - ▶ Engagement with third parties (e.g. regulators, other operators, researchers) to ensure fully aware of any issues/proximity (e.g. to other underground activities).
  - ▶ Search for and document potential leakage pathways (e.g. other wells, faults, mines).
- ▶ Carry out risk based geomechanical assessments of proposed hydraulic fracturing with regard to faults (including maximum magnitude estimates):
  - ▶ Development of a conceptual model of the zone before work commences covering geology, groundwater flows, pathways, microseismicity and subsequent updating of the model as information becomes available;
  - ▶ Modelling of fracturing programme to predict extent of fracture growth based on best information;
  - ▶ Ground motion prediction models to assess the potential impact of induced earthquakes.
  - ▶ Revise geological, hydrogeological and seismic conceptual model using geomechanical information on fractures, stress, rock strength, in situ fluid pressures through wireline monitoring and/or through new cores and stratigraphic tests;
  - ▶ Undertake complex modelling of fluid flows and migration (reservoir simulations);
- ▶ Identify potential seismic receptors within a defined radius of the well site (5km) including: wells, infrastructure, special buildings, residential buildings and industrial/commercial buildings; and
- ▶ Monitoring background induced and natural seismicity before, during and after hydraulic fracturing:
  - ▶ Monitoring and control during operations to ensure hydraulic fractures/pollutants do not extend beyond the gas-producing formations and does not result in seismic events or damage to buildings/installations that could be the result of fracturing; and
  - ▶ Establish the presence of methane in groundwater, including drinking water through sampling of shallow groundwater during wet and dry periods and/or borehole to sample deep groundwater and characterise the hydrological series.
- ▶ Monitor the extent of fracture growth during hydraulic fracturing using a buried microseismic array; and

<sup>32</sup> See: Cuadrilla Bowland Ltd (2014) pp.344/345 .

<sup>33</sup> European Commission (2014) *Technical support for assessing the need for a risk management framework for unconventional gas extraction*. Available from [http://ec.europa.eu/environment/integration/energy/pdf/risk\\_mgmt\\_fwkw.pdf](http://ec.europa.eu/environment/integration/energy/pdf/risk_mgmt_fwkw.pdf) [Accessed April 2015].



- ▶ Implementation of the Traffic Light System (via the surface seismic monitoring array).

### Production Development

As previous, but also including:

- ▶ Where possible, well pad infrastructure and associated development that is no longer required should be removed as soon as is reasonably practicable with land restored; and
- ▶ Pipelines should be buried where possible with land restored following installation.

### Production/operation/maintenance

As previous.

### Decommissioning of wells

- ▶ Sites selected to accommodate development associated with decommissioning activities should be of low agricultural/geological value.
- ▶ Where necessary, sites should be carefully stripped of topsoils prior to construction works commencing to avoid damage. All soils should be handled in suitable conditions (e.g. dry weather) and the most appropriate method of soil handling should be used. Soils should be stored in allocated heaps and protected from erosion, contamination or degradation. Different soil types should be stored separately and the length of time soils are stored should be minimised where possible. Soil excavation and mounds should avoid compaction where possible by making use of appropriate wide tracked vehicles and avoiding working on soil when it is wet. Appropriate drainage systems should be utilised on site to reduce soil erosion.
- ▶ Where possible, development should make best use of previously developed land.
- ▶ Careful consideration should be given during the site selection process to the avoidance of adverse impacts on sensitive land uses that may be affected by decommissioning activity.

### Site restoration and relinquishment

None identified.

## 2.4 Regulatory Framework

### International/European

The **European Thematic Strategy on Soil Protection (2006)** sets out the European Commission's strategy on soils and includes a proposal for an EU wide **Soils Directive**. The overall objective of the strategy is the protection and sustainable use of soil, based on the following guiding principles:

- ▶ Preventing further soil degradation and preserving its functions;
- ▶ When soil is used and its functions are exploited, action has to be taken on soil use and management patterns;
- ▶ When soil acts as a sink/receptor of the effects of human activities or environmental phenomena, action has to be taken at source; and
- ▶ Restoring degraded soils to a level of functionality consistent at least with current and intended use, thus also considering the cost implications of the restoration of soil.

The **EU Integrated Pollution, Prevention and Control (IPPC) Directive 2008/1/EC** defines the obligations to which industrial and agricultural activities with a high pollution potential must comply, through a single permitting process. It sets minimum requirements to be included in all permits, particularly in terms of



pollutants released. The aim of the Directive is to prevent or reduce pollution being released to the atmosphere, water and soil, as well as reducing the quantities of waste arising from industry and agriculture. In order to gain an IPPC permit, operators must demonstrate that they have systematically developed proposals to apply the 'Best Available Techniques' (BAT) to pollution prevention and control and that they address other requirements relevant to local factors.

The European Commission reviewed European legislation on industrial emissions in order to ensure clearer environmental benefits, remove ambiguities, promotes cost-effectiveness and to encourage technological innovation. The review led to the commission proposing and adopting a recast **Directive on Industrial Emissions (IED) 2010/75/EU** which came into force on 06 January 2011.

A number of other European Directives contribute indirectly to soil protection including on **Habitats 92/43/EEC**, **Air 2008/50/EC**, **Water 2000/60/EC** and **Nitrates 91/676/EEC**.

The **World Summit on Sustainable Development (2002)** in Johannesburg proposed broad-scale principles which should underlie sustainable development and growth including an objective on greater resource efficiency. Reusing previously developed land is a good example of resource efficiency of land.

The conservation of resources is one of the underlying objectives of the **European Spatial Development Perspective (ESDP) (1999)** the framework for policy guidance to improve cooperation among community sectoral policies. There also exists a range of legislation in relation to resources.

## UK

The **Environmental Protection Act 1990** defines within England, Scotland and Wales the legal framework for duty of care for waste, contaminated land and statutory nuisance.

The **Environment Act 1995** seeks to protect and preserve the environment and guard against pollution to air, land or water. The Act adopts an integrated approach to environmental protection and outlines where authorisation is required from relevant authorities to carry out certain procedures as well as outlining the responsibilities of the relevant authorities. The Act also amends the Environmental Protection Act 1990 with regard compulsory remediation of contaminated land. The Environmental Protection Act 1990 was also modified in 2006 to cover radioactivity, and then a further modification was made in 2007 to cover land contaminated with radioactivity originating from nuclear installations.

The **Wildlife and Countryside Act 1981** allows the designation of SSSIs for sites with geological importance.

The **Environmental Permitting Regulations (England and Wales) (2010)** consolidates a range of previous permits required for processes which might cause pollution. It covers water discharges, groundwater activities, radioactive substances, waste, mining and installations. It requires operators to obtain permits for some facilities, to register others as exempt and provides for ongoing supervision by regulators. The aim of the Regime is to:

- ▶ Protect the environment so that statutory and Government policy environmental targets and outcomes are achieved;
- ▶ Deliver permitting and compliance with permits and certain environmental targets effectively and efficiently in a way that provides increased clarity and minimises the administrative burden on both the regulator and the operators;
- ▶ Encourage regulators to promote best practice in the operation of facilities; and
- ▶ Continue to fully implement European legislation.

The **Pollution Prevention and Control (England and Wales) Regulations 2000** permit and regulate many industrial activities that may pollute our environment.

The **Overarching National Policy Statement (NPS) for Energy (EN-1)** sets out the Government's policy against which proposals for major energy projects will be assessed and decided on by the National Infrastructure Directorate (NID) within the Planning Inspectorate. The NPS identifies a range of generic impacts that may arise from energy development and associated policy including geological conservation

and land use. The **National Policy Statement for Gas Supply Infrastructure and Gas and Oil Pipelines (EN-4)** provides the primary basis for decisions on applications for gas supply infrastructure and gas and oil pipelines considered to be nationally significant in England and Wales.

## England

In June 2011, the Government outlined its vision for England's soils in the **Natural Environment White Paper (NEWP)**. This set a clear target that by 2030 all of England's soils will be managed sustainably and degradation threats tackled successfully, in order to improve the quality of soil and to safeguard its ability to provide essential ecosystem services and functions for future generations. As part of this vision, the Government committed to undertaking further research to explore how soil degradation can affect the soil's ability to support vital ecosystem services; and how best to manage lowland peatlands in a way that supports efforts to tackle climate change. This will inform our future policies and the direction of future action towards 2030.

The **Contaminated Land (England) Regulations 2006** sets out provisions relating to the identification and remediation of contaminated land. The **Environmental Damage (Prevention and Remediation) Regulations 2009** require action in response to the most significant cases of environmental damage including in respect of risks to human health from contamination of land.

The Government has reviewed the contaminated land regime in England for the first time since its introduction in 2000. Following the review, revised **Statutory Guidance has now been issued under Part 2A of the Environmental Protection Act 1990**. This revised Statutory Guidance while still taking a precautionary approach, allows regulators to make quicker decisions about whether or not land is contaminated under Part 2A. It also offers better protection against potential health impacts by concentrating on the sites where action is actually needed.

In 2009, Defra published **Safeguarding our Soils, A Strategy for England**. The vision in this strategy is that by 2030, all England's soils will be managed sustainably and degradation threats will be tackled successfully. The overall aspiration is that this will improve the quality of England's soils and safeguard their ability to provide essential services for future generations.

The **National Planning Policy Framework (2012)** (NPPF) sets out the Government's planning policy for the use of land in England. With specific regard to geology and soils, it states that "*the planning system should contribute to, and enhance, the natural and local environment by protecting and enhancing valued landscapes, geological conservation interests and soils; preventing both new and existing development from contributing to or being put at unacceptable risk from, or being adversely affected by unacceptable levels of soil pollution or land instability; and remediating and mitigating despoiled, degraded, derelict, contaminated and unstable land, where appropriate*" (paragraph 109). Local planning authorities should take into account the economic and other benefits of the best and most versatile agricultural land. Where significant development of agricultural land is demonstrated to be necessary, local planning authorities should seek to use areas of poorer quality land in preference to that of a higher quality (paragraph 112). The NPPF also states that planning policies should encourage the effective use of land by reusing land that has been previously developed, provided that it is not of high environmental value (paragraph 111).

**Planning Practice Guidance for Onshore Oil and Gas (2013)** provides advice on the planning issues associated with the extraction of hydrocarbons. It will be kept under review and should be read alongside other planning guidance and the NPPF. The guidance identifies a range of issues that mineral planning authorities may need to address. Those particularly relevant to land use, geology and soils include:

- ▶ Risk of contamination to land;
- ▶ Soil resources;
- ▶ The impact on best and most versatile agricultural land;
- ▶ Land stability/subsidence;
- ▶ Nationally protected geological and geomorphological sites and features; and
- ▶ Site restoration and aftercare.

## 3. Water and Flood Risk

### 3.1 Introduction

Water quality and resources within the context of this report are defined as inland surface freshwater and groundwater resources, and inland surface freshwater, groundwater, estuarine, coastal and marine water quality.

There are links between the water quality/resources and flood risk topic and a number of other study topics, in particular the effects and interactions of water quality and resources on biodiversity, population and human health.

### 3.2 Assessment of Effects

This section comprises of the review of the likely effects on water and flood risk arising from the potential activities that could take place in the six main stages of unconventional oil and gas exploration and production. **Table B3.1** presents a summary of the key stages of exploration, production and decommissioning.

Table B3.1 Unconventional Oil and Gas Exploration and Production Lifecycle and Key Activities

Stage	Activities
1	<p><b>Non-intrusive exploration</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Site identification, selection, characterisation;</li> <li>▶ Seismic surveys;</li> <li>▶ Securing of necessary development and operation permits.</li> </ul>
2	<p><b>Exploration drilling and hydraulic fracturing</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Pad preparation road connections and baseline monitoring;</li> <li>▶ Well design and construction and completion;</li> <li>▶ Hydraulic fracturing;</li> <li>▶ Well testing including flaring.</li> </ul>
3	<p><b>Production development</b>, including :</p> <ul style="list-style-type: none"> <li>▶ Pad preparation and baseline monitoring;</li> <li>▶ Facility construction and installation;</li> <li>▶ Well design construction and completion;</li> <li>▶ Hydraulic fracturing;</li> <li>▶ Well testing, possibly including flaring</li> <li>▶ Provision of pipeline connections</li> <li>▶ (Possibly) re-fracturing.</li> </ul>

Table B3.1 (continued) Unconventional Oil and Gas Exploration and Production Lifecycle and Key Activities

Stage	Activities
4	<p><b>Production/operation/maintenance</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Gas/oil production;</li> <li>▶ Production and disposal of wastes/emissions;</li> <li>▶ Power generation, chemical use and reservoir monitoring;</li> <li>▶ Environmental monitoring and well integrity monitoring.</li> </ul>
5	<p><b>Decommissioning of wells</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Well plugging and testing;</li> <li>▶ Site equipment removal;</li> <li>▶ Environmental monitoring and well integrity monitoring.</li> </ul>
6	<p><b>Site restoration and relinquishment</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Pre-relinquishment survey and inspection;</li> <li>▶ Site restoration and reclamation.</li> </ul>

Note: Exploration wells most usually move from Stage 2 to Stage 4, though some may be used for long-term production testing and some may be retained and their sites redeveloped as a production project. For the purposes of this review, the appraisal stage (a term commonly used in industry) spans Stages 2 and 3.

### Non-intrusive Exploration

Stage 1 of the unconventional oil and gas exploration and production lifecycle comprises of non-intrusive activities including site identification, site selection and the securing of regulator approval. These activities would be largely desk-based and in consequence, no effects on water resources or flood risk are anticipated.

Seismic testing would also be undertaken during this stage. Vibroseis is one of the most commonly used method of seismic survey and involves the employment of large vibrator unit vehicles as well as support vehicles for data recording.

Construction of temporary tracks/roads may be required to facilitate site access for vibrator unit vehicles (should vibroseis be undertaken). This may lead to a loss of permeability on site and increased surface water runoff. Runoff has the potential to collect and carry contaminants that may have been disposed of, or spilt, on access roads which could enter surface water bodies and groundwater. Typical contaminants would be likely to include: oil; fuels; and lubricating fluids. Additionally, increased runoff could result in flood risk offsite. However, exploration works would be short term and temporary and the area of access track would be relatively small such that any increase in surface water run-off would be negligible. It is also expected that any potentially significant increase in surface water runoff would be managed through standard construction measures (as appropriate) including, for example, the implementation of appropriate drainage (methods of surface water management are discussed further below) or the use of ground protection mats that are highly permeable and limit compaction. Further, as this stage would not involve significant vehicle movements, the risk of spillages is considered to be low.

In some cases, shot-hole survey techniques may be used. This involves the drilling of a hole with a small diameter for the insertion of explosives which are then detonated with the holes infilled after use. It is unlikely that shot-hole survey techniques would be carried out in close proximity to surface water bodies and therefore would not impact on water quality.

Overall, the potential for impacts on water quality (both surface and groundwater) and flood risk are considered to be negligible. In addition, no activities at this stage would be expected to result in the substantive consumption of water and therefore demand for water resources would be unchanged.

## Exploration drilling and hydraulic fracturing

### Surface Water Contamination

Pad preparation would involve the removal of vegetation and general groundworks to a site of approximately 1 hectare (10,000 sqm). It is likely that the well pad would be constructed from compacted aggregate laid on an impermeable membrane and geotextile layer. Surface water runoff would be collected and attenuated via perimeter ditches. There should be no connectivity between the runoff ditches from the well pad and any other surface water features adjacent to the well pad.

During this early construction work and in particular before interceptor drains have been constructed, there is a risk of runoff contaminated with hydraulic oil, nutrient phosphorous, nitrogen, fuels and lubricating oils entering water bodies, streams and groundwater following, for example, surface spills<sup>1</sup>. Off the pad, additional works including in respect of access roads and utility corridors may be required which could also cause runoff. These risks are generally shared with other large greenfield construction sites and the magnitude of any impacts will depend on the extent of a site, existing site conditions, construction practices and the severity and frequency of rainfall events. The New York State Department of Environment (NYSDEC in AEA, 2012) states that the larger footprint of high volume, multiple well pad installations as well as larger compounds associated with shale gas exploration and production increases the risk of runoff occurring (relative to conventional oil and gas installations) when assessed on a 'per site' basis. An AEA (2012) report<sup>2</sup> concerning the potential environmental and human health risks from unconventional oil and gas exploration and production activities, meanwhile, highlights that the increased scale of shale gas installations means that there is also greater potential for habitat impacts directly associated with stormwater runoff due to the potential for erosions of streams, sediment accumulation, water quality degradation and flooding. Although the likelihood of such events will depend on the extent of any connectivity between any stormwater runoff and receiving waters.

Surface spills/leaks of fracturing and other fluids including, for example, drilling muds/cuttings and flowback water have been reported by some as posing a greater risk of surface (and groundwater) contamination than the process of fracturing itself<sup>3</sup>. Sources of surface spills/leaks could include well 'blowouts' (any sudden and uncontrolled escape of fluids from a well to the surface), vehicle accidents or inadequate storage of hydraulic fracturing fluids and flowback water. In this respect, the Massachusetts Institute of Technology (MIT, 2011) reviewed 43 incidents of environmental pollution related to natural gas operations including shale gas and identified that, alongside groundwater contamination by natural gas or drilling fluid (47% of total incidents), surface spills of stored hydraulic fracturing fluids and flowback water (33% of total incidents) are the most widely reported causes of water contamination. Blowouts, meanwhile, represented only a small proportion (4%) of incidents<sup>4</sup>. Davies et al (2014) reported<sup>5</sup> that in the UK "between 2000 and 2013, the Environment Agency recorded nine pollution incidents involving the release of crude oil within 1 km of an oil

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<sup>1</sup> New York Department of Environment (2011) *Revised Draft Supplemental Generic Environmental Impact Statement On The Oil, Gas and Solution Mining Regulatory Program*. Available from <http://www.dec.ny.gov/data/dmn/rdsgeisfull0911.pdf> [Accessed June 2013].

<sup>2</sup> AEA (2012) *Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe. Report for European Commission DG Environment*. Available from <http://www.total.com/en/special-reports/shale-gas/environmental-challenges-201958.html> [Accessed October 2014].

<sup>3</sup> Groat and Grimshaw (2012) *Fact-based regulation for environmental protection in shale gas development*, Energy Institute, University of Texas: Austin. Available from: [http://cewc.colostate.edu/wp-content/uploads/2012/02/ei\\_shale\\_gas\\_regulation120215.pdf](http://cewc.colostate.edu/wp-content/uploads/2012/02/ei_shale_gas_regulation120215.pdf) [Accessed September 2013].

<sup>4</sup> Massachusetts Institute of Technology (2011). *Study on the Future of Natural Gas*. Available from <http://mitei.mit.edu/publications/reports-studies/future-natural-gas> [Accessed November 2014].

<sup>5</sup> Davies, R.J. Almond, S. Ward, R.S. Jackson, R.B. Adams, C. Worrall, F. Herringshaw, L. Gluyas, J. Whitehead, M.A. (2014) *Oil and gas wells and their integrity: Implications for shale and unconventional resource exploitation*, Marine and Petroleum Geology. Available from <https://www.dur.ac.uk/resources/refine/Publishedversion.pdf> [Accessed April 2015].

or gas well. The records are not clear as to whether the incidents were due to well integrity failure, problems with pipework linked to the well, or other non-well related issues”.

An analysis of notices of violations (NOVs) from the Pennsylvania Marcellus Shale industry between January 2008 and August 2011 by Considine *et al* (2012)<sup>6</sup> highlights that surface spills generally did not have major environmental impacts as they were often small, took place on the well pad and were contained within the boundaries of well pad sites. Where major environmental events occurred, the impacts were often mitigated. The report also highlights that water contamination events from spills that impact bodies of water directly were in most case minor, although they varied by the amount of fluids spilled and the sensitivity of the receiving environment.

A report by Public Health England (2014) concerning the potential health impacts of shale gas extraction<sup>7</sup> concludes that the risk of accidents from surface activities such as the handling and processing of fracturing fluids can be reduced by implementing control measures and best practices, the adoption of accident management plans and through strict enforcement. A review of hydraulic fracturing by the Royal Academy of Engineering and Royal Society (2012)<sup>8</sup> highlights that in the UK, installing impermeable site lining is typically a condition of planning permissions such that surface water run-off is likely to be captured in drainage channels surrounding the site. Additionally, an environmental permit is required in the UK to discharge contaminated surface water runoff that will only be issued if it is not feasible to stop the contamination at source and the contamination will not pollute the receiving water<sup>9</sup>.

## Groundwater Contamination

### *Composition of Fracturing Fluid*

During hydraulic fracturing, water is injected into the well at high pressures causing fractures in the rock. In order to induce and maintain permeability, and generate productive fractures, chemicals are added to the water to create hydraulic fracturing fluid, the composition of which is dependent on site specific conditions including the underlying geology<sup>7</sup>.

Evidence from the United States (US) suggests that up to 750 chemicals were used between 2005 and 2009 in shale gas drilling throughout the US. Typically, fracturing fluid includes<sup>10</sup>:

- ▶ Water: about 98-99% of total volume;
- ▶ Proppant: about 1-1.9% of total volume, usually sand or ceramic particles;
- ▶ Friction reducer: about 0.025% of total volume, usually polyacrylamide; and
- ▶ Disinfectant: about 0.005% to 0.05%, usually glutaraldehyde, quaternary amine or tetrakis hydroxymethyl phosphonium sulphate;
- ▶ Surfactants: 0.05-0.2%;
- ▶ Gelation chemicals (thickeners): usually guar gum or cellulose polymers;

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<sup>6</sup> Considine, T. Waterson, R. Considine, N. Martin, J. (2012) *Environmental Impacts During Marcellus Shale Gas Drilling: Causes, Impacts, and Remedies*. Available from <http://cce.cornell.edu/EnergyClimateChange/NaturalGasDev/Documents/UBSRSI-Environmental%20Impact%20Report%202012.pdf> [Accessed April 2015].

<sup>7</sup> Public Health England (2014) *Review of the Potential Health Impacts and Exposures to Chemical and Radioactive Pollutants as a Result of Shale Gas Extraction*. Available from [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/329744/PHE-CRCE-002\\_for\\_website\\_protected.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/329744/PHE-CRCE-002_for_website_protected.pdf) [Accessed April 2015].

<sup>8</sup> Royal Academy of Engineering and Royal Society (2012) *Shale Gas in the UK, A Review of Hydraulic Fracturing*. Available from <https://royalsociety.org/policy/projects/shale-gas-extraction/report/> [Accessed April 2015].

<sup>9</sup> Environment Agency (2013) *Onshore oil and gas exploratory operations: technical guidance Consultation Draft*.

<sup>10</sup> King (2012) *Hydraulic Fracturing 101*. Journal of Petroleum Technology, April 2012 p34-42. Available from [http://fracfocus.org/sites/default/files/publications/hydraulic\\_fracturing\\_101.pdf](http://fracfocus.org/sites/default/files/publications/hydraulic_fracturing_101.pdf) [Accessed April 2015].



- ▶ Scale inhibitors: phosphate esters or phosphonates;
- ▶ Hydrochloric acid may be used in some cases to reduce fracture initiation pressure; and
- ▶ Corrosion inhibitor, used at 0.2% to 0.5% of acid volumes, and only used if acid is used.

In the UK, Cuadrilla has released details of the composition of fracturing fluid used in hydraulic fracturing at Preese Hall, Lancashire<sup>11</sup>. Results from the Preese Hall-1 Well show that over six fracturing episodes, the following volumes of substances were used as fracturing fluid:

- ▶ 8,399m<sup>3</sup> of fresh water (sourced from the region's water supply company, United Utilities);
- ▶ 462 metric tons of sand (sourced from Sibelco UK);
- ▶ 3.7m<sup>3</sup> of friction reducer (polyacrylamide emulsion in hydrocarbon oil); and
- ▶ 4,252 grams of chemical tracer (consisting of water and sodium salt).

The composition of chemical additives used in fracturing fluids and the disclosure of this information by operators has been a particularly controversial issue in the US. When a Congressional Committee launched an investigation into products used between 2005 and 2009, it found the use of toxic and carcinogenic substances, such as benzene and lead<sup>12</sup>. However, it is understood that some US states have adopted disclosure regulations for chemicals added to fracturing liquids, as well as there being Federal interest in this issue<sup>13</sup>.

In the UK, operators are required to disclose the full details of chemicals to be used during the fracturing process to the relevant regulator, including a brief description of the chemical's purpose and any hazards it may pose to the environment (subject to appropriate protection for commercial sensitivity). Under United Kingdom Onshore Oil and Gas (UKOOG) guidelines<sup>14</sup> operators are also expected to disclose all chemicals by name, volume and concentration on their website and assess the potential risks from the use of fracturing fluids and additives and create risk management plans (fracturing programmes) to effectively manage the additives and make the process used to develop specific plans available for public disclosure. The regulator will then also assess whether an additive is hazardous (i.e. substances or groups of substances that are toxic, persistent and liable to bioaccumulate, and other substances or groups of substances which give rise to an equivalent level of concern, reflecting the definition set out in the Water Framework Directive) or a non-hazardous pollutant using a methodology that follows the requirements of the Groundwater Daughter Directive and under technical guidance, according to the specific site and local hydrogeological conditions<sup>15</sup>. Allowing the use of a chemical at one site does not automatically mean that it will be permitted for use elsewhere as the environmental risks may be different, for example, due to local geological conditions. An example of the implementation of this regulation in England includes a proposed site at Balcombe, Sussex where, following the submission of a list of chemicals for use during fracturing, the regulator (the Environment Agency) prevented the operator (Cuadrilla) from using antimony trioxide due to its potential to contaminate groundwater<sup>16</sup>.

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<sup>11</sup> Cuadrilla (2013) *Composition of Components in Bowland Shale Fracturing Fluid for Preese Hall-1 Well*. Available from <http://www.cuadrillaresources.com/what-we-do/hydraulic-fracturing/fracturing-fluid/> [Accessed October 2014].

<sup>12</sup> US House of Representatives Committee on Energy and Commerce in 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*. Available from <http://www.ciwem.org/policy-and-international/current-topics/energy.aspx> [Accessed April 2015].

<sup>13</sup> SEAB (2011) in AEA (2012).

<sup>14</sup> UKOOG (2013) *UK Onshore Shale Gas Well Guidelines: Exploration and appraisal phase*. Available from <http://www.ukoog.org.uk/images/ukoog/pdfs/ShaleGasWellGuidelines.pdf> [Accessed November 2014].

<sup>15</sup> SEPA, NIEA, NRW and EA (2013) *Technical Guidance WM2: Hazardous waste Interpretation of the definition and classification of hazardous waste* (3rd Edition 2013). Available from [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/369810/LIT\\_5426\\_WM2.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/369810/LIT_5426_WM2.pdf) [Accessed April 2015].

<sup>16</sup> The Guardian (2013) *Fracking firm was barred from using chemical, Balcombe meeting told*. 10 October 2013. Available from <http://www.theguardian.com/environment/2013/oct/10/fracking-chemical-balcombe-meeting> [Accessed November 2014].

A review of research has identified that the main risk of groundwater contamination is commonly considered to be the leakage of fracturing fluid as a result of inadequacies in well cementing or due to the movement of contaminants through existing faults or porous rocks to groundwater resources. In addition, other substances (trace elements, NORM and organic material) may be contained in flowback water which, if not controlled, could cause contamination. These risks are considered in-turn below.

### Well Integrity

The causes of groundwater contamination associated with well design, drilling, casing and cementing generally relate to the quality of the well structure.<sup>17</sup> 'Well integrity' refers to preventing hydrocarbons from leaking out of the well by isolating it from other subsurface formations. The Royal Academy of Engineering and Royal Society (2012)<sup>18</sup> note that well failure may arise from poor well integrity resulting from:

- ▶ Subsurface blowout: which can occur during the original drilling of a well, during the hydraulic fracturing process or as a result of the fracturing of adjacent wells;
- ▶ Annular leak: poor cementation allows contaminants to move vertically through the well either between casings or between casings and rock formations; and
- ▶ Radial leak: casing failure allows fluid to move horizontally out of the well and migrate into the surrounding rock formations.

Blowout events are uncontrolled in nature and are therefore innately dangerous<sup>6</sup>. An investigation by the United States Environment Protection Agency (US EPA, 2012) identified 'blowouts' to be one of the main causes of pollution incidents (alongside surface spills)<sup>19</sup>, although research by the MIT (2011) and Considine *et al* (2012) indicates that blowouts represent only a small proportion of incidents. In this respect, The Royal Academy of Engineering and Royal Society (2012) highlight that blowouts are rare and that whilst some shales can be over-pressurised, blowout is unlikely because shale has very low permeability.

Contamination and migration of methane into aquifers due to unsatisfactory cementing of wells has also been reported<sup>20</sup>. For example, a US EPA<sup>21</sup> investigation into groundwater water quality complaints in Pavillion, Wyoming where hydraulic fracturing occurred at depths as shallow as 372 m below ground surface found that the observed contamination was linked to inadequate vertical well casing lengths and a lack of well integrity. The MIT (2011) review found that almost 50% of the 43 incidents of environmental pollution related to natural gas operations (including shale) reviewed as part of the study were related to the contamination of groundwater as a result of drilling operations. The most common cause of such contamination appeared to be inadequate cementing or casing into wellbores, allowing natural gas to migrate into groundwater zones as it was extracted<sup>4</sup>.

The risk of contamination associated with blowouts can be reduced through the installation of a blowout preventer during drilling to automatically shut down fluid flow in the wellbore should there be any sudden or uncontrolled escape of fluids. However, there have been reports of blowout preventer (and wellhead) failure. For example, a well in North Dakota lost control after a blowout preventer failed, leaking between 50 and 70 barrels (2,100 to 2,940 gallons) per day of hydraulic fracturing fluid and 200 barrels (8,400 gallons) per day of oil<sup>22</sup>.

Measures to address the risk of well failure, meanwhile, include:

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<sup>17</sup> AEA (2012).

<sup>18</sup> Royal Academy of Engineering and Royal Society (2012).

<sup>19</sup> US EPA (2012) *Study of the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources. Progress Report, December 2012*. Available from <http://www2.epa.gov/sites/production/files/documents/hf-report20121214.pdf> [Accessed November 2014].

<sup>20</sup> Secretary of Energy Advisory Board (2011a) *Shale gas production sub-committee: 90 day report*, Report to US Department of Energy, 18 August 2011. Available from <http://www.shalegas.energy.gov/> [Accessed April 2015].

<sup>21</sup> US EPA (2011c) *Investigation of Ground Contamination near Pavillion, Wyoming: DRAFT*. Available from <http://www.epa.gov/ord> [Accessed April 2015].

<sup>22</sup> Atkin, E. (2014) *Fracking Well Blowout Causes Oil And Chemical Wastewater Spill In North Dakota (Updated)*. Available from <http://thinkprogress.org/climate/2014/02/17/3299221/north-dakota-blowout/> [Accessed April 2015].

- ▶ Prior to the installation of casings, wellbore testing to establish the presence of naturally occurring (gamma) radiation, measure the density and porosity of the formation and measure the diameter of the wellbore so that casings are installed accurately;
- ▶ Testing of cement prior to use to ensure that the properties meet the requirements of well design;
- ▶ Installation of a cement bond log to test the equality of the cement bond between casings and formations. If any casings do not meet specifications then remedial works can then be undertaken;
- ▶ Pressure testing of well casing to ensure the mechanical integrity and strength prior to further drilling; and
- ▶ Formation pressure testing following drilling.<sup>23</sup>

The Royal Academy of Engineering and Royal Society (2012) highlight that despite the implementation of cementation testing, wells can still leak over time due to cement shrinkage. Their report points to research on best practice for well construction in the US which has identified that factors affecting leakage include the number of well casings and the extent to which these are cemented. Cement needs to completely surround casings to provide a continuous annular seal between casings and the rock formation, as well as between casings. In terms of the UK, the report notes that it is standard practice to have three strings of casing with at least two (intermediate and production casing) passing through and thereby isolating any freshwater zones. It is also best practice in the UK to cement casings to the surface. Cement bond logs (CBL's) can be used to test the quality of cement bond between casings and formation before subsequent sections are drilled. Casings can be similarly tested and repaired following each fracturing stage. Well integrity is inferred during operations by annular pressures, as well as testing seals and valves at casing joints. Additionally, the use of monitoring wells and the sampling of near surface aquifers to detect methane can indicate groundwater (and surface water) contamination and monitor well integrity. Tracers (usually synthetic organic compounds) can also be added to fracturing fluid and used to detect water contamination, although the proprietary nature of these chemicals, combined with their instability in the environment, limits their usefulness<sup>24</sup>. However, a range of new technologies are being developed in this field in order to enhance the detection of fracturing fluids including, for example, inert DNA-based tracers, nanoparticles and geochemical tracers<sup>25</sup>.

The regulatory framework can also provide an important role in ensuring well integrity. In England, a range of regulatory measures and guidance are in place to reduce the risk of well failure affecting groundwater quality. The Environment Agency requires the adoption of good practice in groundwater protection, and the delineation of groundwater including any local aquifers as part of the well design and fracturing risk assessment process. The Offshore Installations and Wells (Design and Construction, etc) Regulations 1996, meanwhile, ensure that the Health and Safety Executive have to be notified of all drilling operations for oil or gas, and have an opportunity to scrutinise the well design and operational plan before exploration activities begin. The regulations specify that operators should ensure that there can be no unplanned escape of fluids from the well and require wells to be examined by an 'independent and competent person' ('well examiner'). The examiner can request the results of any well integrity tests and raise any health and safety concerns with the operator, although there is currently no legislative requirement for well integrity testing to be undertaken in the UK. These requirements have been reinforced by an amendment to the Petroleum Act 1998, required by Section 50 of the Infrastructure Act 2015 that requires appropriate arrangements to have been made for the independent inspection of the integrity of the relevant well. Evidence that is cited that appropriate arrangements have been made includes a certificate given by the Health and Safety Executive that it:

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<sup>23</sup> API (2009) in Royal Academy of Engineering and Royal Society (2012).

<sup>24</sup> Warner, R. Darrah, T.H. Jackson, R.B. Millot, R. Kloppmann, W. Vengosh. A. (2014) *New Tracers Identify Hydraulic Fracturing Fluids and Accidental Release from Oil and Gas Operations*, in *N Environmental Science & Technology*, Oct. 20, 2014. Available from <http://pubs.acs.org/doi/abs/10.1021/es5032135> [Accessed April 2015].

<sup>25</sup> Revkin, A.C. (2013) *Ideas to Watch in 2013: Traceable Gas-Drilling Fluids*. Available from <http://dotearth.blogs.nytimes.com/2013/01/08/ideas-to-watch-in-2013-traceable-frackin-fluids/> [Accessed November 2014].

- ▶ Has received a well notification under regulation 6 of the Borehole Sites and Operations Regulations 1995;
- ▶ Has received the information required by regulation 19 of the Offshore Installations and Wells (Design and Construction, etc.) Regulations 1996; and
- ▶ Has visited the site of the relevant well.

The industry has, developed guidelines aimed at helping oil and gas well operators incorporate the latest developments in good practice across the full life cycle of well integrity operations<sup>26</sup>.

On completion of drilling, the process of hydraulic fracturing and induced seismicity could itself damage the well casing and affect well integrity. Department of Energy and Climate Change (DECC) licensing requires seismic monitoring to assess likely faults and thus potential impacts on well integrity using a traffic light monitoring system<sup>27</sup>.

#### Mobilisation of solutes or methane

AEA (2012) highlights that hydraulic fracturing can affect the mobility of naturally occurring substances in the subsurface, particularly in the hydrocarbon-containing formation. A concern centres on if fractures extend beyond the target formation and reach aquifers, contaminants could potentially migrate into drinking water supplies.

The pollution of groundwater associated with unconventional oil and gas exploration and production has been widely reported in the US, although there is little evidence to suggest that this is as a direct result of the hydraulic fracturing process. Warner *et al* (2012) found that in particular locations, methane and fugitive gases from deep geological layers can migrate upwards into shallow strata through natural pathways<sup>28</sup>. However, further work by Warner *et al* (2013) comprising an assessment of groundwater impacts in the Fayetteville shale development in Arkansas<sup>29</sup> found no direct evidence of contamination in shallow drinking water aquifers associated with natural gas extraction, for natural hydraulic connectivity between deeper formations and shallow aquifers or for gas contamination in groundwater wells located near shale gas sites. This suggests that local geological conditions may influence the potential for contamination<sup>7</sup>.

Initial findings of research being undertaken by the US EPA (2012) suggests that the most important parameters and conditions affecting the migration of contaminants from target formations to groundwater are: matrix permeability; fracture permeability; distance between the aquifer and the target formation; and the pressure regimes in the aquifer and the target formation. AEA (2012) highlight that a separation of the order of 600 m would result in a remote risk of properly injected fluid resulting in contamination of potable groundwater. The maximum length of some fractures has been reported to be 588 m, although the majority of fractures are less than 100 m and this compares to the vertical height of most of natural fractures as between 200-400m<sup>30</sup>.

The Royal Academy of Engineering and Royal Society (2012) summarised the findings of a study which compared fracture growth and depth of overlying water sources in four major US shale formations between 2001 and 2010. Seismic data indicated that the minimum vertical distances between the bottom of the

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<sup>26</sup> API (2009) *API Guidance Document HF1 – ‘Hydraulic Fracturing Operations – Well Construction and Integrity Guidelines and Oil and Gas UK (2014), OP095 - Well Life Cycle Integrity Guidelines, Issue 2, June 2014 (2014)*. Available from [http://www.api.org/policy-and-issues/policy-items/hf/api\\_hf1\\_hydraulic\\_fracturing\\_operations.aspx](http://www.api.org/policy-and-issues/policy-items/hf/api_hf1_hydraulic_fracturing_operations.aspx) [Accessed April 2015].

<sup>27</sup> The Chartered Institution of Water and Environmental Management (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*. Available from <http://www.ciwem.org/policy-and-international/current-topics/energy.aspx> [Accessed April 2015].

<sup>28</sup> Warner NR, Jackson RB, *et al* (2012) *Geochemical evidence for possible natural migration of Marcellus formation brine to shallow aquifers in Pennsylvania*. *Proc Natl Acad Sci USA* 109(30): 11961–6.

<sup>29</sup> Warner NR, Kresse TM, *et al* (2013). *Geochemical and isotopic variations in shallow groundwater in areas of the Fayetteville Shale development, north-central Arkansas*. *Appl Geochem* 35: 207–20.

<sup>30</sup> Davies RJ, Mathias S, Moss J, Hustoft S and Newport L (2012) *Hydraulic fractures: How far can they Go?* Marine and Petroleum Geology in press. Available from <http://refine.org.uk/media/4886/hydraulicfractures.pdf> [Accessed April 2015].

aquifer and the top of the fracture varied between 1200m and 6,000m, depending on the formation. From a European perspective, the risk of contamination as a result of the hydraulic fracturing process is widely regarded to be low due to the likely distance between the fractures and aquifers. AEA (2012) note that most but not all shale gas reservoirs in Europe exhibit a separation of more than 600 m between the depth of shale gas formations and aquifers. However, where hydraulic fracturing takes place at shallower depths the risk may be greater.

Within the UK, the amendments to the Petroleum Act 1998 arising from the Infrastructure Act 2015 include a commitment that a well consent will not be issued unless it imposes a condition which prohibits associated hydraulic fracturing from taking place in land at a depth of less than 1000 metres. It will also require that the level of methane in groundwater has, or will have, been monitored in the period of 12 months before the associated hydraulic fracturing begins. The Royal Academy of Engineering and Royal Society (2012) stress that it is within an operator's interest to ensure that fractures propagate in a controlled manner and remain within the target shale formation as excessive or uncontrolled growth would be uneconomic. Their report identifies a number of methods to monitor fracture growth including the use of chemical tracers, tiltmeters and microseismic monitoring. Additionally, in the UK, environmental regulators do not currently permit fracturing below freshwater aquifers. In England and Wales, the Environment Agency has adopted the following policy in their Groundwater Protection Principles and Practice document:

*"We will object to [oil and conventional gas exploration and extraction] within SPZ<sup>31</sup>. Outside SPZ1, we will also object when the activity would have an unacceptable effect on groundwater.*

*Where development does proceed, we expect BAT to protect groundwater to be applied where any associated drilling or operation of the boreholes passes through a groundwater resource. Elsewhere, established good practice for pollution prevention should be followed".*

The requirement that hydraulic fracturing will not take place within protected groundwater source areas is repeated in amendments to the Petroleum Act 1998 arising in the Infrastructure Act 2015.

The Environmental Agency should also be informed if any activity could involve the discharge of pollutants into groundwater. A permit application will be required to include:

- ▶ A conceptual model showing the hydrogeological relationship between the zone of interest and any overlapping or adjacent aquifers;
- ▶ The method of well construction, including details of the casing and grouting;
- ▶ Information on how the integrity of the casing is to be tested;
- ▶ Information on where the well stimulation fluid is expected to travel; and
- ▶ Details of the liquids to be injected, water use and disposal of effluents.

In Scotland, exploration would be likely to require a permit from the Scottish Environment Protection Agency (SEPA), under The Water Environment (Controlled Activities) (Scotland) Regulations 2011 (CAR) regime. For example, application for a CAR complex licence would be required to allow a deep borehole (>200m) to be constructed. The resulting CAR licence would include conditions for maintenance and/or monitoring to ensure that the borehole does not result in contamination of groundwater. The application would need to be accompanied by a risk assessment and details of chemicals in drilling fluids.<sup>32</sup>

UKOOG (2013) guidelines, meanwhile, suggest operators develop a Hydraulic Fracturing Programme (HFP) "that describes the control and mitigation measures for fracture containment and for any potential induced seismicity". HFPs should:

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<sup>31</sup> Source Protection Zone (SPZ) are those areas close to drinking water sources where the risk associated with groundwater contamination is greatest. SPZ1 extent is defined by 50-day travel time of groundwater from the borehole and a minimum 50 metre radius.

<sup>32</sup> SEPA (2012) *Regulatory Guidance: Coal bed methane and shale gas*. Available from [http://www.sepa.org.uk/customer\\_information/energy\\_industry.aspx](http://www.sepa.org.uk/customer_information/energy_industry.aspx) [Accessed September 2013].



- ▶ Include the proposed design of the fracture geometry including target zones, sealing mechanism and the location of aquifers, so as not to allow fracturing fluids to migrate to groundwater;
- ▶ Contain performance standards to characterise the basis for the sealing mechanism and to demonstrate that adequate control measures will be implemented (such as microseismic and tiltmeter monitoring of hydraulic fracture growth); and
- ▶ Document and reference research relating to faults that might impact hydraulic fracturing to demonstrate that fracturing fluids cannot migrate, via faults, beyond the designated fracturing zones(s).

This has subsequently been proposed by Cuadrilla in respect of a temporary shale gas exploration site in Lancashire, England.

Notwithstanding the above, there is a recognised need in the UK for a better understanding of shales and overlying geology to support site selection, design and monitoring. In this respect, the British Geological Survey (BGS) has published mapping which shows the depth to each shale gas and oil source rock below principal groundwater aquifers in England and Wales<sup>33</sup>. The BGS is also preparing a national baseline survey of methane focussing on areas where aquifers are underlain by shale units that may be exploited for shale gas<sup>34</sup>.

### Surface Water Spills

Public Health England's (2014) report on the health impacts of shale gas highlights, based on US experience, that the greatest risk of contamination of water sources is posed by the potential for surface spills. The assessment of the potential sources of surface water spills during this stage has already been presented above.

An analysis of groundwater BTEX (benzene, toluene, ethylbenzene and xylene) following surface spills of processed water or crude oil associated with hydraulic fracturing operations by Gross *et al* (2013) identified levels that exceeded US national drinking water maximum contaminant levels (MCLs) for a number of samples, although the findings highlighted that remediation actions taken by the operators after the spill were effective in reducing these concentrations.

### Waste Water Treatment and Disposal

Waste water treatment and disposal (particularly of flowback water) and its potential effects on water quality are dealt with in the section concerning waste (**Appendix B.6**).

### Water Consumption

Hydraulic fracturing is a water intensive process. Estimates of water use during hydraulic fracturing vary significantly and will ultimately depend on local geological characteristics including, for example, the depth of the shale and thickness of the overlying geology. The SEA of the 14<sup>th</sup> Onshore Oil and Gas Licensing Round in the UK (AMEC, 2013)<sup>35</sup> assumed that between 10,000 cubic metres and 25,000 cubic metres of

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<sup>33</sup> British Geological Survey (undated) *Aquifers and shales*. Available from <http://www.bgs.ac.uk/aquifers-shales/> [Accessed November 2014].

<sup>34</sup> British Geological Survey (undated) *National methane baseline survey of UK groundwaters*. Available from <http://www.bgs.ac.uk/research/groundwater/shaleGas/methaneBaseline/home.html> [Accessed November 2014].

<sup>35</sup> AMEC (2013) *Strategic Environmental Assessment for Further Onshore Oil and Gas Licensing: Environmental Report*. Prepared on behalf of the Department of Energy and Climate Change which drew on the AEA 2012 report which noted that horizontal shale gas wells typically use 10,000 to 25,000 m<sup>3</sup> water per well, based largely on US analysis. The AEA report also summarised the limited evidence from activity in Europe, which gave a range: 9000 – 29,000 m<sup>3</sup>/well (from Cuadrilla in Holland); 1,600m<sup>3</sup> (Halliburton at Lubocino-1 well in Poland); 7,000m<sup>3</sup> – 8,000m<sup>3</sup> (the Danish Energy Agency). Industry estimates suggest ranges of 10,000m<sup>3</sup> to 20,000m<sup>3</sup> (<http://www.total.com/en/energies-savoir-faire/petrole-gaz/exploration-production/secteurs-strategiques/gaz-non-conventionnels/focus-gaz-de-schiste/environmental-challenges>).



water would be required per well during Stage 2 of the unconventional oil and gas exploration and production lifecycle. This is broadly consistent with estimates relating to water use during the hydraulic fracturing of four wells associated with a proposed temporary shale gas exploration site in Lancashire, England which is anticipated to be in the region of 90,000 cubic metres over a 2-3 year period.

Comparisons of water consumption between unconventional oil and gas production and other users have been made. New York State Department of Environmental Conservation (NYSDEC in AEA, 2012) for example, highlights that water requirements associated with hydraulic fracturing would be expected to be low (less than 0.25% of the total water resource use in New York State based on the peak forecast usage rate for the oil and gas industry in the state). Moor (2012)<sup>36</sup>, meanwhile, highlights that water consumption of 19,000m<sup>3</sup> is the same amount of water needed: to water a golf course or a month; to run a 1GW coal fired power plant for 12 hrs; or the amount lost to leaks in the North West of England every hour. Moor (2012) also notes that the rate of abstraction is important in that water is required only periodically as hydraulic fracturing is not a continuous process.

Whilst the volume of water associated with hydraulic fracturing process is *relatively* low, effects on water resource availability could be significant locally. AEA (2012) identify a number of potential effects that could occur as a result of water consumption associated with hydraulic fracturing activities<sup>37</sup>:

- ▶ Reduced stream flow affecting the availability of resources for downstream use, such as for public water supply;
- ▶ Adverse impacts on aquatic habitats and ecosystems arising from, for example, degradation of water quality, reduced water quantity, changes to water temperature, oxygenation and flow characteristics, including the effects of sediment and erosion under altered responses to stormwater runoff;
- ▶ Interplay with downstream dischargers, affecting their ability to discharge where limits are related to stream flow rate, or the overall concentration of pollutants where discharge rates remain unaffected; and
- ▶ Impacts on water quality, affecting the use which can be made of surface waters.

The SEA of the 14<sup>th</sup> Onshore Oil and Gas Licensing Round in the UK (AMEC, 2013) identified several factors that would need to be taken into consideration in order to determine the significance of water consumption on water resources. These include:

- ▶ The timing of the consumption of the water (i.e. summer, winter, etc);
- ▶ The possibility of cumulative effects occurring either as a result of multi well pads or several pads in one area;
- ▶ Existing water resources and the volume of water presently extracted by existing users in that area; and
- ▶ The volume of waste water than can be recycled and used as fresh injection fluid.

These findings support those of Broderick *et al* (2011) who highlight that local effects could be much more significant in areas with low water resource availability, particularly in the longer term and taking into account the effects of climate change and increasing water demand<sup>38</sup>. In the US, the USEPA (in AEA, 2012) has highlighted stakeholder concerns regarding high volume withdrawals from small streams in the headwaters of watersheds supplying drinking water in the Marcellus Shale area which may lead to the need for engineering solutions for reduced aquifer levels. Further effects of reduced water levels cited in this report include:

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<sup>36</sup> Moore (2012) *Gas Works? Shale gas and its policy implications*, The Policy Exchange. Available from <http://www.policyexchange.org.uk/images/publications/gas%20works%20-%20feb%2012.pdf> [Accessed September 2013].

<sup>37</sup> AEA (2012).

<sup>38</sup> Broderick J., *et al* (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/sites/default/files/coop\\_shale\\_gas\\_report\\_update\\_v3.10.pdf](http://www.tyndall.ac.uk/sites/default/files/coop_shale_gas_report_update_v3.10.pdf) [Accessed April 2015].

- ▶ The potential for chemical changes to aquifer water, including altered salinity, as a result of the exposure of naturally occurring minerals to an oxygen rich environment;
- ▶ Stimulated bacterial growth, causing taste and odour problems in drinking water; and
- ▶ Upwelling of lower quality water or other substances (e.g. methane – shallow deposits) from deeper and subsidence or destabilization of geology.

The AEA (2012) report also highlights that, following low rainfall, water withdrawal permits for shale gas well development in the Susquehanna River Basin in Pennsylvania were temporarily suspended.

The choice of a water supply will depend on a number of factors, including (NYSDEC in AEA, 2012):

- ▶ Distance from, and location of, the source relative to the point of use. The costs of transporting large quantities of water is a function of distance and travel times. Planning permissions may control the number of vehicle movements and routes to be taken.
- ▶ Available quantity and whether a single source can supply the required volume or whether multiple sources across a well field are required.
- ▶ Reliability. Shale gas operations require access to water year round and therefore a source that is always available is a more valuable one which may not be available during e.g. during periods of drought. However, mitigation measures (e.g. reservoirs) can be used.
- ▶ Accessibility. The choice of a water supply may depend on whether locations where water is available are readily accessible.
- ▶ Quality of water. The composition of the water will affect the efficacy of the additives and equipment used. Freshwater will be preferred over other sources.
- ▶ Licensing. Licences will be required for abstractions and these need to be obtained with acceptable conditions.
- ▶ Cost. Sources that have a higher associated cost to acquire, treat, transport, licence, are less desirable.

From a UK perspective, should water be supplied from a mains supply (either nearby to the site or tankered from a supply nearby), it would be the responsibility of the water utility company to ensure that the extra demand accords with the conditions of their water resource plans and abstraction licences. In considering any licensed abstraction application, the responsible statutory body would also consider the effects on flows, the effects on other water users, the impacts on biota, and demands during low flow periods. Licenses would only be granted where such effects are acceptable to the regulator. Taking these regulatory requirements in to account, the SEA of the 14th Onshore Oil and Gas Licensing Round in the UK (AMEC, 2013) concluded that the risk of significant adverse effects on water resource availability as a result of hydraulic fracturing would be low. Further, the SEA highlights that Water UK, which represents the water industry, and UKOOG have signed a Memorandum of Understanding (MoU) which ensures their respective members will cooperate throughout the shale gas exploration and extraction process in order to minimise adverse effects on water resources and the environment. Under the MoU, members of UKOOG and Water UK will undertake timely consultation and discussion in order to identify and resolve risks around water resource availability. It is also noteworthy that the industry in Europe is not expected to be at substantial scale before the 2020s. This will allow time for any necessary new investment in water supply infrastructure.

Outside the regulatory process, effects on water resource availability may be mitigated through the recycling and reuse of flowback water (the fractured fluid injected into the shale rock during hydraulic fracturing which returns to the surface through the drilled well). Reported recycling rates in the US vary between 10% and 77%<sup>39</sup>. In the case of a proposed temporary shale gas exploration site in Lancashire, England, the operator (Cuadrilla) has indicated that the reuse of flowback water will reduce water requirements by approximately 20%.

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<sup>39</sup> AEA (2012) pp 16 which noted studies identifying fresh water as comprising 80-90% of the water used as well as studies reporting up to 77% of wastewater generated from the Pennsylvania Marcellus Shale being recycled.

Water demand could also be reduced through the adoption of waterless fracturing technologies including nitrogen gas fluids such as gels and carbon dioxide and nitrogen gas foams<sup>8</sup>. There are examples of waterless technologies being deployed in the US including, for example, at the Utica trial wells in Ohio which used liquid petroleum gas<sup>40</sup>.

Overall, when compared with other activities, water demand associated with hydraulic fracturing is relatively low. However, in already water stressed environments effects on water resource availability could nonetheless be significant, particularly if multiple developments come forward within a catchment. Notwithstanding, regulation such as that employed in the UK could help to ensure that water demand associated with hydraulic fracturing does not place undue pressure on water resource availability.

### Flood Risk

As noted above, pad preparation would involve the removal of vegetation and general groundworks to a site and the laying of an impermeable surface to reduce the risk of contaminants leaking into soil/groundwater. This surface would change the natural drainage patterns of the site and could result in the increase of flooding off site as runoff rates may be faster and the natural water storage the site provides would be lost. This risk is similar to other large (particularly greenfield) construction sites.

Sites located within areas of flood risk may also be susceptible to flooding. The SEA of the 14th Onshore Oil and Gas Licensing Round in the UK (AMEC, 2013) highlights that, where sites are in flood risk areas, the following risks may arise:

- ▶ The well may become inundated with flood water and disrupt drilling or cause damage to the casing;
- ▶ Plant and equipment may be damaged;
- ▶ Storage tanks may become damaged or suffer a loss of power and may release contaminants into the flood water; and
- ▶ Hydrocarbons may be released and cause pollution or lead to explosions or fires.

In the UK, site based Flood Risk Assessment would be required for all developments over one hectare (10,000 sqm) and/or where flood risk may be an issue. Due consideration would also be given to flood risk issues at the planning application stage. With standard mitigation including, for example, the installation of drainage channels, flood risk would therefore not be expected to represent a significant issue in the UK context.

### Production Development

During production, the risk to groundwater and surface water bodies as well as flood risk would be similar to that at Stage 2. However, as additional wells would be drilled/fractured the risk of inadequate well design or accidents occurring could be higher.

Water consumption at this stage would also be considerably higher, reflecting the drilling and fracturing of additional wells. As during Stage 2, it is estimated that between 10,000m<sup>3</sup> to 25,000m<sup>3</sup> of water would be required per well and whilst the number of wells per pad will vary, some of research suggests that pads could have up to 24 wells. As highlighted above, when compared with other activities, water demand associated with hydraulic fracturing is relatively low but in water stressed areas the volume of water potentially required during Stage 3 could place substantial pressure on resource availability. However, appropriate regulation such as that adopted in the UK and the recycling of flowback water for reinjection (following treatment) could help to ensure that water demand associated with hydraulic fracturing does not place undue pressure on water resource availability.

Waste water treatment and disposal (particularly of flowback water) is dealt with in the section concerning waste.

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<sup>40</sup> Brino, A. (2012) *Waterless fracking technique makes its debut in Ohio* in Mid West Energy News. Available from <http://www.midwestenergynews.com/2012/05/15/waterless-fracking-technique-makes-its-debut-in-ohio/> [Accessed November 2014].

## Production/operation/maintenance

Once wells are operational, the primary issue with regards to water will be the collection and disposal of produced water. 'Produced water' is any water that is "produced" to the surface from an oil or gas reservoir along with the oil or gas. This water may come from the following sources:

- ▶ Connate water present in the reservoir prior to production;
- ▶ Condensed water which is condensed out of the produced gas in the production tubing; and
- ▶ Injected water which has broken through from the injection wells to the producers.

The major substances found in produced water typically include: hydrocarbons, sands, dissolved salts and iron, metals and Naturally Occurring Radioactive Minerals (NORMS). The handling and management of produced water may pose a risk to surface and ground water contamination due to accidental spills and runoff, similar to those described under the assessment of Stage 2.

During the production stage, there would be ongoing risks of surface and ground water contamination issues associated with well integrity, as described above. Additionally, re-fracturing may be required in order to stimulate the flow of shale gas. In the US, the frequency of re-fracturing is not certain and is estimated to be once per 5 – 10 years on average, if at all. For the purposes of their report, AEA (2012) assumed that a well would be re-fractured between 0 and 4 times over a well lifetime of up to 40 years. The risks of contamination associated with re-fracturing would be similar to those during stages 2 and 3 although AEA (2012) note that, whilst wells would be monitored during re-fracturing, there is uncertainty with respect to the risks associated with re-fracturing on well integrity.

Re-fracturing would result in additional water demand. However, the reuse of fracturing fluid may be a more economically viable option during production, compared to the exploration stage, thereby potentially reducing the volume of water required during re-fracturing.

Surface water runoff and flood risk aspects would be the same as those identified at stages 2 and 3.

## Decommissioning of wells

Following production, wells must be properly closed with cement plugs and/or mechanical barriers in the wellbore to eliminate the pathway to the surface or freshwater sources<sup>27</sup>. The inadequate sealing of wells could therefore result in subsurface pathways for contaminant migration leading to groundwater pollution and potentially surface water pollution.

AEA (2012) highlight that there is normally no pathway for release of fluids used during hydraulic fracturing to other formations and that some of the chemicals used in fracturing fluids will be adsorbed to the rocks or biodegraded in situ and that for shale gas measures at significant depths, the volume of the rock between the producing formation and the groundwater is substantially greater than the volume of fracturing fluid used. Experience in the US to-date is that the risks posed by poorly controlled and logged historical wells far outweigh the risks posed by wells designed and constructed to current standards.

From a UK perspective, well decommissioning requires regulatory approval from DECC. Regulation 15 of the Offshore Installations and Wells (Design and Construction, etc) Regulations 1996, meanwhile, require that operators ensure that wells are designed and constructed such that (so far as is reasonably practicable), they can be suspended or abandoned in a safe manner; and after suspension or abandonment there can be no unplanned escape of fluids from it or from the reservoir to which it led. In consequence, the SEA of the 14<sup>th</sup> Onshore Oil and Gas Licensing Round in the UK (AMEC, 2013) concludes that it would be anticipated that all steps would be taken to ensure permanent isolation of subsurface formations and groundwater.

There is no specific regulatory requirement for post abandonment monitoring in the UK. However, DECC requires that operators indicate, as part of their Environmental Risk Assessment, how risks associated with aftercare operations and monitoring are expected to be addressed in the period until permits are surrendered or control of the site relinquished. The scope and duration of the monitoring requirements will be agreed between the operator and DECC in consultation with other Government Departments.

The decommissioning activities at this stage may require water (i.e. for cement etc) but this would not be of a scale likely to result in any effects on local water demand and availability.

In terms of flood risk, there would be no change in the risk of increased surface water runoff than expected for Stages 2 to 4.

### Site restoration and relinquishment

Site restoration activities pose a low risk to water resources and flooding. The generation of dust may however increase the turbidity of nearby surface water bodies.

## 3.1 Mitigation Measures

The following section sets out the potential mitigation measures available at each stage of the project life cycle.

### Non-intrusive Exploration

- ▶ Surface Water Management Plans should be prepared setting out measures for controlling runoff including, for example, the installation of drainage channels.
- ▶ Assessments of flood risk should be undertaken as part of the site selection process. These assessments should seek to identify and categorise the potential risk of flooding to/from a site and appropriate mitigation.

### Exploration drilling and hydraulic fracturing

- ▶ Surface Water Management Plans should be prepared setting out measures for controlling runoff including, for example, the installation of drainage channels and measures to test, discharge or (if necessary) treat surface water.
- ▶ Assessments of flood risk should be undertaken as part of the site selection process. These assessments should seek to identify and categorise the potential risk of flooding to/from a site and appropriate mitigation.
- ▶ The well pad should be constructed from compacted aggregate laid on an impermeable membrane and geotextile layer. Surface water runoff would be collected and attenuated via perimeter ditches. There should be no connectivity between the runoff ditches from the well pad and any other surface water features adjacent to the well pad. Onsite storage facilities should also be bunded where appropriate.
- ▶ HGV routes should be agreed with the relevant regulator(s) in order to minimise the risk of accidents occurring.
- ▶ All potentially polluting substances should be stored in suitable vessels which are designed to ensure safe storage.
- ▶ A closed loop system should be used to contain drilling muds and reduce the risk of spillages;
- ▶ Accident Management Plans should be developed and spill kits provided to ensure the prevention/containment of accidental spills.
- ▶ Wells should comprise at least a two-barrier cement sealed design with surface casing.
- ▶ Blowout preventers should be installed during drilling in order to prevent any sudden or uncontrolled escape of fluids.
- ▶ Measures should be adopted to ensure well integrity including consultation on well design with appropriate regulators, bore testing, cement testing, the installation of a cement bond and

continual pressure and formation pressure testing. The results of well integrity testing should be independently verified.

- ▶ Guidance in relation to the minimum separation distance of wells should be developed so as to avoid blowout.
- ▶ A Hydraulic Fracturing Programme similar to that in operation in the UK should be prepared by the operator and agreed with the relevant regulator.
- ▶ Where possible, non-hazardous chemicals should be used in fracturing fluids.
- ▶ Consideration should be given to the development of a list of approved chemicals for use in fracturing fluids or, as in the UK, a methodology to enable regulators to assess the hazard potential of any chemicals used.
- ▶ Careful consideration should be given during site selection to water resource availability, in liaison with water providers and regulators. The operator and the relevant regulator(s) should assess the potential impacts on water resources at an early stage.
- ▶ Options to reduce water demand during hydraulic fracturing should be considered where possible. This may include the treatment and re-use of flowback water or the adoption of waterless technologies.
- ▶ Guidelines should be developed to establish best practice in unconventional oil and gas exploration and production.
- ▶ Rainwater collected on the surface of the pad should be regularly tested to determine whether it is uncontaminated and can be discharged from site or used within the hydraulic fracturing process, or whether it requires collection and removal from site as hazardous waste e.g. if contaminated with oil/chemicals.
- ▶ Ongoing groundwater monitoring should be undertaken in order to determine the presence of contaminants/methane. Monitoring wells should be established and the sampling of near surface aquifers undertaken. Tracers should also be added to fracturing fluids.
- ▶ Ambient air monitoring should be undertaken in order to detect gas leakage.
- ▶ Regular seismic monitoring should be undertaken by the operator (and independently verified) to assess likely faults and the potential impact on well integrity.
- ▶ The propagation of fractures should be monitored (for example, through the use of chemical tracers, tiltmeters and microseismic monitoring).
- ▶ Permits should require information relating to (inter-alia), the relationship between the zone of interest and any overlapping or adjacent aquifers, methods of well construction, well integrity testing, where the well stimulation fluid is expected to travel, details of the liquids to be injected, water use and disposal of effluents.
- ▶ Well abandonment/decommissioning plans should be prepared by operators and agreed with the relevant regulator(s). These should include details of any monitoring to be undertaken following well abandonment and the means of well plugging.

## **Production Development**

As for Stage 2.

## **Production/operation/maintenance**

As for Stage 2.



## Decommissioning of wells

As for Stage 2.

### Site restoration and relinquishment

- ▶ Plant and vehicles involved in this work should be checked regularly to ensure they are in good condition and not leaking fuels;
- ▶ If any contaminants are identified, they should be handled appropriately to ensure they are not spilled or liable to reach ground/surface waters;
- ▶ Soil re-profiling should take permeability into consideration so as to ensure surface water runoff rates are similar to baseline conditions; and
- ▶ Hardstanding which is to remain in situ should be kept to a minimum.

## 3.2 Regulatory Framework

### International/European

The **Water Framework Directive** (WFD) is the most substantial piece of EC water legislation to date and replaces a number of Directives including the Surface Water Abstraction Directive. It establishes a framework for the protection of inland surface waters, transitional waters, coastal water and groundwater and is designed to improve and integrate the way water bodies are managed, including encouraging the sustainable use of water resources. The key objectives at the European level are general protection of the aquatic ecology, specific protection of unique and valuable habitats, protection of drinking water resources, and protection of bathing water.

In accordance with Article 4(1), the Directive objectives for surface water, groundwater, transitional and coastal water bodies are to:

- ▶ Prevent deterioration;
- ▶ Reduce pollution;
- ▶ Protect, enhance and restore condition;
- ▶ Achieve 'good status' by 2015, or an alternative objective where allowed; and
- ▶ Comply with requirements for protected areas.

Article 7.3 of the Directive notes that member states shall ensure the necessary protection for the bodies of water identified [for the purposes of providing human consumption for 50 persons or more] with the aim of avoiding deterioration in their quality in order to reduce the level of purification treatment required in the production of drinking water. In addition, member states may establish safeguard zones for those bodies of water.

The WFD adopts the 'polluters pays principle' in seeking to ensure that the costs and benefits of discharging pollutants to the water environment are appropriately valued, and that implementation of the Directive is achieved in a fair and proportionate way across all sectors.

The aim of the **Marine Strategy Framework Directive 2008** is to protect more effectively the marine environment across Europe. It aims to achieve good environmental status of the EU's marine waters by 2021 and to protect the resource base upon which marine-related economic and social activities depend.

With specific regard to coastal water quality, the **Bathing Waters Directive 2006/7/EC** sets standards for the quality of bathing waters in terms of:

- ▶ The physical, chemical and microbiological parameters;
- ▶ The mandatory limit values and indicative values for such parameters; and

- ▶ The minimum sampling frequency and method of analysis or inspection of such water.

The **Floods Directive 2007/60/EC** aims to provide a consistent approach to managing flood risk across Europe. The approach is based on a 6 year cycle of planning which includes the publication of Preliminary Flood Risk Assessments, hazard and risk maps and flood risk management plans. The Directive is transposed into English law by the *Flood Risk Regulations 2009*.

The **Urban Waste Water Treatment Directive 91/271/EEC** has the objective of protecting the environment from the adverse effects of untreated 'urban waste water' ('sewage'). The Directive establishes minimum requirements for the treatment of significant sewage discharges. An important aspect of the Directive is the protection of the water environment from nutrients, (specifically compounds of nitrogen and phosphorus), and/or nitrates present in waste water where these substances have adverse impacts on the ecology of the water environment or abstraction source waters. It was transposed into English law through the *Urban Waste Water Treatment (England and Wales) Regulations 1994 (as amended)*.

The **Mining Waste Directive 2006/21/EC** aims to prevent or reduce as far as possible the adverse effects on the environment and any resultant risks to human health from the management of waste from the extractive industries. The Directive sets out how to achieve this aim by providing for measures, procedures and guidance on how extractive industries should be managed.

The **Environmental Impact Assessment Directive 2011/92/EU** aims for the environmental impacts from certain projects to be identified and for mitigation measures to be proposed. Environmental Impact Assessments (EIAs) are not mandated for all shale gas operations and would be necessary when operations exceed 500,000m<sup>3</sup> gas extraction or are deemed likely to have significant environmental impacts, which could include impacts associated on water resources.

The **Integrated Pollution Prevention and Control Directive (2008/1/EC)** requires industrial activities to have a permit (issued by the relevant competent authority of the member state) containing emission limit values and other conditions based on the application of Best Available Techniques (BAT) and set to minimise emissions of pollutants likely to be emitted in significant quantities to air, water or land. Permit conditions also have to address energy efficiency, waste minimisation, prevention of accidental emissions and site restoration.

In addition, the following European Directives have relevance to the protection of the water environment and resources:

- ▶ Dangerous Substances Directive 76/464/EEC;
- ▶ Quality of Shellfish Waters Directive 79/923/EEC;
- ▶ Directive on Priority Substances 2008/105/EC;
- ▶ Groundwater Directive 2006/118/EC;
- ▶ Waste Framework Directive 2008/98/EC;
- ▶ Industrial Emissions Directive 2010/75/EU; and
- ▶ Drinking Water Directive 98/83/EC.

## UK

The **Water Resources Act 1991** makes various provisions in respect of the protection of groundwater in England and Wales. Section 199 requires notice to be given to the Environment Agency of an intention to construct or extend a borehole for the purposes of searching for, or the extraction of, minerals. The Environment Agency also requires notification of an intention to extract groundwater and where the operation is likely to extract in excess of 20m<sup>3</sup> per day, the operator will require an abstraction licence.

Section 50 of the **Infrastructure Act 2015** inserts an amendment to the Petroleum Act 1998 regarding safeguards for onshore hydraulic fracturing. These include a commitment that a well consent will not be issued unless it imposes a condition which prohibits associated hydraulic fracturing from taking place in land at a depth of less than 1000 metres, identifies that certain areas will be excluded from hydraulic fracturing

(groundwater source protection zones and internationally and nationally designated conservation sites) and requires that a range of conditions are met before a hydraulic fracturing consent can be issued.

A permit under the ***Environmental Permitting (England and Wales) Regulations 2010*** (EPR) is required where fluids containing pollutants are injected into rock formations that contain groundwater (a “groundwater activity” under the EPR). An environmental permit may also be needed if the activity poses a risk of mobilising natural substances that could then cause pollution. The permit, if granted, will specify limits on the activity and any requirements for monitoring. The regulations stipulate that there must be no direct discharge of pollutants into groundwater whilst the indirect entry of non-hazardous pollutants must be limited so as not to cause pollution. If the target formation does not contain any significant groundwater, or is so deep that it falls outside any hydrogeologically active zone, there may be no groundwater activity to permit. However, a permit will be required if the regulator (the Environment Agency) considers well stimulation might lead to the movement of pollutants into adjacent groundwater that would not otherwise have received them. Pollutants in this case might be substances introduced by fracturing or the mobilisation of natural substances like hydrocarbons from the target formation.

The Environment Agency requires operators to submit the following details:

- ▶ A conceptual model showing the hydrogeological relationship between the zone of interest and any overlying or adjacent aquifers;
- ▶ The method of well construction, including details of the casing and grouting;
- ▶ Information on how the integrity of the casing is to be tested;
- ▶ Information on the location of the proposed operation and where the well stimulation fluid is expected to travel to;
- ▶ Details of the liquids to be injected, water ingress, water use and disposal of effluents;
- ▶ Details of any chemicals added in the process or substances used to prop open fissures;
- ▶ Safeguards to prevent cross-contamination of aquifers;
- ▶ Safeguards to prevent uncontrolled loss of fluids in the borehole to formations or ground surface (blowouts);
- ▶ Potential quality risks to receptors and groundwater resources;
- ▶ Details of how the operation itself is to be monitored; and
- ▶ Proposed environmental monitoring (including monitoring groundwater and surface water receptors).

Schedule 22 (paragraph 7) of the EPR covers the analysis the regulator needs to apply to set permit conditions to ensure the environmental objectives of Article 4 of the WFD are met. Consistent with Article 11(3)(j) of the WFD, paragraph 8 of the EPR states that:

*“...the regulator may grant an environmental permit for—*

- ▶ *(a) the injection of water containing substances resulting from the operations for exploration and extraction of hydrocarbons or mining activities, and injection of water for technical reasons, into geological formations from which hydrocarbons or other substances have been extracted or into geological formations which for natural reasons are permanently unsuitable for other purposes, provided that the injection doesn't contain substances other than those resulting from the above operations.”*

The intention of this clause is to allow for the return of water naturally present in geological formations. However, it should be noted that the European Commission's opinion is that Article 11(3)(j) of the WFD (and, by extension, paragraph 8 of the EPR) does not apply to shale gas operations as the water resulting from

shale gas activities is expected to consist mainly of flowback fluid rather than naturally occurring formation water and which requires treatment in accordance with the Mining Water Directive<sup>41</sup>.

In Scotland, activities liable to have an adverse effect on the water environment fall within the scope of the **Water Environment (Controlled Activities) (Scotland) Regulations 2011**. The Scottish Environment Protection Agency (SEPA) has taken the view that drilling for the purposes of unconventional gas extraction, due to the drilling depth being greater than 200m, falls within the scope of the Regulations and will require authorisation. Operators are expected to consult SEPA in advance of any application to discuss the operation and agree any mitigation and monitoring measures that will be applied. Where SEPA considers that the activity poses an unacceptable risk to the water environment or other water users, authorisation will be withheld.

The **Flood and Water Management Act 2010** makes provisions about water, including those related to water resources, including:

- ▶ To widen the list of uses of water that water companies can control during periods of water shortage, and enable the UK Government to add to and remove uses from the list;
- ▶ To encourage the uptake of sustainable drainage systems by removing the automatic right to connect to sewers and providing for unitary and county councils to adopt SUDS for new developments and redevelopments;
- ▶ To reduce 'bad debt' in the water industry by amending the Water Industry Act 1991 to provide a named customer and clarify who is responsible for paying the water bill; and
- ▶ To make it easier for water and sewerage companies to develop and implement social tariffs where companies consider there is a good cause to do so, and in light of guidance that will be issued by the Secretary of State following a full public consultation.

The Flood and Water Management Act 2010 contains provisions for regional working and co-operation such as the establishment of regional flood and coastal committees and the bringing together of lead local flood authorities, who will have a duty to cooperate, to develop local strategies for managing local flood risk. In addition, the Flood Risk Regulations 2009 impose a duty on the Environment Agency and lead local flood authorities to take steps to identify and prepare for significant flood risk.

**Shoreline Management Plans (SMPs)**, currently under revision by Coastal Groups and the Environment Agency, assess the risks to people, development, and the natural and historic environment from coastal processes. These plans (SPM2) will provide a route map for local authorities for the time period of the next 20 years, and leading up to the next 50-100 years. They will include an action plan of what is required to manage coastal processes and where, and will form the basis of decision making for such works.

The **Marine and Coastal Access Act 2009** sets out a number of measures including the establishment of Marine Conservation Zones (MCZs) and Marine Spatial Plans. The main objectives of the **Marine Policy Statement (2011)** are to enable an appropriate and consistent approach to marine planning across UK waters, and to ensure the sustainable use of marine resources and strategic management of marine activities from renewable energy to nature conservation, fishing, recreation and tourism.

The **Offshore Installations and Wells (Design and Construction, etc) Regulations 1996** (which apply to all wells drilled in the UK regardless of whether they are onshore or offshore) place goal-setting duties on installation owners and operators to ensure the integrity of an installation throughout its lifecycle and provide a framework for ensuring the safe condition of wells on land and offshore including an examination scheme. The regulations require that the Health and Safety Executive is notified of all drilling operations for oil or gas, and have an opportunity to scrutinise the well design and operational plan before exploration activities begin. The regulations specify that operators should ensure that there can be no unplanned escape of fluids from the well and require wells to be examined by an 'independent and competent person' ('well examiner'). The

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<sup>41</sup> See Note for the Attention of Mr Matthew Groote, Chair of the Envi Committee, European Parliament: Transmission Note on the EU environmental legal framework applicable to shale gas projects. 26th January, 2012. Available from [http://ec.europa.eu/environment/integration/energy/pdf/legal\\_assessment.pdf](http://ec.europa.eu/environment/integration/energy/pdf/legal_assessment.pdf) [Accessed April 2015].



examiner can request the results of any well integrity tests and raise any health and safety concerns with the operator.

# 4. Air

## 4.1 Introduction

Air quality within this context concerns the levels of pollutants emitted into the air and their significance, in terms of the risk of adverse effects on the environment and/or human health. Carbon dioxide and other greenhouse gas emissions are excluded from the air quality topic and are reported under the climate change and adaptation topic.

There are links between the air quality topic and other topics in the study, specifically human health, climate change and waste.

## 4.2 Assessment of Effects

This section comprises of the review of the likely effects on air arising from the potential activities that could arise in one of the six main stages of unconventional oil and gas exploration and production. **Table B4.1** presents a summary of the key stages of exploration, production and decommissioning.

Table B4.1 Unconventional Oil and Gas Exploration and Production Lifecycle and Key Activities

Stage	Activities
1	<p><b>Non-intrusive exploration</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Site identification, selection, characterisation;</li> <li>▶ Seismic surveys;</li> <li>▶ Securing of necessary development and operation permits.</li> </ul>
2	<p><b>Exploration drilling and hydraulic fracturing</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Pad preparation road connections and baseline monitoring;</li> <li>▶ Well design and construction and completion;</li> <li>▶ Hydraulic fracturing;</li> <li>▶ Well testing including flaring.</li> </ul>
3	<p><b>Production development</b>, including :</p> <ul style="list-style-type: none"> <li>▶ Pad preparation and baseline monitoring;</li> <li>▶ Facility construction and installation;</li> <li>▶ Well design construction and completion;</li> <li>▶ Hydraulic fracturing;</li> <li>▶ Well testing, possibly including flaring</li> <li>▶ Provision of pipeline connections</li> <li>▶ (Possibly) re-fracturing.</li> </ul>



Table B4.1 (continued) Unconventional Oil and Gas Exploration and Production Lifecycle and Key Activities

Stage	Activities
4	<p><b>Production/operation/maintenance</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Gas/oil production;</li> <li>▶ Production and disposal of wastes/emissions;</li> <li>▶ Power generation, chemical use and reservoir monitoring;</li> <li>▶ Environmental monitoring and well integrity monitoring.</li> </ul>
5	<p><b>Decommissioning of wells</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Well plugging and testing;</li> <li>▶ Site equipment removal;</li> <li>▶ Environmental monitoring and well integrity monitoring.</li> </ul>
6	<p><b>Site restoration and relinquishment</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Pre-relinquishment survey and inspection;</li> <li>▶ Site restoration and reclamation.</li> </ul>

Note: Exploration wells most usually move from Stage 2 to Stage 4, though some may be used for long-term production testing and some may be retained and their sites redeveloped as a production project. For the purposes of this review, the appraisal stage (a term commonly used in industry) spans Stages 2 and 3

### Non-intrusive Exploration

On site non-intrusive exploration surveys would result in emissions from vehicles and machinery. Due to the minor scale of works required and the short term duration of these surveys, the effect of air emissions is expected to be negligible at this stage. However, should significant new road infrastructure be required to facilitate site access then there may be the risk of increased emissions to air.

### Exploration drilling and hydraulic fracturing

The preparation of the pad site would involve the removal of vegetation and topsoil for the area involved, plus levelling of the ground and laying a surface comprising of membrane layers and aggregates. Heavy machinery and generators used for the site preparation would give rise to exhaust emissions, however this is expected to be of limited significance during the initial preparations compared to drilling and fracturing activities and would be similar to other large construction projects including conventional oil and gas exploration (although the volume of emissions could be greater commensurate with the size of well pad associated with unconventional oil and gas exploration)<sup>1</sup>. The preparation activities may involve vehicle movements over unpaved ground and the handling of dusty materials.

The exact scale of works required to clear and prepare the site would depend on local factors such as geology, habitat and hydrology. However estimates by Cuadrilla for Preston New Road, Lancashire UK, indicated that site preparation and construction of the well pad and access track would take up to two months,<sup>2</sup> and Cuadrilla estimated for the Beconsall site that vehicle delivery and handling of 3,200 tonnes of

<sup>1</sup> AEA (2012) *Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe* p.250, Table A6.2 and section 2.4.4. Available from <http://ec.europa.eu/environment/integration/energy/pdf/fracking%20study.pdf> [Accessed April 2015].

<sup>2</sup> Cuadrilla Bowland Ltd (2014) *Temporary Shale Gas Exploration, Preston New Road, Lancashire: Environmental Statement* pp.32-35. Available from [http://www.cuadrillaresources.com/wp-content/uploads/2014/07/PNR\\_ES\\_Vol1\\_Environmental\\_Statement.pdf](http://www.cuadrillaresources.com/wp-content/uploads/2014/07/PNR_ES_Vol1_Environmental_Statement.pdf) [Accessed April 2015].

aggregate would be required during preparation.<sup>3</sup> The pad preparation would give rise to dust, particularly during periods of low rainfall. Minor construction work such as construction of access roads, security fences and site cabins for the workforce would also take place, all of which may give rise to minor releases of dust.<sup>4</sup>

Like other types of construction projects, HGV movements would be required to transport materials to and from the site during each of the activities under this stage, especially for the provision of water for hydraulic fracturing if pipelines to a mains supply are not in place. It is estimated stage 2 would generate a significant increase in vehicle movements, including both HGVs and smaller vehicles. The principal emissions from diesel and petrol engines are carbon monoxide (CO), nitrogen oxides (NO<sub>x</sub>), un-burnt hydrocarbons and particulate matter (PM). CO, NO<sub>x</sub>, hydrocarbons and PM can all cause adverse health effects, particularly for the respiratory system (outlined in more detail in **Appendix B.9 Health**). NO<sub>x</sub> also contributes to smog and ground level ozone formation with further potential health impacts, in addition to the environmental effects of acid rain formation and damage to vegetation.<sup>5</sup> Carbon dioxide (CO<sub>2</sub>) is also released from vehicle exhausts (the climate change impact from this is discussed further in **Appendix B.5 Climate**).

The scale of vehicle movements may have a negative effect on air quality due to emissions from vehicles along the transport route, although this may be relatively minor and localised. The proposed Cuadrilla operations in Preston New Road, Lancashire, estimate the increased transport as a result of their operations for the well pad and fracturing would include average daily movements of: 34 two-way movements per day during pad construction (lasting two months), 46 two-way movements per day during mobilisation and drilling of the first well (five months), 49 two-way movements for drilling of three subsequent wells (lasting three months each), 35 two-way movements per day during hydraulic fracturing (one to two months per well) and 23 two-way movements per day during initial flow testing (three to four months) on average.<sup>6</sup> While temporary, vehicle movements could peak at 250 truck movements per day during the most intense periods which would be sustained for a few days<sup>1</sup>. In addition to exhaust fumes, vehicles are also expected to track dust and dirt from the site, particularly when travelling over unpaved ground although such effects can be mitigated to some extent through the use of wheel washes and vehicle sprays.<sup>4</sup>

However, given the temporary nature of this work, these movements are not expected to result in significant effects on air quality, although there may be localised transient effects, depending on the existing local air quality. The movement of water and waste during the hydraulic fracturing process are the greatest contributors to the number vehicle movements, and the movement of HGVs needed during fracturing itself could be approximately halved if pipeline connections for water and waste water are in place.<sup>1</sup>

The installation of surface and buried arrays used to collect seismic data and for monitoring fluid injection is not anticipated to generate any significant air emissions due to the limited earthworks and vehicle movements required.<sup>2</sup>

The drilling of the exploratory well would take place across approximately five months for the vertical and horizontal sections of the first well (for a depth of 3,500m and lateral distance of 2,000m), with subsequent wells expected to take three months each.<sup>2</sup> Drilling works would include construction activities such as casing and cementing as well as the drilling itself. Diesel generators are likely to be used to power the drilling rigs. Cuadrilla estimates the use of three generators to be used 24 hours per day during drilling operations.<sup>7</sup> These generators emit a number of pollutants including NO<sub>x</sub>, hydrocarbons, CO, and PM. Simultaneously with drilling operations, it is expected that there would be movements of vehicles to and from the site as outlined above. Typical emissions of air pollutants for diesel generators used in hydraulic fracturing are set out below in **Table B4.2**.

<sup>3</sup> Cuadrilla Resources Ltd (2010) *Beaconsall Hydrocarbon Exploration Site, Planning Application July 2010*, Section 2 – Supporting Statement to the Application.

<sup>4</sup> Celtique Energie Weald Ltd (2014) *Northup Field, Wisborough Green, Planning Application*, Chapter 15 Air Quality.

<sup>5</sup> Vehicle Certification Agency, Department for Transport (2014) *Cars and Air Pollution*. Available from <http://www.dft.gov.uk/vca/fcb/cars-and-air-pollution.asp> [Accessed November 2014].

<sup>6</sup> Cuadrilla Bowland Ltd (2014) Appendix R1 – Transport Assessment (Exploration Works).

<sup>7</sup> Cuadrilla Bowland Ltd (2014) Appendix F – Air Quality.

Table B4.2 Typical specific emissions of air pollutants from stationary diesel engines used for drilling, hydraulic fracturing and completion

	Emissions per engine fuel input [g/kWhdiesel]	Emissions per natural gas throughput of well [g/kWhNG]
SO <sub>2</sub>	0.253	0.004
NO <sub>x</sub>	3.487	0.059
PM	0.291	0.005
CO	0.756	0.013
Non-methane VOCs	0.011	0.000

Source: European Parliament (2011) Impacts of shale gas and shale oil extraction on the environment and on human health

During the hydraulic fracturing process, diesel fumes would also be emitted from the pumps that inject fracturing fluid into the well. Emissions include PM, NO<sub>x</sub>, CO, volatile organic compounds (VOCs) and sulphur dioxide (SO<sub>2</sub>). For Mercellus Shale wells in the US, it was estimated that diesel fuel use from pumping during hydraulic fracturing amounts to 111,000 litres diesel per well.<sup>8</sup> For Cuadrilla's exploratory drilling in Preston New Road, Lancashire, this is expected to include a generator operating for 24 hours per day during fracturing, plus a further 12 generators in use for less than 12 hours per day during fracturing and other operations.<sup>7</sup> While the duration of fracturing activities may vary, it is expected that this would last up to two months for each well, broken down into 30 – 45 fracturing stages within the well.<sup>2</sup>

In addition, it is expected that dust would be generated during hydraulic fracturing by the on-site handling (conveying and blending) the proppant, which is normally sand based. It is estimated that 0.25% of the proppant sand may be emitted to air as fine dust.<sup>9</sup>

Methane can be emitted from unconventional gas extraction during the fracturing stage. As the fracturing fluid returns to the surface, it also contains natural gas and small amounts of VOCs. The volume of gas released from flowback water will vary with the amount of fracturing fluid injected into the rock formation and subsequently returning to the surface, along with well and gas pressures. Flowback water typically returns to the surface within the first few days or weeks following injection of fracturing fluid. Studies in the US have estimated the volume of gas released from flowback water to range between 260,000 – 1,180,000m<sup>3</sup> per well. This represents the entire volume of gas released from flowback water and does not reflect measures to contain or capture the gas, so is expected to overstate the actual emissions to air from flowback in the UK, given that holding ponds cannot be used and the requirements for reduced emission and 'green completions'.<sup>10</sup>

In the UK, flaring is regulated by DECC as part of a licence condition and it is DECC's established policy that flaring should be reduced to the economic minimum.<sup>11</sup> Flaring would primarily result in the production of CO<sub>2</sub> but also NO<sub>x</sub>, SO<sub>2</sub>, CO, and PM, as well as methane and VOCs in the event of incomplete combustion.<sup>10</sup> Emissions to air during flaring may be a greater issue during the exploratory stages, as there is less likely to be gas collection infrastructure in place compared to the later production stages. Cuadrilla anticipates flaring

<sup>8</sup> Broderick J., et al (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/sites/default/files/coop\\_shale\\_gas\\_report\\_update\\_v3.10.pdf](http://www.tyndall.ac.uk/sites/default/files/coop_shale_gas_report_update_v3.10.pdf) [Accessed April 2015].

<sup>9</sup> Kellam P. (2012) *New Standards for Location Safety and Environmental Concerns, SPE Workshop, Reducing Environmental Impact of Unconventional Resource Development, San Antonio, Texas, April 2012*, as cited in AEA (2012).

<sup>10</sup> Mackay, D.J.C. and Stone, T.J. (2013) *Potential Greenhouse Gas Emissions Associated with Shale Gas Extraction and Use, Department of Energy and Climate Change*. Available from [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/237330/MacKay\\_Stone\\_shale\\_study\\_report\\_09092013.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/237330/MacKay_Stone_shale_study_report_09092013.pdf) [Accessed April 2015].

<sup>11</sup> DECC (2013) *About Shale Gas and Hydraulic Fracturing (Fracking)*. Available from [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/268017/About\\_shale\\_gas\\_and\\_hydraulic\\_fracturing\\_Dec\\_2013.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/268017/About_shale_gas_and_hydraulic_fracturing_Dec_2013.pdf) [Accessed April 2015].

to take place during an initial test period for 90 days.<sup>2</sup> Venting natural gas is not permitted in the UK, except for safety reasons, as part of DECC's licence conditions.<sup>12</sup>

As an alternative to flaring, 'green completion' involves the capture of methane from the fracturing process for use or export off site to reduce emissions to air.<sup>12</sup> Although not occurring at all sites, a recent study in the US found that for sites that capture gas emissions from flowback water, 99% of the potential emissions were captured during the green completion process.<sup>13</sup> Green completions can therefore significantly reduce the amount of methane released to air from flowback fluid, however appropriate infrastructure for transport offsite may not be in place until later production stages. For the UK, MacKay and Stone (2013) recommended that green completions should be adopted at all stages following exploration and that emissions of methane should be reduced to as low a level as reasonably practicable (ALARP), and the UK Government has accepted this recommendation.<sup>14</sup>

After the initial recovery of the hydraulic flowback fluid (in the flowback water), produced water will continue in many cases to come to the surface with decreasing quantities of hydraulic fracturing fluid. Produced water is generated from the rocks across the lifetime of the well while produced water is not expected to be generated in significant quantities in the UK due to the low permeability of shale, it can be a greater issue in other locations. Produced water can also collect in the well over time, reducing the flow of natural gas. In some cases, this may necessitate the expulsion of liquid under high pressure ('blowdown') which would further cause methane to be released to air.<sup>15</sup>

Leakages (fugitive emissions) of methane and other pollutants such as NO<sub>x</sub>, CO and hydrocarbons may occur during well completion and well production from pumps, valves, pressure relief valves, flanges, agitators and compressors.<sup>1</sup> Glycol dehydrators, used to remove water from the natural gas stream, are a further source of methane emissions. A recent study of 150 sites in the US found releases of methane from pneumatic controllers and equipment leaks to be the greatest contributors to methane emissions, with flowback emissions having been reduced substantially through improved gas collection during flowback. By their design, pneumatic devices typically release small quantities of methane on a continuous or intermittent basis.<sup>15</sup> Overall, methane emissions during the hydraulic fracturing process were found to represent an average of 0.42% of gross gas production.<sup>13</sup>

During the exploration and pilot stages, there may be smaller, less robust gas pipeline infrastructure in place connecting the well to the main gas pipeline, compared to later stages. There may therefore be fugitive emissions of methane and other gases during the transport of gas off site through the temporary pipelines. It is anticipated that fugitive emissions are less likely from more robust pipeline infrastructure put in place during later production stages. These gases may include methane, ethane, CO<sub>2</sub>, hydrogen sulphide, nitrogen and helium, in addition to volatile and semi-volatile organic compounds and naturally occurring radioactive material (NORM).<sup>1</sup>

Unconventional gas wells typically produce more cuttings per well than conventional wells. A vertical well with a depth of 2,100m would produce an average of 120m<sup>3</sup> of cuttings, while an unconventional well with an additional lateral 1,200m section would produce approximately 170m<sup>3</sup> of cuttings.<sup>1</sup> These cuttings would need to be transported off site for treatment and/or recycling by vehicle, and would contribute to emissions associate with vehicle exhausts outlined above.

Shale gas can be classed as either 'wet' or 'dry'. While both gases contain methane, wet gas contains small quantities of hydrocarbons such as ethane and butane. These additional hydrocarbons can be captured and sold, however they are associated with higher emissions of VOCs, for example through venting hydrocarbon storage tanks. The extent of emissions to air would depend on the nature and composition of shale gas at a

<sup>12</sup> DECC (2014) *Fracking UK Shale: Local Air Quality*. Available from [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/277219/Air.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/277219/Air.pdf) [Accessed April 2015].

<sup>13</sup> Allen, D.T., et al (2013) *Measurements of methane emissions at natural gas production sites in the United States*, Proceedings of the National Academy of Sciences of the United States of America, 110 (44), 17768-17773. Available from [www.pnas.org/cgi/doi/10.1073/pnas.1304880110](http://www.pnas.org/cgi/doi/10.1073/pnas.1304880110) [Accessed November 2014].

<sup>14</sup> DECC (2014) *The Government's Response to the MacKay-Stone Report: Potential greenhouse Gas Emissions Associated with Shale Gas Extraction and Use*. Available from [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/305811/140424\\_MacKay\\_Stone\\_Response\\_.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/305811/140424_MacKay_Stone_Response_.pdf) [Accessed April 2015].

<sup>15</sup> Environment Agency (2012) *Monitoring and control of fugitive methane from unconventional gas operations*. Available from [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/291523/scho0812buwk-e-e.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/291523/scho0812buwk-e-e.pdf) [Accessed April 2015].

particular drilling location. Emissions from oil tanks can also result in VOCs releases.<sup>16</sup> Emissions of methane and VOCs from storage tanks can occur through:

- ▶ Working losses – gas vapours at the top of the tank are expelled as additional liquid is added to the tank;
- ▶ Breathing losses – from volatilisation of hydrocarbons due to external temperature changes; and
- ▶ Flashing losses – arising when a liquid containing dissolved gases is transferred to a container with lower pressure, allowing gases to vaporise.<sup>15</sup>

Fugitive emissions to air may also occur as a result of fuel spillage from plant and equipment, however this could be controlled through normal industrial spill prevention and response procedures and would be common to any similar construction activity. A 2011 MIT study of gas well drilling in the US found that a third of documented incidents between 2005 and 2009 related to accidental spills and leaks.<sup>17</sup> The scale of vehicle movements involved may also result in a potential increase in the risk of spillages and associated emissions to air as a result of road accidents.

Emissions to air in the US have particularly been the cause for concern due to reports of poor health in the vicinity of shale gas operations and air quality monitoring identifying harmful and carcinogenic substances. The situation in the US is not considered to be repeated in the UK and Europe due to EU limits on the use and emissions of harmful substances.<sup>18</sup>

## Production Development

Activities which give rise to adverse effects on air quality at this Stage would be similar to Stage 2. These include:

- ▶ Groundworks from expanding the wellpad and associated dust generation;
- ▶ Deliveries to the site to deliver equipment and plant;
- ▶ Drilling equipment powered by diesel or other forms of combustion engines;
- ▶ Deliveries of water (if not connected to mains supplies);
- ▶ Deliveries of materials used in the fracturing fluid (other than raw water);
- ▶ Fracturing fluid pumps; and
- ▶ Removal of cuttings and spent drilling muds.

In addition, the well may be re-fractured again in the future, which would result in further emissions of methane and other gases as outlined in Stage 2.

Bringing multiple wells per pad into production would cause a medium term continuation of the activities outlined above. As these activities would result in emissions from several different sources, it is possible that there would be a strong and sustained localised negative effect on communities and biodiversity closest to the wellpads resulting from a significant increase in air pollution and particulate deposition.

The key pollutants released at this stage are particulate matter, NO<sub>x</sub>, SO<sub>2</sub>, CO and VOCs.

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<sup>16</sup> Public Health England (2014) *Review of the Potential Public Health Impacts of Exposures to Chemical and Radioactive Pollutants as a Result of the Shale Gas Extraction Process*. Available from [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/329744/PHE-CRCE-002\\_for\\_website\\_protected.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/329744/PHE-CRCE-002_for_website_protected.pdf) [Accessed April 2015].

<sup>17</sup> MIT (2011) *The Future of Natural Gas: An Interdisciplinary MIT Study*, as cited in RSBP (2014) *Hydraulic Fracturing for Shale Gas in the UK*. Available from [http://www.rspb.org.uk/Images/shale\\_gas\\_report\\_evidence\\_tcm9-365779.pdf](http://www.rspb.org.uk/Images/shale_gas_report_evidence_tcm9-365779.pdf) [Accessed April 2015].

<sup>18</sup> European Parliament (2011) *Impacts of shale gas and shale oil extraction on the environment and on human health*. Available from <http://europeecologie.eu/IMG/pdf/shale-gas-pe-464-425-final.pdf> [Accessed April 2015].



## Production/operation/maintenance

Once the wells are operational, there is a risk that there would be ongoing fugitive emissions of methane and other trace hydrocarbons via leakages from valves, flanges, compressors etc. Evidence from the US also suggests that gases such as methane could leak from the well during production due to loss of well integrity.<sup>19</sup> However, there is insufficient evidence to conclude the likelihood or quantities of gases that may be released (although it is expected to be minor, if at all). Furthermore, it is assumed that regular well integrity testing would prevent or mitigate against any loss of well integrity.

As under Stage 3, methane can be emitted from unconventional gas extraction during the re-fracturing stage to stimulate the flow of shale gas again. In the US, the frequency of refracturing is not certain and is estimated to be once per 5 – 10 years on average, if at all. AEA reports that it is uncertain whether the US approach is transferable to Europe, with an expected potential for wells to be refractured once every 10 years and a potential maximum well lifetime of 10 to 40 years for European operations.<sup>1</sup> Given the lack of data for well lifetimes and the large numbers of wells in the US that have been shut down within 10 years, the life span of wells is not certain at this time and estimates of up to 40 years may be optimistic.<sup>20</sup> For each refracturing event, air emissions would arise as per the original fracturing process, such as release of vehicle and plant emissions, release of methane, leakages and dust generation from proppant handling.

By this stage, it is anticipated that water pipelines would be connected to the site to provide water and remove waste water from the fracturing process. This would substantially reduce vehicle movements and associated exhaust emissions compared to exploration and test stages where water may be tankered on and off site. Infrastructure to collect gas released from the fracturing fluid may also be in place to collect and export the gas. Additionally, if a power connection is in place on the site during long-term production, emissions from diesel generators to pump fracturing fluid into the well may no longer arise. Additionally, if not in place at the exploration stage, it is expected that appropriate infrastructure for the capture and export of gas released from flowback fluid would be installed to reduce emissions to air.

Transportation of materials and equipment and wastes from the site during the production and maintenance phase is expected to be minimal in the most part. However, re-fracturing would result in the need for HGV movements to deliver water, chemicals to site. This increase in vehicle movement may generate emissions from vehicles alongside local transport networks within rural areas. However, given the short term nature of this work, this is not expected to be significant.

Across the lifetime of a well, a study in the US has estimated 4 - 8% of methane from shale gas production is released into the atmosphere from venting and fugitive emissions (where venting is permitted).<sup>21</sup> However, in part this will represent emission estimates based on historical practice (so excluding green completions). The wider applicability of this study's findings to the UK and Europe is not certain due geological and operational differences; however, it is indicative of the scale and risks arising from venting and fugitive emissions.

More seriously, well blow-outs can result in large scale, uncontrolled releases of fluids and gases. The total scale of losses is not known, however this could still contribute to atmospheric emissions and local pollution.<sup>1</sup> Examples of incidents in the US include a release of 132,000 litres of wastewater and natural gas due to a blow-out, and accidental ignition of fracturing fluid resulting in 33m high flames. These resulted from incorrect operation and behaviour, so could be minimised through regulation, monitoring and training.<sup>18</sup> While potentially a major hazard, blowouts are rare and are would be expected to be unlikely in the UK or elsewhere where the permeability of the host formation (shale) is very low. This means that even if the rock formation is over-pressurised, it does not easily result in a sudden escape of fluids due to the lack of mobility of the fluid. Blow-outs are more likely to occur in shallower and more permeable formations.<sup>22</sup> Blow-out

<sup>19</sup> Ingraffea, A. (2012) *Fluid Migration Mechanisms Due to Faulty Well Design and/or Construction: An overview and Recent Experiences in the Pennsylvania and Marcellus Play*. Available from [http://www.fraw.org.uk/files/extreme/ingraffea\\_2013.pdf](http://www.fraw.org.uk/files/extreme/ingraffea_2013.pdf) [Accessed April 2015].

<sup>20</sup> Hughes, J.D. (2014) *Drilling Deeper: A Reality Check on U.S. Government Forecasts for a Lasting Tight Oil & Shale Gas*, Post Carbon Institute.

<sup>21</sup> Howarth, R.W., Santoro, R. and Ingraffea, A. (2011) *Methane and the greenhouse-gas footprint of natural gas from shale formations*, *Climatic Change*, 106 (4), 679-690. Available from <http://www.acsf.cornell.edu/Assets/ACSF/docs/attachments/Howarth-EtAl-2011.pdf> [Accessed April 2015].

<sup>22</sup> Royal Academy of Engineering and Royal Society (2012) *Shale Gas in the UK, A Review of Hydraulic Fracturing*. Available from <https://royalsociety.org/policy/projects/shale-gas-extraction/report/> [Accessed April 2015].



preventers should be fitted on all wells to automatically shut down flows in the event of an uncontrolled escape, and the well casing and cement must also be strong enough to contain the subsequent underground build up of pressure in the well.

Although there would still be activities occurring on site which would have adverse effects on air quality, the scale of activities would be considerably lower at this stage. Minor negative effects would be expected as the low level emission of certain pollutants over a long period of time may cause depositions that impact on certain habitats or other vulnerable receptors.

Overall, emissions to air from shale gas wells are considered to be relatively low across the development, fracturing and operational stages. However, more significant cumulative effects may arise if there are a number of wells in a small area.<sup>16</sup> Additionally, the sensitivity of the local area and nearby receptors, plus existing background levels of air pollutants, would all affect the significance of air emissions in a particular location.

### Decommissioning of wells

The decommissioning of an unconventional gas well would be generally similar to the process used for a conventional oil and gas.

Activities which may affect local air quality would be primarily associated with vehicle movements to and from the site to removal plant, equipment, wastes and other materials. The total number of movements would be uncertain at this stage, however, it is assumed likely to be of a smaller scale than that in Stage 2 (given that there would be no drilling activities or associated vehicle movements) and not a significant contribution to air quality.

The plugging of the well would require some construction related activities but these would be of a small scale and short term in duration.

Evidence from the US suggests that gases such as methane could leak from the well during production due to loss of well integrity.<sup>23</sup> However, there is insufficient evidence to conclude the likelihood or quantities of gases that may be released (although it is expected to be minor, if at all). Furthermore, it is assumed that regular well integrity testing would prevent or mitigate against any loss of well integrity.

### Site restoration and relinquishment

The restoration of the site would involve a similar level of activity required to prepare the pad site. Large plant and machinery would be expected to be on site for removal of the well pad and access track, and there would be movements of earth and soil. This may give rise to dust depending on ground conditions, soil types and recent rainfall patterns and localised vehicle emissions.

Fugitive emissions could arise in the event of inadequate sealing of the well. Current design and construction standards should limit releases, but the eventual scale of loss is uncertain across the long term period after abandonment, considered across several hundred years. This is, however, expected to be of similar scale to fugitive emissions from conventional wells, with only minor amounts of gas expected to continue to be released to air if appropriately designed and constructed.<sup>1</sup>

## 4.3 Mitigation Measures

The following section sets out the potential mitigation measures available at each stage of the project life cycle. 1· 2· 4· 7·<sup>10, 12, 16, 18, 22, 24</sup>

<sup>23</sup> Ingraffea, A. (2012).

<sup>24</sup> AEA (2012) *Climate Impact of Potential Shale Gas Production in the EU*, Issue 2. Available from [http://ec.europa.eu/clima/policies/eccp/docs/120815\\_final\\_report\\_en.pdf](http://ec.europa.eu/clima/policies/eccp/docs/120815_final_report_en.pdf) [Accessed April 2015].

## Non-intrusive Exploration

- ▶ Vehicles and machinery should shut down their engines when stationary or not in use to reduce emissions;
- ▶ Transport Plans could reduce the amount of trips made or the mileage that vehicles need to complete; and
- ▶ Low Emissions Vehicles should be used where possible.

## Exploration drilling and hydraulic fracturing

- ▶ Air emission specifications should be considered during all equipment selection and procurement.
- ▶ Where possible, low or 'zero' sulphur fuels should be used for the engines of drilling rigs and fracturing equipment.
- ▶ Vehicles and machinery should shut down their engines when stationary or not in use to reduce emissions.
- ▶ Consider the use of low emission vehicles or HGVs conforming to the highest available standards for vehicle emissions.
- ▶ Develop a transport plan to reduce HGV traffic (for example through load sharing); designate parking and storage areas; and identify appropriate transport routes and times e.g. avoiding peak traffic hours to minimise congestion and idling emissions.
- ▶ Local sources of materials, personnel, equipment and waste disposal can help reduce vehicle movements to the site.
- ▶ Connection to water supplies and wastewater infrastructure can reduce requirements to tanker water to and from site, reducing emissions from vehicles.
- ▶ If there is no water supply available, consider treatment and reuse of fracturing fluid to reduce water deliveries.
- ▶ If flaring is the only option available for the disposal of test gases, only the minimum volume of hydrocarbons required for the test should be flowed and well test durations should be reduced to the extent practical. Volumes of hydrocarbons flared should be recorded. This could include the use of an enclosed flare or other method to ensure waste gas is oxidised. In order to reduce air pollution, the method of flaring should be selected to minimise incomplete combustion, black smoke and hydrocarbon fallout.
- ▶ If available, use a mains electricity supply rather than diesel or petrol generators to reduce emissions to air. Alternatively, use battery powered equipment if practical.
- ▶ Where diesel drilling or fracturing equipment is in use, three-way catalytic converters can help reduce pollutant emissions.
- ▶ A Dust Suppression Plan could reduce the levels of dust that are caused by ground works. The scale of the management plan would generally be dependent on local conditions and the presence of sensitive receptors.
- ▶ Implement good site management practices to help mitigate dust issues. This should include displaying contact information for the site; recording all dust and air quality complaints and measures taken to reduce emissions; and recording unusual incidents and the actions taken to resolve incidents.
- ▶ Where receptors are located nearby, undertake daily site and off site inspections (including local roads) to monitor and record dust levels. Conduct inspections more frequently when carrying out dusty activities or in dry/windy conditions.
- ▶ Consider site layout in advance, so that machinery, dusty activities and site access routes are situated as far as possible from nearby receptors.

- ▶ Conduct off site air quality monitoring and use the results to inform site practices. This should include monitoring in advance of site development and drilling works, so that baseline levels and impacts from operations can be determined.
- ▶ Cover exposed soil and vehicle routes as soon as possible.
- ▶ Ensure that vehicles entering or leaving the site are covered to prevent dust escaping during transport (if containing dusty material such as aggregates), and use road sweepers and wheel washers to avoid tacking dust and mud off site.
- ▶ Consider erecting screens to act as windbreaks or dust screens around particularly dusty activity areas, such as handling the proppant. Screens should be as high as any stockpiles. Landscaping around the site may also provide some screening.
- ▶ Keep fences, barriers, scaffolding and screens clean using wet methods.
- ▶ Ensure that fine powder materials such as cement are delivered and stored in enclosed containers, with control systems to prevent escape or overfilling during delivery.
- ▶ Seal or cover any dusty materials that are not currently in use on the site. Sand or aggregates may be stored in a bunded area and sprayed with water to suppress dust. Remove dusty materials from the site when no longer needed.
- ▶ Ensure that dust generating equipment such as cutting, grinding or sawing is used with appropriate dust suppression such as water sprays or local exhaust ventilation systems (LEV).
- ▶ Spray or damp down dusty areas to suppress dust movement, using non-potable water where possible. Avoid dry sweeping large areas.
- ▶ Do not vent emissions from flowback fluid directly to atmosphere, except for safety reasons.
- ▶ Gases released from flowback fluid should be separated and collected for use or sale where possible ('green completions'), which may not be feasible during initial exploratory stages. If collection is not possible, use enclosed flares. Flaring within a burn chimney can increase the height of emissions and improve dispersion of pollutants.
- ▶ If produced water collects in the well and requires expulsion from the well to maintain gas flow rates, reduce the release of gaseous emissions through the use of a plunger lift system. This uses a plunger within the well to control the gradual release of fluids and gases for separation at the surface.
- ▶ Control emissions from storage tanks through the use of vapour recovery units, transfer of gases to pipelines or flaring.
- ▶ Reduce emissions from glycol dehydrators by using vapour recovery units, zero emissions dehydrators with pipe, valve and pump modifications, desiccant dehydrators (using salts to remove water) and flash tank separators.
- ▶ Emissions from pneumatic devices can be reduced through the use of low bleed devices and intensive maintenance of equipment such as liquid level controllers, pressure regulators and valve controllers. Maintenance should include cleaning and tuning, and repairing or replacing leaking gaskets, tubing fittings and seals.
- ▶ Compressor emissions can be controlled by using dry seals rather than wet seals in centrifugal compressors, and periodic replacement of rod packing systems in reciprocating-rod compressors. Avoid depressurising the compressor system (blowdown) which can result in large natural gas losses.
- ▶ A rigorous equipment maintenance regime should be in place to help reduce incidents of failure or leaks, including plant such as compressors, pumps and pipe joints.
- ▶ Implement a leak detection and repair regime to help reduce fugitive emissions when leaks occur.

- ▶ Utilise a blowout preventor (BOP) to shut down fluid flow in the event of unexpected well blow-out.

### Production Development

- ▶ Air quality monitoring should be carried out on a continuous basis during this stage. While this will not prevent air pollution per se, it will allow for early identification of any potential significant effects.
- ▶ Air emission specifications should be considered during all equipment selection and procurement.
- ▶ Vehicles and machinery could shut down their engines when stationary or not in use to reduce emissions.
- ▶ A Dust Suppression Plan could reduce the levels of dust that are caused by ground works.
- ▶ Implement reduced emissions completions (RECs), also known as 'green completions', to separate water, sand and gas from flowback water and sell or use the collected gas to reduce flaring, once infrastructure for this is in place.

### Production/operation/maintenance

- ▶ Regular testing of well integrity during the production lifecycle.
- ▶ Due to the uncertainty of emissions to air during production due to well leakage it is suggested that air quality monitoring should be carried out on a continuous basis during this stage. While this will not prevent air pollution per se, it will allow for early identification of leakages/loss of well integrity.
- ▶ Consider the use of natural-gas fired rather than diesel equipment, particularly at later stages or refracturing, when gas may be available on site.
- ▶ Implement a regime of regulation, monitoring and staff training for correct operation and behaviour to help reduce the risk of accidents and blow-outs.

### Decommissioning of wells

- ▶ Transport Plans should be drafted up to reduce the number of trips required to remove materials and plant from the site.
- ▶ Low Emission Vehicles should be used if possible.
- ▶ Due to the uncertainty of emissions to air after production due to well leakage it is suggested that air quality monitoring should be carried out. While this will not prevent air pollution, per se, it will allow for early identification of leakages/loss of well integrity.

### Site restoration and relinquishment

- ▶ Dust suppressions practices should be adopted where necessary.
- ▶ Undertake periodic air monitoring e.g. every few years to detect possible well failure after abandonment.

## 4.4 Regulatory Framework

### International/European

The **Air Quality Framework Directive** 96/62/EC and its Daughter Directives set a framework for monitoring and reporting levels of air pollutants across EU member states, setting limits or reductions for certain air pollutants.

The **Ambient Air Quality and Cleaner Air for Europe Directive** 2008/50/EC consolidated earlier air quality directives and also defines and establishes objectives and targets for ambient air quality to avoid, prevent or reduce harmful effects on human health and the environment as a whole. It sets legally binding limits for concentrations in outdoor air of major air pollutants that impact on public health such as particulate matter (PM<sub>10</sub> and PM<sub>2.5</sub>) and nitrogen dioxide (NO<sub>2</sub>). The 2008 directive replaced nearly all the previous EU air quality legislation and was made law in England through the **Air Quality Standards Regulations 2010**, which also incorporates the 4<sup>th</sup> air quality daughter directive 2004/107/EC that sets targets for levels in outdoor air of certain toxic heavy metals and polycyclic aromatic hydrocarbons. Equivalent regulations exist in Scotland, Wales and Northern Ireland.

The UK monitors and models air quality to assess compliance with the air quality limit and target values set out in the EU legislation above. The results of the assessment are reported to the Commission on an annual basis. Air quality monitoring is also carried out by local authorities to meet local air quality management objectives.

The **National Emissions Ceilings Directive 2001/81/EC** came into force in 2001, and Member States were required to transpose it into their national legislation by November 2002. This Directive set 'ceilings' (maximum values to be achieved by 2010) for total national emissions of four pollutants: sulphur dioxide; oxides of nitrogen; volatile organic compounds; and ammonia. These four pollutants contribute to acidification, eutrophication, and formation of ground level ozone. This is transposed into UK legislation in the **National Emissions Ceiling Regulations 2002**.

Following a review of EU air quality policy, the EU published the Clean Air Policy Package in 2013 with new proposals on ambient air quality and emissions ceilings. The package includes a new *Clean Air Programme for Europe (2013)*, which sets out new air policy objectives for 2030 to reduce health impacts and eutrophication in ecosystems. The package will also involve revisions to the National Emissions Ceiling Directive.

The **EU Thematic Strategy on Air Quality (2005)** identifies that despite significant improvements in air quality across the EU, a number of serious air quality issues still persist. The strategy promotes an approach, which focuses upon the most serious pollutants, and that more is done to integrate environmental concerns into other policies and programmes. The objective of the strategy is to attain levels of air quality that do not give rise to significant negative impacts on and risks to human health and the environment. The strategy emphasises the need for a shift towards less polluting modes of transport and the better use of natural resources to help reduce harmful emissions.

The **Industrial Emissions Directive (IED) 2010/75/EU** combines seven existing air pollution directives, including the Large Combustion Plant Directive and the Integrated Pollution Prevention and Control (IPPC) Directive. As with previous directives aimed at minimising emission release, part of the benefit of the Industrial Emissions Directive is that it includes several new industrial processes, sets new minimum emission limit values (ELVs) for large combustion plant and addresses some of the implementation issues of the IPPC.

The **Environmental Impact Assessment Directive 2011/92/EU** aims for the environmental impacts from certain projects to be identified and for mitigation measures to be proposed. Environmental Impact Assessments (EIAs) are not mandated for all shale gas operations and would be necessary when operations exceed 500,000m<sup>3</sup> gas extraction or are deemed likely to have significant environmental impacts, which could include impacts from emissions to air, among others.

The European Commission recommendation on minimum principles for the exploration and production of hydrocarbons (such as shale gas) using high volume hydraulic fracturing (2014) has been published to lay down minimum principles which should be taken into account by Member States when developing regulation for hydraulic fracturing. The Recommendation acknowledges that EU legislation was not developed when hydraulic fracturing was occurring in Europe, and that certain environmental aspects, such as strategic planning, underground risk assessment, well integrity, baseline and operational monitoring, capturing methane emissions and disclosure of information on chemicals used on a well by well basis, may not be adequately covered in existing legislation. The Recommendation sets out minimum principles for hydraulic fracturing which should complement existing legislation and specifies that these should be implemented by Member States within six months.

The **Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (1999)** originally set emissions ceilings for 2010 for sulphur, NO<sub>x</sub>, VOCs and ammonia to reduce emissions across Europe. Reductions were focussed in countries which would have the greatest environmental and health impacts and where emissions were relatively cheap to reduce. The protocol has recently been extended with targets to 2020. The Protocol also set limit values for emissions from sources such as combustion plant, cars and HGVs, electricity production, paint and aerosols, among others.

Vehicle standards for pollutant emissions from road vehicles are set in the EU for light-duty and heavy-duty vehicles, the '**Euro Standards**'. Light-duty vehicles such as cars and vans are currently restricted in particulate matter and NO<sub>x</sub> emissions from diesel under Euro 6, while large goods vehicles are limited on CO, NO<sub>x</sub>, hydrocarbon and particulate matter emissions to help improve air quality.

The **Non-Road Mobile Machinery Directive 97/68/EC** and subsequent amendments up to 2012 address air pollution from diesel and spark emission engines from mobile plant such as excavators, bulldozers and compressors. The aim is to progressively reduce polluting emissions of CO, NO<sub>x</sub>, hydrocarbons and particulate matter from mobile exhaust emissions. This legislation applies to new machines only, and does not limit emissions during use. In September 2014, the European Commission proposed simplified regulations with more stringent emission limit values.

## UK

The **Air Quality (Standards) Regulations 2010** transpose into UK law Directive 2008/50/EC on ambient air quality and cleaner air for Europe and Directive 2004/107/EC relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air. The objective of the Regulations is to improve air quality by reducing the impact of air pollution on human health and ecosystems. The standards set out air quality objectives, limit values and target values for pollutants, namely benzene, 1,3 butadiene, carbon monoxide, lead, nitrogen dioxide, PM<sub>10</sub>, sulphur dioxide and PM<sub>2.5</sub>.

The **Air Quality Strategy for England, Scotland, Wales and Northern Ireland (2007)** sets out a way forward for work and planning on air quality issues. It sets out air quality objectives and policy options to improve air quality for the benefit of health and the environment.

The **Environment Act 1995** was enacted to protect and preserve the environment and guard against pollution to air, land or water. It requires local authorities to undertake local air quality management (LAQM) assessments against the standards and objectives prescribed in regulations. Where any of these objectives are not being achieved, local authorities must designate air quality management areas and prepare and implement remedial action plans to tackle the problem.

Under the **Environmental Protection Act 1990**, local authorities can serve an Abatement Notice where a statutory nuisance exists, or is likely to occur or recur. Statutory nuisances include: smoke, fumes or gases, dust, steam or smell or other effluvia arising from premises or development sites which are deemed to be prejudicial to health or a nuisance.

The **Environmental Permitting (England and Wales) Regulations 2010** sets up a pollution control regime. The environmental regulator would specify conditions for environmental permits, for example limiting the type and quantity of emissions released to air. Extractive gases such as those released from flowback fluid are considered mining waste, so the site would need to provide a Waste Management Plan as part of the permit application for a mining waste operation. The Plan must set out objectives to prevent or reduce the production of extractive waste; encourage recovery; and ensure safe disposal. The permit may need to include areas designated for the deposit of waste gases as part of the mining waste facility. An industrial emissions permit would also be required for operations that flare more than 10 tonnes of gas per day.

Planning permission for hydraulic fracturing operations is required under the **Town and Country Planning Act 1990**. In determining whether or not to grant planning permission, this would involve consideration of the effects from traffic and local air pollution, and the effects on the local environment and receptors. Planning permission and any planning conditions would be determined by the local Minerals Planning Authority, which would include local authorities (such as county or unitary council) in England, Wales and Scotland, and the Department of Environment in Northern Ireland, or the National Park Authority if operations are located in a National Park. The **National Planning Policy Framework** is in place at a





national level to set out the Government's planning policies for England, and includes consideration of impacts on air quality.

The ***Environmental Protection (Controls on Ozone Depleting Substances) Regulations 2011*** introduces controls on the production, use and emissions from equipment of a large number of 'controlled substances' that deplete the ozone layer.

Under the ***Sulphur Content of Liquid Fuels (England and Wales) Regulations 2007***, there are restrictions of sulphur in gas oil and heavy fuel oil to help reduce emissions of sulphur dioxide to the atmosphere. Gas oil is restricted to a maximum of 0.1% sulphur by mass, and heavy fuel oil to 1%.

The ***Clean Air Act 1993*** controls the release of 'dark smoke' from chimneys and industrial sites. It also controls grit, dust and fumes from non-domestic furnaces and regulates chimney heights.

# 5. Climate Change

## 5.1 Introduction

Climate change within the context of this review is concerned with increasing the likelihood of climate change effects through greenhouse gas emissions, and the ability to adapt to the effects of climate change such as the occurrence of more extreme weather events.

There are links between climate change and other topics in the study, specifically biodiversity and nature conservation, water, human health and air.

## 5.2 Assessment of Effects

This section comprises of the review of the likely effects on climate change arising from the potential activities that could arise in one of the six main stages of unconventional oil and gas exploration and production. **Table B5.1** presents a summary of the key stages of exploration, production and decommissioning.

Table B5.1 Unconventional Oil and Gas Exploration and Production Lifecycle and Key Activities

Stage	Activities
1	<p><b>Non-intrusive exploration</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Site identification, selection, characterisation;</li> <li>▶ Seismic surveys;</li> <li>▶ Securing of necessary development and operation permits.</li> </ul>
2	<p><b>Exploration drilling and hydraulic fracturing</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Pad preparation road connections and baseline monitoring;</li> <li>▶ Well design and construction and completion;</li> <li>▶ Hydraulic fracturing;</li> <li>▶ Well testing including flaring.</li> </ul>
3	<p><b>Production development</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Pad preparation and baseline monitoring;</li> <li>▶ Facility construction and installation;</li> <li>▶ Well design construction and completion;</li> <li>▶ Hydraulic fracturing;</li> <li>▶ Well testing, possibly including flaring</li> <li>▶ Provision of pipeline connections</li> <li>▶ (Possibly) re-fracturing.</li> </ul>

Table B5.1(continued) Unconventional Oil and Gas Exploration and Production Lifecycle and Key Activities

Stage	Activities
4	<b>Production/operation/maintenance</b> , including: <ul style="list-style-type: none"> <li>▶ Gas/oil production;</li> <li>▶ Production and disposal of wastes/emissions;</li> <li>▶ Power generation, chemical use and reservoir monitoring;</li> <li>▶ Environmental monitoring and well integrity monitoring.</li> </ul>
5	<b>Decommissioning of wells</b> , including: <ul style="list-style-type: none"> <li>▶ Well plugging and testing;</li> <li>▶ Site equipment removal;</li> <li>▶ Environmental monitoring and well integrity monitoring.</li> </ul>
6	<b>Site restoration and relinquishment</b> , including: <ul style="list-style-type: none"> <li>▶ Pre-relinquishment survey and inspection;</li> <li>▶ Site restoration and reclamation.</li> </ul>

Note: Exploration wells most usually move from Stage 2 to Stage 4, though some may be used for long-term production testing and some may be retained and their sites redeveloped as a production project. For the purposes of this review, the appraisal stage (a term commonly used in industry) spans Stages 2 and 3

### Non-intrusive Exploration

Stage 1 of the unconventional oil and gas exploration and production lifecycle would comprise non-intrusive activities. Site identification, selection and characterisation and the securing of regulator approval would be expected to be largely desk-based and in consequence, no substantial effects on climate change would be anticipated from these activities.

Seismic testing would be undertaken during this stage. Vibroseis is a common method of seismic survey and typically involves 3-5 large truck mounted vibrator units which sub-sonically vibrate the ground while a number of support vehicles record the returning shock waves for analysis. In some cases, shot-hole survey techniques may be used. This involves the drilling of a hole with a small diameter for the insertion of explosives which are then detonated with the holes infilled after use.

Greenhouse gas (GHG) emissions will result from associated vehicle movements and the operation of machinery. However, it is anticipated that the intensity of activity would be low and the associated number of vehicle movements would be small such that any effects on climate change are unlikely to be significant in a local or national context.

There may be a requirement for the temporary construction of new roads to facilitate access to sites which could result in disturbance to soils and emissions of carbon dioxide (CO<sub>2</sub>) and methane together with loss of soil carbon sequestration. However, it is assumed that land take would be relatively small and that any soils displaced during construction would be returned following the completion of works. Further, alternatives to access track/road construction may be implemented such as the laying of protection mats that would minimise soil disturbance. Notwithstanding, should significant new road infrastructure be required to facilitate site access then associated emissions may be more substantive.

## Exploration drilling and hydraulic fracturing

### Greenhouse Gas Emissions

Like conventional oil and gas exploration, pad preparation and associated construction activities would generate GHG emissions. Sources of emissions would include the direct or indirect combustion of fossil fuels from construction traffic, plant and generators and the embodied carbon within construction materials. Disturbance to soils and emissions of CO<sub>2</sub> and methane together with loss of soil carbon sequestration may also contribute to climate change, although it is anticipated that sites would be restored following either completion of exploration drilling or decommissioning of wells such that effects would be reduced in longer term (i.e. following exploratory drilling or beyond the site restoration stage, depending on whether a site is taken forward to the production stage). The exact magnitude of emissions related to pad preparation would be dependent on site specific characteristics such as requirements for infrastructure such as roads, the distance to be travelled by vehicles during the transportation of materials and wastes and the carbon content of soils. A report by MacKay and Stone (2013) concerning potential greenhouse gas emissions associated with shale gas extraction and use<sup>1</sup> estimates (based on median values of GHG emissions taken from a range of source data) that site preparation would generate 229 tCO<sub>2</sub>eq per well (taking into account GHG emissions during both stages 2 and 3 of the unconventional oil and gas exploration and production lifecycle).

GHG emissions would also be generated from the energy used in the drilling of boreholes, the volume of which would depend on the depth and length of drilling required and the number of wells drilled. There would also be additional emissions associated with transportation and treatment of wastes (e.g. mud and cuttings) arising from drilling activities and from the embodied carbon associated with well construction (associated with the casing and cementation). However, Broderick *et al* (2011) highlight that the initial drilling stages would be similar to conventional oil and gas such that the level of emissions generated would be comparable<sup>2</sup>. In the case of a proposed temporary shale gas exploration site in Lancashire, England<sup>3</sup>, the operator (Cuadrilla) has estimated that emissions associated with drilling across four wells would constitute 9.5% of all project emissions (11,592 tCO<sub>2</sub>eq).

The hydraulic fracturing process is usually powered by large, diesel-fired internal combustion engines. A report by AEA (2012) concerning the climate impact of potential shale gas production in the EU states that more energy is required to fracture the formation than required to drill the wellbore<sup>4</sup> (although alternative lighter fuels or electricity could be used). However, Cuadrilla has estimated that hydraulic fracturing would generate only 2.3% of all project emissions (3,581 tCO<sub>2</sub>eq) (compared to estimated emissions of 11,592 tCO<sub>2</sub>eq during drilling) in respect of their proposed temporary shale gas exploration site in Lancashire<sup>5</sup>. Additional emissions are generated by the hydraulic fracturing process due to the requirement for the transportation and treatment of large volumes of water, sand and chemicals for the proppant fluids, as well as from the embodied carbon in the chemicals themselves and other additional construction materials (e.g. well casing).

The exact volume of GHG emissions associated with hydraulic fracturing activities depends upon a number of factors including the length of the well bore, quantities of water and other chemicals required for fracturing, treatment and transportation requirements. MacKay and Stone (2013) estimate that drilling and hydraulic fracturing operations during the pre-production phase (i.e. stages 2 and 3 of the unconventional oil and gas exploration and production lifecycle for the purposes of this review) would generate 711 tCO<sub>2</sub>eq per well. This is based on median values of GHG emissions taken from a range of data sources where the maximum value reported was 1,790 tCO<sub>2</sub>eq per well. Indirect emissions associated with the transportation of water

<sup>1</sup> MacKay, D.J.C. and Stone, T.J. (2013) *Potential Greenhouse Gas Emissions Associated with Shale Gas Extraction and Use*. Report on behalf of DECC. Available from [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/237330/MacKay\\_Stone\\_shale\\_study\\_report\\_09092013.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/237330/MacKay_Stone_shale_study_report_09092013.pdf) [Accessed April 2015].

<sup>2</sup>Broderick, J., *et al* (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/sites/default/files/coop\\_shale\\_gas\\_report\\_update\\_v3.10.pdf](http://www.tyndall.ac.uk/sites/default/files/coop_shale_gas_report_update_v3.10.pdf) [Accessed April 2015].

<sup>3</sup>Cuadrilla Bowland Ltd (2014) *Temporary Shale Gas Exploration Preston New Road, Lancashire: Environmental Statement*. Available from [http://www.cuadrillaresources.com/wp-content/uploads/2014/07/PNR\\_ES\\_Vol1\\_Environmental\\_Statement.pdf](http://www.cuadrillaresources.com/wp-content/uploads/2014/07/PNR_ES_Vol1_Environmental_Statement.pdf) [Accessed April 2015].

<sup>4</sup> AEA (2012) *Support to the identification of potential risks for the environment and human health arising from hydrocarbon operations involving hydraulic fracturing in Europe*. Available from <http://ec.europa.eu/environment/integration/energy/pdf/fracking%20study.pdf> [Accessed April 2015].

(including wastewater transport and treatment) are estimated to be 21 tCO<sub>2</sub>eq per well and the embodied carbon in chemicals 300 tCO<sub>2</sub>eq.

AEA (2012) and MacKay and Stone (2013) state that well completion is likely to be the main source of GHG emissions during the pre-production phase. Following the completion of hydraulic fracturing, a combination of fracturing fluid and water is returned to the surface (flowback) which includes methane. MacKay and Stone (2013) estimate GHG emissions associated with well completion to be 2,788 tCO<sub>2</sub>eq per well (during stages 2 and 3) based on the median values of GHG emissions from a range of source data and assuming that 90% of methane emissions released during flowback are captured and flared. However, it should be noted that estimates of the volume of gas released during well completion vary significantly. In this respect, the maximum emissions cited in the MacKay and Stone (2013) report (assuming again that 90% of methane emissions released during flowback are captured and flared) is 8,469 tCO<sub>2</sub>eq per well. In the case of a proposed temporary shale gas exploration site in Lancashire, England<sup>5</sup>, meanwhile, the operator (Cuadrilla) has estimated that emissions associated with flaring across four wells would be approximately 89,000 tCO<sub>2</sub>eq (to be captured under the EU Emissions Trading Scheme).

Alongside geology and well productivity, the method of well completion is a key factor in influencing levels of GHG emissions. Gas generated during well completion may be flared (i.e. combusted in an open flame), cold vented or captured/recovered (known as reduced emissions completion (REC) or green completions<sup>1</sup>). Broderick *et al* (2011) outline a number of factors that may impact upon the potential for gas to be vented, flared or processed, including:

- ▶ The potential for gas to be contaminated;
- ▶ Inconsistent and low flow rates;
- ▶ Levels of methane dissolved in flowback water (open pit collection necessarily allows this gas to be released to the atmosphere, enclosed tanks afford the opportunity of collection for flaring); and
- ▶ Regulatory requirements (in the UK, for example, flaring is regulated by the Department of Energy and Climate Change (DECC) as part of a licence condition and it is DECC's established policy that flaring should be reduced to the economic minimum)<sup>6</sup>.

Venting would be expected to generate the highest volume of emissions as gas would be directly released to the atmosphere. In the UK, venting is not permitted unless necessary for safety reasons. With regard to flaring, Broderick *et al* (2011) highlight that this method reduces climate change impacts by converting methane and other volatile organic compounds (VOCs) to CO<sub>2</sub>, although it may cause local environmental impacts. Green completions (or REC), meanwhile, usually involve the use of portable equipment which consists of a skid or trailer, mounted set of piping connections and vessels that include a plug catcher, a sand trap and a three phase separator. The plug catcher is connected to the wellhead and is used to remove any large solids from the drilling and completion. The sand trap removes finer solids present in the production stream, while the three phase separator removes water and condensate from the gas. Liquid hydrocarbons may be collected during completion and sold for additional revenue. Water is typically stored in water tanks or in a reserve impoundment for later treatment or disposal. If necessary, captured gas may enter a portable dehydrator at the well site or it may be routed to a permanent glycol dehydration unit in the gathering system, if one is available at or near the site, to remove heavy moisture from the gas before it enters the sales pipeline<sup>7</sup>.

Tyner and Johnson's (2014) analysis<sup>8</sup> of industry-reported well activity and production data for Alberta in 2011 highlights that green completions were used at approximately 53% of wells completed, and in other cases the majority (99.5%) of flowback gases were flared rather than vented. In the US, operators will be

<sup>5</sup> Cuadrilla Bowland Ltd (2014).

<sup>6</sup> AMEC (2013) *Strategic Environmental Assessment for Further Onshore Oil and Gas Licensing: Environmental Report*. Prepared on behalf of the Department of Energy and Climate Change. Available from [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/273997/DECC\\_SEA\\_Environmental\\_Report.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/273997/DECC_SEA_Environmental_Report.pdf) [Accessed April 2015].

<sup>7</sup> IPIECA (2013) *Green Completions*. Available from <http://www.ipieca.org/energyefficiency/solutions/78161> [Accessed November 2014].

<sup>8</sup> Tyner, D.R. and Johnson, M.R. (2014) *Emission Factors for Hydraulically Fractured Gas Wells Derived Using Well- and Battery-level Reported Data for Alberta, Canada*, in *Environmental Science and Technology* 2014, 48, 14772–14781. Available from <http://www.ncbi.nlm.nih.gov/pubmed/25402949> [Accessed April 2015].

required (from 2015) to use green completions under the Environment Protection Agency's (EPA) 2012 oil and gas standards (during a transitional period that ends in January 2015 they will have the option to flare)<sup>9</sup>. Additionally, the US Natural Gas STAR Programme encourages oil and natural gas companies to adopt proven, cost-effective technologies and practices that improve operational efficiency and reduce methane emissions including in respect of well completion. The STAR Programme has been subsequently expanded internationally<sup>10</sup>.

In its review of completions and associated gas<sup>11</sup>, the US EPA (2014) highlights that the effectiveness of green completions can vary according to reservoir characteristics and other parameters including length of completion, number of fractured zones, pressure, gas composition and fracturing technology/technique. The review notes that a number of limitations exist for performing green completions, including:

- ▶ Proximity of pipelines for the sale of captured gas;
- ▶ Pressure of produced gas (which may not be sufficient to overcome the sales backline pressure); and
- ▶ Inert gas concentration (which may exceed sales line concentration limits).

Notwithstanding, the US EPA report indicates that a reduction in emissions of 90% has been estimated (based on data for more than 12,000 well completions) and that any amount of gas that cannot be recovered can be directed to a completion combustion device in order to achieve a minimum 95% reduction in emissions compared to venting. The review also highlights a range of emerging technologies for controlling emissions including liquefaction of natural gas, natural gas liquids recovery, gas reinjection and electricity generation. Emissions measurements for 27 well completions in the US reported by Allen *et al* (2013), meanwhile, range from less than 0.01 megagram (Mg) of methane (0.25 tCO<sub>2</sub>eq) to more than 17 Mg (6,375 tCO<sub>2</sub>eq), with an average value of 1.7 Mg (42.5 tCO<sub>2</sub>eq)<sup>12</sup>. They note that well completions with the lowest emissions (i.e. those completion events where 99% of potential emissions were captured or controlled) were those in which the flowback from the well was sent immediately to a separator and all of the gases from the separator were sent to sales. MacKay and Stone (2013) also note that if 100% of methane released during flowback was captured and injected into the grid (if grid connection was available at this stage) there would be no emissions associated with well completion.

A further source of GHG emissions are unintentional methane leaks (known as fugitive emissions). The work of Jackson *et al* (2013), amongst others, highlights that a potential source of fugitive emissions could also be from gas that has escaped into aquifers as a result of poor well construction during drilling, production or after abandonment<sup>13</sup> and through soil<sup>14</sup>. In the US, for example, Vidic *et al* (2013) derived a figure of 3.4% well leakage based on data from the Department of Environmental Protection<sup>15</sup>. From a UK perspective, MacKay and Stone (2013) consider there to be sufficient regulations in place that leakage of gas into aquifers is unlikely to occur whilst the risk of contamination as a result of the hydraulic fracturing process is widely regarded to be low in Europe due to the likely distance between the fractures and aquifers<sup>16</sup> (the potential for leakage of gas into aquifers is considered further in **Appendix B.3 Water and**

<sup>9</sup> EPA (2012) *Oil and Natural Gas Sector: New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants Reviews; Final Rule*. Available from <http://www.gpo.gov/fdsys/pkg/FR-2012-08-16/pdf/2012-16806.pdf> [Accessed November 2014].

<sup>10</sup> For further information see US EPA (2015) Natural Gas STAR Programme. Available from <http://www.epa.gov/gasstar/basic-information/index.html> [Accessed November 2014].

<sup>11</sup> US EPA (2014) *Oil and Natural Gas Sector Hydraulically Fractured Oil Well Completions and Associated Gas during Ongoing Production: Report for Oil and Natural Gas Sector Oil Well Completions and Associated Gas during Ongoing Production Review Panel*. Available from <http://www.epa.gov/airquality/oilandgas/2014papers/20140415completions.pdf> [Accessed November 2014].

<sup>12</sup> Allen, D.T., Torres, V.M., Thomas, J., Sullivan, D.W., Harrison, M., Hendler, A., Herndon, S.C., Kolb, C.E., Fraser, M.P., Hill, D. Lamb, B.K. Miskimins, J., Sawyer, R.F. and Seinfeld, J.H. (2013) *Measurements of methane emissions at natural gas production sites in the United State*. PNAS (2013) published ahead of print September 16, 2013, doi:10.1073/pnas.1304880110. Available from <http://www.pnas.org/content/110/44/17768.abstract> [Accessed April 2015].

<sup>13</sup> Jackson *et al* (2013) *Increased stray gas abundance in a subset of drinking water wells near Marcellus shale gas extraction*, PNAS, 110 (28), 11250-11255. Available from <http://www.pnas.org/content/110/28/11250.short> [Accessed November 2014].

<sup>14</sup> Teasdale, J.C., Hall, J.A., Martin, J.P., Manning, D.A.C. (2014) *Ground Gas Monitoring: Implications for Hydraulic Fracturing and CO<sub>2</sub> Storage*. Environmental Science and Technology 2014, 48, 13610-13616. Available from <http://pubs.acs.org/doi/pdf/10.1021/es502528c> [Accessed April 2015].

<sup>15</sup> Vidic *et al*. (2013) *Impact of shale gas development on regional water quality*. Science 17 May 2013; Vol. 340 no. 6134 1235009. Available from <http://www.sciencemag.org/content/340/6134/1235009.abstract> [Accessed April 2015].

<sup>16</sup> AEA (2012).



**Flood Risk**). However, based on monitoring data obtained from landfill sites in the UK, Teasdale *et al* (2014)<sup>14</sup> conclude that atmospheric pressure is a key influence on gas movement. As atmospheric pressure varies over time the implication for shale gas exploration and production is that there is a high likelihood of monitoring missing an emission event. In consequence, they highlight a potential need for longer statutory monitoring in order to identify any longer-term seasonal variations in the ground gas regime<sup>17</sup>.

In its review of oil and gas sector leaks, the US EPA (2014) identifies a number of technologies currently in use to detect leaks including analyser, optical gas imaging cameras, soap solution, acoustic leak detection, ambient monitors and electronic screening devices<sup>18</sup>. The US Natural Gas STAR Programme has recommended a number of technologies and practices designed to reduce leakage<sup>19</sup> whilst from a UK perspective, United Kingdom Onshore Oil and Gas (UKOOG) guidelines<sup>20</sup> set out good practice in minimising fugitive emissions, stating (p.31):

*“Operators should plan and then implement controls in order to minimise all emissions. Operators should be committed to eliminating all unnecessary flaring and venting of gas and to implementing best practices from the early design stages of the development and by endeavouring to improve on these during the subsequent operational phases.”*

Reflecting this guidance, the operator of a proposed temporary shale gas exploration site in Lancashire, England<sup>21</sup> has indicated that a range of measures are to be implemented to control fugitive emissions, including:

- ▶ The appropriate maintenance of equipment and pipework;
- ▶ Hydrostatic pressure testing of all equipment and pipework used to process or move gas around the site to identify potential leaks;
- ▶ The use of an enclosed completions system to enable gas to be burnt via flare instead of being vented from tanks for lagoons; and
- ▶ Regular fugitive emissions monitoring.

The operator in this instance estimates that these measures are expected to achieve a 97-98% reduction in fugitive emissions (total fugitive emissions have been calculated as approximately 16,000 tCO<sub>2</sub>eq across four wells).

### Climate Change Impacts

Construction and exploration could be affected by climate change where sites are located, for example, in coastal areas that may be affected by coastal inundation or sea level rise or in areas of flood risk that could be susceptible to extreme weather conditions. This risk is similar to other types of development. Climate change effects such as intensified weather events therefore have the potential to affect activities during Stage 2. However, in view of the nature of the development and associated activities, together with the duration of the exploration stage (6 years under the initial term for the UK onshore Petroleum Exploration and Development Licence), it is not expected that associated activities would be substantially affected by the impacts of climate change.

Given the requirement for hydraulic fracturing during this stage and associated water consumption (10,000m<sup>3</sup> – 25,000m<sup>3</sup> per well), there is the potential for activities to be both affected by climate change impacts on water resource availability and/or to affect future water resource availability, although this is dependent on existing and future local water resource availability (see **Appendix B.3 Water and Flood Risk** for further information in respect of the effects of shale gas operations on water resource availability).

<sup>17</sup> Current UK practice is to take point measurements from all monitoring wells on a site for a minimum investigation period of 6 weeks. It is required that at least one of the point measurements needs to be taken during falling atmospheric pressure.

<sup>18</sup> US EPA (2014) *Oil and Natural Gas Sector Leaks: Report for Oil and Natural Gas Sector Leaks Review Panel April 2014*. Available from <http://www.epa.gov/airquality/oilandgas/2014papers/20140415leaks.pdf> [Accessed November 2014].

<sup>19</sup> For further information see US EPA (2015) *Recommended Technologies and Practices*. Available from <http://www.epa.gov/gasstar/tools/recommended.html> [Accessed November 2014].

<sup>20</sup> UKOOG (2013) *UK Onshore Shale Gas Well Guidelines: Exploration and appraisal phase*. Available from <http://www.ukoog.org.uk/images/ukoog/pdfs/ShaleGasWellGuidelines.pdf> [Accessed November].

<sup>21</sup> Cuadrilla Bowland Ltd (2014).

## Production Development

The range and type of effects associated with Stage 3 of the unconventional oil and gas exploration and production lifecycle would be similar to those identified under Stage 2. This stage would require additional infrastructure including storage tanks, road connections and the installation of pipelines required to collect natural gas for transfer to the existing natural gas pipeline infrastructure. This would generate further GHG emissions associated with construction traffic, plant and generators and the embodied carbon within construction materials together with emissions of CO<sub>2</sub> and methane associated with soil disturbance and loss of soil carbon sequestration which may contribute to climate change. GHG emissions associated with the drilling of wells and fracturing would also be expected to be greater during this stage, reflecting the construction of additional wells. However, for the purposes of this study, estimates of GHG emissions cover activities under both stages 2 and 3 and are therefore not repeated here to avoid double counting.

As with Stage 2, construction could be affected by climate change where sites are located, for example, in coastal areas that may be affected by coastal inundation or sea level rise or in areas of flood risk that could be susceptible to extreme weather conditions. Climate change effects such as intensified weather events therefore have the potential to affect activities during Stage 3.

## Production/operation/maintenance

### Greenhouse Gas Emissions

During the production stage there would be GHG emissions associated with power generation and onsite combustion plant (e.g. generators) and from vehicle movements related to the transportation of maintenance workers and wastes to/from sites. However, the AEA (2012) report concerning the climate impact of potential shale gas production in the EU states (at page 28) that “*Since most of the emissions in this stage arise from equipment which would be used for conventional gas production, while there are significant emissions during the production stage, they are not significantly different from conventional gas production*”.

Like the exploratory stage, a further source of GHG emissions during this stage is likely to be fugitive methane and other trace hydrocarbons via leakages from on-site equipment including valves, flanges and compressors as well as from flaring and venting. Across the lifetime of a well, a study in the US has estimated 4 - 8% of methane from shale gas production is released into the atmosphere from venting and fugitive emissions (where venting is permitted).<sup>22</sup> Like AEA (2012), MacKay and Stone (2013) assume that GHG emissions from these sources would be similar to those associated with conventional gas production. From a UK perspective, the Digest of UK Energy Statistics estimates emissions associated with production and processing of conventional gas to be 100 tCO<sub>2</sub>e per million m<sup>3</sup>. Based on MacKay and Stone’s central estimate of well productivity (estimated total of 85 million m<sup>3</sup> over the 20 year lifetime of the wells<sup>23</sup>), it is assumed that total GHG emissions per well would be 8,500 tCO<sub>2</sub>e during production.

An additional source of GHG emissions during this stage (compared to conventional oil and gas production) would be any re-fracturing required in order to stimulate the flow of shale gas. In the US, the frequency of re-fracturing is not certain and is estimated to be once per 5 – 10 years on average, if at all. For the purposes of their report, AEA (2012) assumed that a well would be re-fractured between 0 and 4 times over a well lifetime of up to 40 years. This would generate additional GHG emissions similar to those noted in respect of hydraulic fracturing and well completion during stages 2 and 3 (on a per well basis) although as with stages 2 and 3, emissions are likely to vary depending on site specific characteristics and there may also be opportunities to reduce emissions depending on well completion methods.

The accumulation of liquids in mature wells can impede and sometimes halt gas production. When the accumulation of liquid results in the slowing or cessation of gas production, the removal of fluids is required in order to maintain production. This is known as ‘liquid unloading’. The US EPA (2014) states that emissions to the atmosphere during liquid unloading events are a potentially significant source of VOCs and note that the 2014 GHG Inventory estimates the 2012 liquids unloading emissions to be 14% of natural gas

<sup>22</sup> Howarth, R.W., Santoro, R. and Ingraffea, A. (2011) *Methane and the greenhouse-gas footprint of natural gas from shale formations*, Climatic Change, 106 (4), 679-690. Available from <http://www.acsf.cornell.edu/Assets/ACSF/docs/attachments/Howarth-EtAl-2011.pdf> [Accessed April 2015].

<sup>23</sup> 20 years represents the total licence period for Petroleum Exploration and Development Licences in the UK. It should be noted that a well’s lifetime may extend beyond a 20 year period (up to around 40 years).

production sector emissions in the US, although the majority of emissions from liquid unloading events come from a small percentage of wells with the length of time of each event and the frequency of events influencing the volume of emissions<sup>24</sup>. The measurement of methane emissions from production sites in the US by Allen *et al* (2013) identified that methane emissions from nine unloading events in the US ranged from less than 0.02 Mg (0.5 tCO<sub>2</sub>eq) to 3.7 Mg (92.5 tCO<sub>2</sub>eq) with some wells being unloaded only once during their current life and others being unloaded monthly (the average emission per unloading event was 1.1 Mg of methane).

The US EPA (2014) identify a number of technologies that have been developed to remove liquids from wells that generate fewer emissions (compared to blowdowns which involve shutting the well to allow bottom hole pressure to increase, then venting the well to the atmosphere). These technologies include well swabbing, velocity tubing and artificial lift. Plunger lifts are the most common technology employed in the US, although the US EPA highlights that the emissions reduction efficiency plunger lifts can achieve varies greatly depending on how the system is operated.

Indirectly, the combustion of extracted hydrocarbons would generate approximately 190 gCO<sub>2</sub>e/kWh (which represents combustion emissions for methane). From a European perspective, the AEA (2012) review states that emissions from electricity generated from shale gas are 2-10% lower than electricity generated from conventional pipeline gas located outside of Europe (in Russia and Algeria), and 7-10% lower than electricity generated from LNG imported into Europe. In a UK context, MacKay and Stone (2013) state that lifecycle emissions associated with shale gas (between 200 and 253 g CO<sub>2</sub>e per kWh<sub>(th)</sub>) are comparable to gas extracted from conventional sources (199-207 g CO<sub>2</sub>e per kWh<sub>(th)</sub>) and lower than LNG (233 – 270 g CO<sub>2</sub>e per kWh<sub>(th)</sub>) (assuming 90% of methane is captured and flared during well completion). When shale gas is used for electricity generation, MacKay and Stone (2013) highlight that its carbon footprint is significantly lower than coal and point to US experience where a switch from coal to gas in electricity production has “*significantly reduced the USA’s emissions rate*”.

However, recent literature has come to different conclusions regarding lifecycle GHG emissions from shale gas production and use relative to that of conventionally produced natural gas or other fuel sources such as coal<sup>25</sup>. Brandt *et al* (2014)<sup>26</sup> state that because of the high global warming potential of methane, which is a major component of natural gas, climate change benefits depend on system leakage rates. Their review of published emissions estimates concludes that official inventories have underestimated methane emissions and that there is a poor understanding of excess methane, although they state that hydraulic fracturing is unlikely to be a dominant contributor to emissions. A review of recent research concerning lifecycle GHG emissions from shale gas (and conventional gas) by Howarth (2014)<sup>27</sup>, meanwhile, highlights that shale gas and conventional natural gas have a larger GHG than coal or oil for both electricity and heat generation<sup>28</sup>. On balance, the more commonly accepted view presented in the literature reviewed as part of this study would seem to indicate that lifecycle GHG emissions from shale gas are less than those of other fossil fuels. In this regard, Heath *et al* (2014) have attempted to harmonize previously published estimates of lifecycle GHG emissions for shale gas, conventional gas and coal for electric power generation<sup>25</sup>. They highlight that, even following harmonization, there remains variability in the results due to (inter-alia) gas type and play assessed, evaluation year and methane leakage rate. Notwithstanding, they conclude that per unit electrical output, “*the central tendency of current estimates of GHG emissions from shale gas-generated electricity indicates life cycle emissions less than half those from coal and roughly equivalent to those from conventional natural gas*”.

<sup>24</sup> US EPA (2014) *Oil and Natural Gas Sector Liquids Unloading Processes: Report for Oil and Natural Gas Sector Liquids Unloading Processes Review Panel April 2014*. Available from <http://www.epa.gov/airquality/oilandgas/2014papers/20140415liquids.pdf> [Accessed November 2014].

<sup>25</sup> Heath, G.A. O'Donoghue, P. Arent, D.J. and Bazilian, M. (2014) *Harmonization of initial estimates of shale gas life cycle greenhouse gas emissions for electric power generation*, in PNAS August 5, 2014 vol. 111 no. 31. Available from <http://www.pnas.org/content/111/31/E3167.abstract?tab=ds> [Accessed April 2015].

<sup>26</sup> Brandt, A.R. *et al* (2014) *Methane Leaks from North American Natural Gas Systems*, Science, Vol 343 14 February 2014. Available from <http://www.novim.org/images/pdf/ScienceMethane.02.14.14.pdf> [Accessed April 2015].

<sup>27</sup> Howarth, R.W. (2014) *A bridge to nowhere: methane emissions and the greenhouse gas footprint of natural gas*, Energy Science and Engineering 2014; 2(2): 47–60. Available from [http://www.eeb.cornell.edu/howarth/publications/Howarth\\_2014\\_ESE\\_methane\\_emissions.pdf](http://www.eeb.cornell.edu/howarth/publications/Howarth_2014_ESE_methane_emissions.pdf) [Accessed April 2015].

<sup>28</sup> This conclusion is based on a 20-year time period for comparing the warming potential of methane to CO<sub>2</sub> as opposed to 100 years which is commonly adopted in other life cycle assessments. In Howarth's opinion this reflects the fact that methane has an atmospheric lifetime of only 12 years or so, while CO<sub>2</sub> has an effective influence on atmospheric chemistry for a century or longer.

The extent to which domestic production and consumption of shale gas would affect GHG emissions would vary subject to changes in prices affecting demand and supply relative to other sources of energy, national policy and legislation on energy and, in the long term, changes in investment in alternative supplies of gas and other energy sources. In consequence, MacKay and Stone (2013 p29) conclude that the effects of shale gas use “*will vary over time in ways that are challenging to predict*”. They also stress the need to consider the impact of shale gas production and consumption on global emissions and point to the fact that the switch to shale gas in the US has increased exports of coal, increasing the carbon intensity of energy production in other countries. Further, it is also important to acknowledge that shale gas production and consumption could displace lower carbon energy sources. In this respect, paragraph 159 of the UK Energy and Climate Change Committee (2011) report on shale gas states that “*in planning to decarbonise the energy sector DECC should generally be cautious in its approach to natural gas. Although gas emissions are less than coal they are higher than many lower carbon technologies*”.

The Intergovernmental Panel on Climate Change (IPCC) Working Group 3 (2014) 5<sup>th</sup> Assessment Report<sup>29</sup> concludes that alongside the expansion of low-carbon technology deployment, fossil fuels will play a diminishing role in energy generation with unconventional gas having the potential to lower emissions for a transitional period where gas competes with coal (if fugitive emissions and energy requirements associated with hydraulic fracturing can be minimised). In this context, a report by the UK Energy Research Centre (2014)<sup>30</sup> assesses the extent to which natural gas has the potential to act as a ‘bridge’ to a low carbon future on both a global and regional basis out to 2050. It concludes that there is a good potential for gas to act as a transition fuel up to 2035 but that this projection is subject to a number of conditions/caveats, including:

- ▶ the role of gas as a transition fuel is time-limited - global gas consumption must decline in all years after 2035;
- ▶ the absolute and relative increase in gas consumption must occur alongside a much greater reduction in coal consumption;
- ▶ gas is only a short-term complement to the much larger increase in low-carbon energy sources that must occur to replace the reduction in coal consumption and for the low-carbon transition actually to be achieved;
- ▶ carbon capture and storage (CCS) is of particular importance; and
- ▶ gas is able to play a bridging role in some regions but not in others with more limited potential in Africa, Canada, Central and South America, the Middle East and Mexico.

### Climate Change Impacts

Similar to stages 2 and 3, production could be affected by climate change. Climate change effects such as intensified weather events therefore have the potential to affect activities during Stage 4, particularly given the fact that production would take place over a relatively long time frame (20 years) during which time the impacts of climate change (e.g. sea level rise) could become more pronounced.

Given the likely requirement for re- fracturing during this stage and associated water consumption, there is the potential for activities to be both affected by climate change impacts on water resource availability and/or to affect future water resource availability, although this is dependent on existing and future local water resource availability.

### Decommissioning of wells

Following production, wells must be properly closed with cement plugs and/or mechanical barriers in the wellbore to eliminate the pathway to the surface or freshwater sources. The inadequate sealing of wells could therefore result in the release of fugitive emissions. AEA (2012) state that leakage or failure rates for modern plug and abandonment procedures are not known although data reported for oil and shallow gas wells in 1993 in Western Canada indicate that 45% of the surveyed wells had gas migration. A recent study

<sup>29</sup> Intergovernmental Panel on Climate Change (IPCC) Working Group 3 (2014) *Climate Change 2014: Mitigation of Climate Change. 5th Assessment Report*. Available from <https://www.ipcc.ch/report/ar5/wg2/> [Accessed April 2015].

<sup>30</sup> UK Energy Research Centre (2014) *A Bridge to a Low-Carbon Future? Modelling the Long-Term Global Potential of Natural Gas*. Available from <https://www.bartlett.ucl.ac.uk/sustainable/documents-news-events/gas-as-a-bridge> [Accessed April 2015].



of 19 abandoned wells in Pennsylvania by Kang (2014)<sup>31</sup>, meanwhile, identified methane emissions from plugged wells which may be due to degradation of the plug and wellbore integrity, the lack of monitoring and maintenance, and/or poor well completions. Although it is not clear whether the wells surveyed were recently abandoned (or if they were related to conventional and/or unconventional oil and gas exploration and production), the findings of the study would suggest a need for further research/monitoring, guidance and, potentially, regulation in this area. In this respect, Kang notes that in the US, abandonment procedures for oil and gas wells have been motivated mainly by oil and gas resource conservation and protection and groundwater protection but not by the consideration of methane emissions. Within the UK, Davies et al<sup>32</sup> noted that between 2000 and 2013, “no [pollution] incidents were reported at well sites in the UK that were inactive or abandoned”.

During decommissioning, there would be emissions of GHGs associated with the use of machinery and plant as well as from construction traffic. There would also be emissions associated with the embodied carbon in concrete used to plug wells and, potentially, the treatment of any waste arisings.

Associated works may require the clearance of vegetation and loss of soil layers which could result in emissions of CO<sub>2</sub> and methane together with loss of soil carbon sequestration. However, it is not expected that the area of land required to undertake decommissioning activities (beyond existing well pads) would be significant. In this respect, AEA (2012, p69) note that there is generally little difference between conventional and unconventional wells in the post-abandonment phase and that the consequences for land take would be “comparable with many other industrial and commercial land-uses, and are of no more than minor significance”.

The total magnitude of GHG emissions associated with this stage would be dependent on site specific characteristics such as requirements for infrastructure such as roads, the distance to be travelled by vehicles during the transportation of materials and wastes and the carbon content of any soils displaced. However, it is not expected that emissions would be of a magnitude considered to be nationally significant but instead be similar to those associated with the decommissioning of conventional oil and gas wells.

Decommissioning could be affected by climate change where sites are located, for example, in coastal areas that may be affected by coastal inundation or sea level rise or in areas of flood risk that could be susceptible to extreme weather conditions. Climate change effects such as intensified weather events therefore have the potential to affect activities during Stage 5 particularly given the fact that decommissioning would take place in the longer term (i.e. beyond the lifetime of a well) during which time the impacts of climate change (e.g. sea level rise) could become more pronounced. This risk would be similar to that associated with the decommissioning of conventional oil and gas wells.

### Site restoration and relinquishment

Like site restoration activities associated with conventional oil and gas wells, it is expected that in most cases all associated infrastructure and hardstanding would be removed during the site restoration and relinquishment stage. Due to the need for invasive demolition techniques and land excavation, there would be GHG emissions associated with the use of plant and from construction traffic. There may also be additional GHG emissions related to the treatment of wastes.

Following the completion of site restoration activities, there would be no further GHG emissions or energy use, reducing effects on climate change in the longer term. Depending on the end use of well pad sites (which would be determined on a site-by-site basis following discussions between the operator and the regulator(s)), there may be opportunities to enhance carbon sequestration through rehabilitation and re-vegetation. Site restoration may also provide an opportunity to enhance climate change resilience through measures such as green infrastructure provision that reduces surface water run-off or flood attenuation schemes. However, the extent to which such measures could be implemented would be dependent on a

<sup>31</sup> Kang, M. (2014) CO<sub>2</sub>, Methane, and Brine Leakage through Subsurface Pathways: Exploring Modelling, Measurement, and Policy Options. A Dissertation Presented to the Faculty of Princeton University in Candidacy for the Degree of Doctor of Philosophy. Recommended for Acceptance by the Department of Civil and Environmental Engineering. Note that the findings of the study are subject to peer review.

<sup>32</sup> Davies, R.J. Almond, S. Ward, R.S. Jackson, R.B. Adams, C. Worrall, F. Herringshaw, L. Gluyas, J. Whitehead, M.A.(2014), *Oil and gas wells and their integrity: Implications for shale and unconventional resource exploitation*, Marine and Petroleum Geology. Available from <https://www.dur.ac.uk/resources/refine/Publishedversion.pdf> [Accessed April 2015].

site's location, characteristics and end use and in this respect AEA (2012) highlight that it may not be possible to return entire sites to beneficial use due to, for example, concerns regarding public safety. The report states (at page 69) that over a wider area "*this could result in a significant loss of land, and/or fragmentation of land area such as an amenity or recreational facility, valuable farmland, or valuable natural habitat*".

## 5.3 Mitigation Measures

The following section sets out the potential mitigation measures available at each stage of the project life cycle.

### Non-intrusive Exploration

- ▶ The feasibility of measures to reduce GHG emissions through and related to the permitting process should be considered. These measures may include, for example:
  - ▶ development of guidance suggesting measures to reduce GHG emissions during all stages of the unconventional oil and gas exploration of production lifecycle;
  - ▶ discussion with regulators on appropriate mandatory requirements to be applied at each stage to ensure that the best technology is implemented in all cases (as per MacKay and Stone, 2013); and
  - ▶ implementation of GHG emissions recording and monitoring protocols, reflecting recommendations contained in the AEA (2012) report concerning the climate impact of potential shale gas production in the EU and of MacKay and Stone (2013).

### Exploration drilling and hydraulic fracturing

As for Stage 1, but also including:

- ▶ Site selection should be informed by an assessment of flood risk to ensure that risks associated with climate change impacts are identified and addressed (e.g. through the implementation of sustainable drainage systems). During the site selection process, careful consideration should be given by the operator to the avoidance of carbon sinks (e.g. peats);
- ▶ Where possible, measures should be taken to offset (at least in part) GHG emissions arising from construction and operational activities. These measures may include, for example:
  - ▶ the use of construction materials with low embodied carbon;
  - ▶ measures to reduce private vehicle use for workers;
  - ▶ the use of low emission vehicles or HGVs conforming to the highest available standards for vehicle emissions;
  - ▶ the use of low emissions equipment and alternative energy sources;
  - ▶ development of a transport plan to reduce HGV traffic (for example through load sharing); designate parking and storage areas; and identify appropriate transport routes and times e.g. avoiding peak traffic hours to minimise congestion and idling emissions;
  - ▶ sourcing local materials, personnel, equipment and waste disposal to help reduce vehicle movements to the site;
  - ▶ connecting to water supplies and wastewater infrastructure to reduce requirements to tanker water to and from site, reducing emissions from vehicles;
  - ▶ provision for the transportation of materials and construction wastes by rail where practicable;



- ▶ identifying opportunities for the on-site reuse, recycling and recovery of inert and non-hazardous waste; and
- ▶ where possible, retaining equipment on-site.
- ▶ Reflecting the recommendations identified by MacKay and Stone (2013), operators should:
  - ▶ in managing vented or flared methane throughout the exploration, pre-production and production of shale gas, adopt the principle of reducing emissions to as low a level as reasonably practicable (ALARP); and
  - ▶ monitor their sites to: (1) ensure early warning of unexpected leakages; and (2) obtain emissions estimates for regulators and government. This may include, for example, ambient air monitoring, hydrostatic pressure testing of pipework and equipment used to transport gas, regular seismic monitoring and monitoring of fracture propagation.
- ▶ Reflecting the recommendations of Teasdale *et al* (2014), monitoring of emissions should be undertaken over a sufficient duration so as to capture seasonal variations in the ground gas regime.
- ▶ Enclosed completion systems should be adopted to avoid venting from lagoons or tanks;
- ▶ Liquid unloading from wells should be undertaken utilising low emissions technologies such as well swabbing, velocity tubing, artificial lift and plunger lifts;
- ▶ Governments, regulators and industry should undertake research into shale gas production with a view to developing more effective extraction techniques, such as improved REC and self-healing cements, reduced water consumption and vehicle demand which minimise wider environmental impacts including whole-life-cycle GHG emissions; and
- ▶ Permits should require information relating to (inter-alia), the relationship between the zone of interest and any overlapping or adjacent aquifers, methods of well construction, well integrity testing, where the well stimulation fluid is expected to travel, details of the liquids to be injected, water use and disposal of effluents.

## Production Development

As for Stage 2.

## Production/operation/maintenance

As for Stage 2.

## Decommissioning of wells

- ▶ Well design and methods of plugging should minimise long term fugitive emissions. Monitoring should be undertaken to detect any release of emissions.

## Site restoration and relinquishment

- ▶ Where appropriate, consideration should be given to the implementation of soil sequestration projects as part the restoration process;
- ▶ Where appropriate, consideration should be given to how sites can be used to enhance climate change resilience during restoration (e.g. through flood attenuation schemes).

## 5.4 Regulatory Framework

### International/European

The **United Nations Framework Convention on Climate Change** (UNFCCC) sets an overall framework for international action to tackle the challenges posed by climate change. The Convention sets an ultimate objective of stabilising greenhouse gas concentrations "*at a level that would prevent dangerous anthropogenic (human induced) interference with the climate system.*" The Convention requires the development and regular update of greenhouse gas emissions inventories from industrialised countries, with developing countries also being encouraged to carry out inventories. The countries who have ratified the Treaty, known as the Parties to the Convention, agree to take climate change into account in such matters as agriculture, industry, energy, natural resources and where activities involve coastal regions. The Parties also agree to develop national programmes to slow climate change.

The **Kyoto Protocol**, adopted in 1997, is the key international mechanism agreed to reduce emissions of greenhouse gases. The Kyoto Protocol sets binding targets for 37 industrialised countries and the European Community for reducing greenhouse gas emissions. These targets equate to an average of 5% reductions relative to 1990 levels over the five-year period 2008-12. The key distinction between this and the UNFCCC is that the Convention encourages nations to stabilise greenhouse gases while the Kyoto Protocol commits them to doing so through greenhouse gas reductions. Countries must meet their targets primarily through national measures however, the Kyoto Protocol offers them an additional means of meeting their targets by way of three market-based mechanisms: emissions trading, the clean development mechanism (CDM) and Joint Implementation (JI).

The Protocol's first commitment period started in 2008 and ended in 2012. At the Durban conference in December 2011, governments decided that the Kyoto Protocol would move into a second commitment period in 2013, in a seamless transition from the end of the second commitment period in 2012. Governments of Parties to the Kyoto Protocol also made amendments to the Protocol, among others, the range of greenhouse gases covered. A major outcome was the establishment of the Durban Platform for Enhanced Action, which spelt out a path to negotiate a new legal and universal emission reduction agreement by 2015, to be adopted by 2020.

In March 2007, the EU's leaders endorsed an integrated approach to climate and energy policy that aims to combat climate change and increase the EU's energy security while strengthening its competitiveness. They committed Europe to transforming itself into a highly energy-efficient, low carbon economy. It set a series of demanding climate and energy targets to be met by 2020, known as the "20-20-20" targets. These are:

- ▶ A reduction in EU greenhouse gas emissions of at least 20% below 1990 levels;
- ▶ 20% of EU energy consumption to come from renewable resources; and
- ▶ A 20% reduction in primary energy use compared with projected levels, to be achieved by improving energy efficiency.

To secure a reduction in EU greenhouse gases, the **EU Emissions Trading Scheme (EU ETS)**, a Europe wide scheme, was introduced in 2005. EU ETS puts a price on carbon that businesses use and creates a market for carbon. It allows countries that have emission units to spare (emissions permitted to them but not 'used') to sell this excess capacity to countries which are likely to exceed their own targets. Since CO<sub>2</sub> is the principal greenhouse gas, this is often described as a carbon market or trading in carbon; the total amount of carbon emissions within the trading scheme being limited, and reduced over time. The **Integrated Climate and Energy Package** included a revision and strengthening of the Emissions Trading System (ETS). A single EU-wide cap on emission allowances will applied from 2013 and will be cut annually, reducing the number of allowances available to businesses to 21% below the 2005 level in 2020. The free allocation of allowances will be progressively replaced by auctioning, and the sectors and gases covered by the system will be somewhat expanded.

The **Renewable Energy Directive** (2009/28/EC) mandates levels of renewable energy use within the European Union. The Directive requires EU member states to produce a pre-agreed proportion of energy consumption from renewable sources such that the EU as a whole shall obtain at least 20% of total energy consumption from renewables by 2020. This is then apportioned across member states. Under Article 4 of

the Directive, each member state is also required to complete a National Renewable Energy Action Plan that will set out the trajectory and measures that will enable the target to be met.

The **Mining Waste Directive** (2006/21/EC) aims to prevent or reduce as far as possible the adverse effects on the environment and any resultant risks to human health from the management of waste from the extractive industries. The Directive sets out how to achieve this aim by providing for measures, procedures and guidance on how extractive industries should be managed including a requirement that operators take adequate measures to prevent/ reduce gas emissions.

The **Integrated Pollution Prevention and Control Directive** (2008/1/EC) (IPPC) requires industrial activities to have a permit (issued by the relevant competent authority of the member state) containing emission limit values and other conditions based on the application of Best Available Techniques (BAT) and set to minimise emissions of pollutants likely to be emitted in significant quantities to air, water or land. Permit conditions also have to address energy efficiency, waste minimisation, prevention of accidental emissions and site restoration.

The **Industrial Emissions Directive (IED)** (2010/75/EU) combines seven existing air pollution directives, including the Large Combustion Plant Directive and the Integrated Pollution Prevention and Control (IPPC) Directive. As with previous directives aimed at minimising emission release, part of the benefit of the IED is that it includes several new industrial processes, sets new minimum emission limit values (ELVs) for large combustion plant and addresses some of the implementation issues of the IPPC.

The **Environmental Impact Assessment Directive** 2011/92/EU aims for the environmental impacts from certain projects to be identified and for mitigation measures to be proposed. Environmental Impact Assessments (EIAs) are not mandated for all shale gas operations and would be necessary when operations exceed 500,000m<sup>3</sup> gas extraction or are deemed likely to have significant environmental impacts, which could include impacts associated with emissions.

## UK

In the UK, the **Climate Change Act (2008)** introduced legislative targets for reducing the UK's impacts on climate change and the need to prepare for its now inevitable impacts. The Act sets binding targets for a reduction in CO<sub>2</sub> emissions of 80% by 2050, compared to a 1990 baseline. Interim targets and five-year carbon budget periods will be used to ensure progress towards the 2050 target. The Climate Change Act 2008 also requires the Government, on a regular basis, to assess the risks to the UK from the impact of climate change and report to Parliament. The first **Climate Change Risk Assessment** was published in 2012. Government will be required to publish and regularly update a programme setting out how the UK will address these likely impacts, based on the principles of sustainable development, thereby ensuring that environmental, economic and social issues are all fully considered. The Climate Change Act 2008 also introduced powers for Government to require public bodies and statutory undertakers (in this context these are utilities companies which provide a public service) to carry out their own risk assessments and make plans to address those risks.

Section 49 of the **Infrastructure Act 2015** details how the likely impact of onshore oil and gas exploration on the UK carbon budget will be determined. Specifically, advice will be sought from the Committee on Climate Change on the impact which combustion of, and fugitive emissions from onshore oil and gas exploration and production activities on the Government's ability to meet the duties imposed by the net UK carbon account target for 2050.

The **Carbon Plan: Delivering our low carbon future (2011)** sets out how the UK will achieve decarbonisation within the framework of energy policy: to make the transition to a low carbon economy while maintaining energy security, and minimising costs to consumers, particularly those in poorer households. It includes proposals for energy efficiency, heating, transport and industry.

The **Energy Act (2011)** provides for some of the key elements of the Government's energy programme and including a step change in the provision of energy efficiency measures to homes and businesses. It also makes improvements to the framework for enabling and securing low carbon energy supplies and fair competition in the energy markets.

Gas is expected to retain a key role in electricity generation, as well as remaining a dominant fuel for domestic heating and a major fuel source for industry. The UK Government published its **Gas Generation Strategy** in December 2012 setting out the important role gas has to play to maintain adequate capacity margins, meet demand and provide supply-side flexibility. The role of gas will be determined by the market, whilst keeping emissions within the limits set out in the Carbon Budgets. The Government expects a continued need for new investment in gas plant (up to 26GW could be required by 2030), and the objective of the Strategy is to reduce the uncertainty around gas generation for investors.

The **Environmental Permitting (England and Wales) Regulations 2010** sets up a pollution control regime. The environmental regulator would specify conditions for environmental permits, for example limiting the type and quantity of emissions released to air. Extractive gases such as those released from flowback fluid are considered mining waste, so the site would need to provide a Waste Management Plan as part of the permit application for a mining waste operation. The Plan must set out objectives to prevent or reduce the production of extractive waste; encourage recovery; and ensure safe disposal. The permit may need to include areas designated for the deposit of waste gases as part of the mining waste facility. An industrial emissions permit would also be required for operations that flare more than 10 tons of gas per day.



## 6. Waste and Resource Use

### 6.1 Introduction

Waste management in this context is defined as the processing, recycling or disposal of a range of waste types including municipal, commercial and industrial, construction, excavation and demolition and hazardous wastes. However, it is important to note that consideration of the management of waste links to a number of other study topics, the most relevant being climate change given the potential for flared gases to be recovered for energy use.

### 6.2 Assessment of Effects

This section comprises of the review of the likely effects of waste generation arising unconventional oil and gas exploration and production activities. **Table B6.1** presents a summary of the key stages of exploration, production and decommission.

Table B6.1 Unconventional Oil and Gas Exploration and Production Lifecycle and Key Activities

Stage	Activities
1	<p><b>Non-intrusive exploration</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Site identification, selection, characterisation;</li> <li>▶ Seismic surveys;</li> <li>▶ Securing of necessary development and operation permits.</li> </ul>
2	<p><b>Exploration drilling and hydraulic fracturing</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Pad preparation road connections and baseline monitoring;</li> <li>▶ Well design and construction and completion;</li> <li>▶ Hydraulic fracturing;</li> <li>▶ Well testing including flaring.</li> </ul>
3	<p><b>Production development</b>, including :</p> <ul style="list-style-type: none"> <li>▶ Pad preparation and baseline monitoring;</li> <li>▶ Facility construction and installation;</li> <li>▶ Well design construction and completion;</li> <li>▶ Hydraulic fracturing;</li> <li>▶ Well testing, possibly including flaring;</li> <li>▶ Provision of pipeline connections;</li> <li>▶ (Possibly) re-fracturing.</li> </ul>



Table B6.1 (continued) Unconventional Oil and Gas Exploration and Production Lifecycle and Key Activities

Stage	Activities
4	<p><b>Production/operation/maintenance</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Gas/oil production;</li> <li>▶ Production and disposal of wastes/emissions;</li> <li>▶ Power generation, chemical use and reservoir monitoring;</li> <li>▶ Environmental monitoring and well integrity monitoring.</li> </ul>
5	<p><b>Decommissioning of wells</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Well plugging and testing;</li> <li>▶ Site equipment removal;</li> <li>▶ Environmental monitoring and well integrity monitoring.</li> </ul>
6	<p><b>Site restoration and relinquishment</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Pre-relinquishment survey and inspection;</li> <li>▶ Site restoration and reclamation.</li> </ul>

Note: Exploration wells most usually move from Stage 2 to Stage 4, though some may be used for long-term production testing and some may be retained and their sites redeveloped as a production project. For the purposes of this review, the appraisal stage (a term commonly used in industry) spans Stages 2 and 3

### Non-intrusive Exploration

This majority of activities in this Stage are desk-based such as site identification and securing permits. As a result, it is not expected that waste would be generated.

Certain seismic survey techniques, such as vibroseis, require roads or hard surfaces for use. In the majority of cases, it is assumed that a site would be accessed by existing roads, however, if an area is not accessible by existing roads it may require the construction of temporary access routes. Given the temporary nature of the road and the minimal traffic expected, these access routes may consist of a layer of crushed stone/gravel/cobbles. The volume of materials recycled would depend on the length of access routes required to complete the seismic surveys.

In the UK, aggregates come from a variety of sources and are classified as ‘primary’ aggregate and ‘secondary’ aggregate. Primary aggregates are extracted material such as rock or gravel which has undergone physical processing e.g. crushing or sizing, also known as ‘natural’ aggregate. Secondary aggregates include manufactured aggregate, which are minerals arising from industrial processes, and recycled aggregate, which includes processed materials previously used in construction. There may be possibilities both to use recycled aggregate on the site and/or to recycle aggregates after use. Recycling aggregates after use would help reduce waste generated from the site, and using recycled or secondary aggregate would help reduce demand for new resources. Recycled aggregates can typically be used in road construction, ground improvements, earthworks, foundations and trenches.<sup>1,2</sup> Although these access roads may be used again should the site be used for production, the removal of the road would therefore not be expected to result in a waste stream as the materials could be recycled.

<sup>1</sup> WRAP (2010) *Construction Applications*. Available from <http://aggregain.wrap.org.uk/opportunities/applications/> [Accessed November 2014].

<sup>2</sup> British Geological Survey & Department of Communities and Local Government (2013) *Mineral Planning Factsheet: Construction Aggregates*. Available from <https://www.bgs.ac.uk/mineralsuk/planning/mineralPlanningFactsheets.html> [Accessed April 2015].

There are also alternatives to aggregates available such as high density polyethylene panels, which could be installed to create temporary access routes and protect the ground. In the UK, panels may be hired from providers and then returned to the vendor after use to avoid waste generation.<sup>3,4</sup>

### Exploration drilling and hydraulic fracturing

The preparation of the well pad would require the clearance of vegetation, the stripping of topsoils and the levelling of the site in order to lay a solid foundation, similar to other conventional oil and gas projects. This is not expected to result in producing notable volumes of waste as usual practice in the UK would be for the soil to be stored around the perimeter of the site, creating screening bunds to be accessed following site decommissioning for the restoration of the site. Any vegetation stripped from the surface could be chipped, shredded and composted where feasible but otherwise would require disposal to landfill.

The well pad site typically comprises of an area between 1 and 2 hectares.<sup>5</sup> The proposed Cuadrilla operations in Lancashire, UK, specify that this would include a 1.55 hectare well pad plus a further hectare of surrounding surface works. The remainder of the Cuadrilla site comprises a further 5.5 hectares for surface water collection ditches, landscaped bunds, fencing and pipelines.<sup>6</sup> There may be a single well or multiple wells on a well pad. The well pad is likely to be constructed from compacted aggregate laid on an impermeable membrane and geotextile layer. Surface water runoff would be collected and attenuated via perimeter ditches. There should be no connectivity between the runoff ditches from the well pad and any other surface water features adjacent to the well pad. Access to the well pad could be through the use of the access routes created during stage 1; however, if only temporary access routes used at the non-intrusive stage, the access roads would also need to be constructed, which may require crushed aggregate as above for non-intrusive exploration.

Concrete and mixed construction waste is also expected to be generated from the construction of site compounds, well pad and associated infrastructure. This waste would be typical of construction projects and not a significant contributor to the overall project waste. It is estimated that 0.46 tonnes of mixed construction waste is produced per £100,000 spent on an energy utility project.<sup>6</sup>

A surface seismic monitoring array would be installed to collect seismic data to provide a baseline and to monitor the induced seismic effects from fluid injection. For the proposed Cuadrilla exploratory drilling site at Preston New Road, Lancashire, this includes eight surface arrays and 80 buried arrays. Cuadrilla assumed that soil and stone from the installation of the arrays would be reused onsite. Each buried array is also expected to generate 3m<sup>3</sup> of bentonite slurry and 0.03m<sup>3</sup> of cement waste requiring offsite disposal.

Once the pad had been constructed, initial test boreholes would be drilled, with some being developed into full wells. The process of drilling creates waste in the form of drill cuttings, spent drill muds and excess cement which is returned to the surface. Boreholes down to approximately 100m are also required for the buried seismic arrays and for groundwater monitoring, which would create further drilling wastes requiring disposal. In the UK, drilling wastes are covered under section 1, 'wastes resulting from exploration, mining, quarrying, and physical and chemical treatment of minerals' in schedule 1 of the List of Wastes (England) Regulations 2005, implemented following the adoption of the EU Waste Directive (67/548/EEC) and after the List of Wastes Decision (2000/532/EC). Those wastes in the list relevant to drill cuttings and which are considered hazardous include:

- ▶ Oil-containing drilling muds and wastes (waste: 01 05 05); and
- ▶ Drilling muds and other drilling wastes containing dangerous substances (waste: 01 05 06).

<sup>3</sup> Terraforma (2014) *Dura-Base*. Available from <http://terrafirma.gb.com/en/> [Accessed November 2014].

<sup>4</sup> Groundtrax (2014) *Ground Protection & Ground Reinforcement*. Available from <http://www.groundtrax.com/> [Accessed November 2014].

<sup>5</sup> AEA (2012) *Support to the Identification of Potential Risks for the Environment and Human Health arising from Hydrocarbons Operations involving Hydraulic Fracturing in Europe*. Available from <http://ec.europa.eu/environment/integration/energy/pdf/fracking%20study.pdf> [Accessed April 2015].

<sup>6</sup> Cuadrilla Bowland Ltd (2014) *Temporary Shale Gas Exploration Preston New Road, Lancashire: Environmental Statement*. Available from [http://www.cuadrillaresources.com/wp-content/uploads/2014/07/PNR\\_ES\\_Vol1\\_Environmental\\_Statement.pdf](http://www.cuadrillaresources.com/wp-content/uploads/2014/07/PNR_ES_Vol1_Environmental_Statement.pdf) [Accessed April 2015].

Drill cuttings are rock fragments created from the drill process, flushed to the surface by the drill mud. The average volume of drill cuttings per well for unconventional oil and gas is typically higher than for conventional operations as the length of wells is considerably longer due to the horizontal section. A vertical well with a depth of 2,100m would produce an average of 120m<sup>3</sup> of cuttings, while an unconventional well with an additional lateral 1,200m section would produce approximately 170m<sup>3</sup> of cuttings.<sup>5</sup>

Cuttings may be moved offsite and (within the UK) would be disposed of at an EA licensed landfill site; or could be disposed of onsite if appropriate; or reinjected into a geological formation. Reinjection is usually the preferred option and is now a proven technology and geological risks (i.e. loss of containment in receiving formation) are low.<sup>7</sup>

Drilling muds may be oil or water-based, with oil based muds reported to be more conventional and more commonly used in the US.<sup>8</sup> However, shale gas best practice in the UK specifies that water based drilling muds should always be used when drilling through shallow soils or local aquifers.<sup>9</sup> Drilling muds are re-circulated, while spent muds are a waste product. They typically contain a mix of the geological formations encountered (drill cuttings), liquid (water or oil), clay (bentonite) plus any additives used. In general, their physical and chemical composition will vary according to each project's drilling design and underlying geology.

Water based drilling muds would contain rock fragments from the drill cuttings which may be suitable for use in recovery operations, after appropriate treatment. Oil based muds are more likely to be classified as a hazardous waste and within the UK would require disposal at an appropriately EA licensed disposal site.

Spacer fluid is used to remove drilling mud from the well and to prepare it for cement injection. This is estimated at 30m<sup>3</sup> spacer fluid per well for the Cuadrilla exploratory drilling at Preston New Road, Lancashire. In order to ensure the integrity of the well and protect groundwater, steel casing is cemented into the wellbore in stages by pumping cement slurry between the wall of the well and the steel casing. As a result of this process, a proportion of the cement returns to the surface and requires on site storage before being taken offsite for treatment/disposal at a suitable site, estimated at approximately 5% of the total concrete used for construction of the well chamber. Proposed Cuadrilla operations estimate 20m<sup>3</sup> of cement waste to be generated per well.<sup>6</sup>

During the hydraulic fracturing process, 10,000 – 25,000m<sup>3</sup> fracturing fluid is typically injected into the shale rock.<sup>5</sup> Some of the liquid that is injected returns to the surface through the drilled well. This fluid is known as 'flowback water' and is typically very saline and contains minerals dissolved from the rocks. The proportion of fracturing fluid that returns as flowback water varies between wells, with some US studies reporting flowback of between 10 – 40% of the fracturing fluid<sup>10</sup> although other studies report flowback can be as high as 75%.<sup>11</sup> The volume of flowback water returned depends on the properties of the rock formation (such as the geology of the host formation and mobility of naturally occurring compounds), fracturing design and the type of fracturing fluid used.<sup>12</sup>

The composition of flowback water depends on the constituents of the fracturing fluid which had been injected into the well as well as the presence and concentrations of naturally occurring substances in the shale. Cuadrilla has published the nature of the fracturing fluid approved for its UK operations:

- ▶ Polyacrylamide friction reducers (0.075%), commonly used in cosmetics and facial creams, suspended in a hydrocarbon carrier;

<sup>7</sup> Department of Energy and Climate Change (2010) *Strategic Environmental Assessment for a 14th and Subsequent Onshore Oil & Gas Licensing Rounds, Environmental Report*, Appendix 5: Consideration of Activities.

<sup>8</sup> Sharma, M.M., et al (2012) *A New Family of Nanoparticle Based Drilling Fluids*, Society of Petroleum Engineers, SPE Annual Technical Conference and Exhibition, 8-10 October, San Antonio, Texas, USA. Available from [http://www.spe.org/atce/2012/pages/schedule/technical\\_program/documents/spe160045-page1.pdf](http://www.spe.org/atce/2012/pages/schedule/technical_program/documents/spe160045-page1.pdf) [Accessed April 2015].

<sup>9</sup> United Kingdom Onshore Operators Group (UKOOG) (2013) *UK Onshore Shale Gas Well Guidelines: Exploration and appraisal phase*. Available from [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/185935/UKOOGShaleGasWellGuidelines.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/185935/UKOOGShaleGasWellGuidelines.pdf) [Accessed April 2015].

<sup>10</sup> Halliburton (2014) *Produced and Flowback Water Recycling and Reuse Economics, Limitations, and Technology*, Oil and Gas Facilities. Available from <http://www.spe.org/ogf/print/archives/2014/02/> [Accessed April 2015].

<sup>11</sup> AEA (2012).

<sup>12</sup> King GE (2012) *Hydraulic Fracturing 101*, Journal of Petroleum Technology, April 2012 p34 – 42, as cited in AEA (2012).

- ▶ Hydrochloric acid (0.125%), frequently found in swimming pools and used in developing drinking water wells; and
- ▶ Biocide (0.005%), used on rare occasions when the water provided from the local supplier used in the hydraulic fracturing needs to be further purified.

To date, Cuadrilla operations have used 99.95% water and sand (proppant) with 0.05% polyacrylamide only.<sup>13</sup> More broadly in the US, fracturing fluid may also include various surfactants, thickeners, and scale and corrosion inhibitors. The nature and content of fracturing fluid in the US is not as transparent as in the UK and is not necessarily transferrable to UK activities, due to differing requirements over the publication of fracturing fluid composition and restrictions on the types of chemicals used. However, these substances would return to surface as part of the constituents of flowback water (refer to **Appendix B.3: Water** for further detail on the composition of fracturing fluid). The table below sets out typical contaminants in flowback water for shale gas wells in the US, and constituents could therefore vary in the UK or elsewhere depending on the geological composition of the shale and the components of the injected fracturing fluid. The minimum and maximum values come from records of 541 shale gas wells and seven well samples analysed by the study authors. Sources for the 541 shale gas records reviewed by the authors included peer-reviewed journals, book chapters plus government and industry documents and analytical results.

Table B6.2 Typical levels of contaminants in flowback water from shale gas extraction

Parameter	Minimum (mg/L)	Maximum (mg/L)
pH	1.21	8.36
Alkalinity	160	188
Nitrate	Not detected (ND)	2,670
Phosphate	ND	5.3
Sulphate	ND	3,663
Radium 226 (pCi/g)	0.65pCi/g	1.031pCi/g
Hydrogen carbonate	ND	4,000
Aluminium	ND	5,290
Boron	0.12	24
Barium	ND	4,370
Bromine	ND	10,600
Calcium	0.65	83,950
Chloride	48.9	212,700
Copper	ND	15
Fluoride	ND	33
Iron	ND	2,838
Potassium	0.21	5,490
Lithium	ND	611
Magnesium	1.08	25,340

<sup>13</sup> Cuadrilla (2014) *Fracturing Fluid*. Available from <http://www.cuadrillaresources.com/what-we-do/hydraulic-fracturing/fracturing-fluid> [Accessed October 2014].

Table B6.2 (continued) Typical levels of contaminants in flowback water from shale gas extraction

Parameter	Minimum (mg/L)	Maximum (mg/L)
Manganese	ND	96.5
Sodium	10.04	204,302
Strontium	0.03	1,310
Zinc	ND	20

Source: Alley B., Beebe A., Rodgers J., Castle J.W. (2011) *Chemical and physical characterization of produced waters from conventional and unconventional fossil fuel resources*, Chemosphere, 85, (1), 74-82.

Flowback water analysed by the Environment Agency from the Cuadrilla Preese Hall exploratory well in Lancashire, UK was found to contain high levels of sodium, chloride, bromide, iron, lead, magnesium, zinc and low levels of naturally occurring radioactive materials (NORMs) such as radium, picked up from the rock formations.<sup>14</sup> The fluid contained up to 179µg/litre of lead (compared to drinking water standards of 10µg/litre) and chromium was present at over four times the drinking water standard, at 222 µg/litre.<sup>15</sup> Flowback fluid typically also contains high salt levels. Salinity levels determined from test drilling in the north-west of England identified various salt contents ranging from brackish to highly saline water (23,000ppm to 103,000ppm sodium chloride).<sup>16</sup>

Naturally occurring radioactive material (NORM) can be present in flowback water at levels above the regulatory thresholds for radioactivity. In these circumstances, within the UK, the flowback water would be designated as radioactive waste and has to be disposed of or treated accordingly. This would require both the well operator and any waste water treatment facilities receiving the waste to hold a radioactive substances permit. Preliminary analysis by the Environment Agency showed the flowback fluid at the Preese Hall site in Lancashire contained radioactivity in the form of radium-226 between 14 – 90 Bq/litre, well above the 1 Bq/litre regulatory threshold for controlling NORM activities. Potassium-40 and radium-228 were also found to be present. A study of the flux of radioactivity in flowback fluid from shale gas development in the Carboniferous, Bowland Shale, UK; the Silurian Shale, Poland; and the Carboniferous Barnett Shale, US by Almond *et al* (2014)<sup>17</sup> found that levels of NORM in flowback water are much higher than found in groundwater, but well below permitted UK exposure limits. Their radioactivity is also lower than that of fluids produced by conventional oil or gas production, or nuclear power.

Some of the water that flows to the surface also includes produced water (water coming to the surface, under pressure, ‘produced’ from saturation of the host formation). After the initial recovery of the hydraulic flowback fluid (in the flowback water), produced water will continue in many cases to come to the surface with decreasing quantities of hydraulic fracturing fluid. Flowback water typically returns to the surface within the first few days or weeks following injection of fracturing fluid, while produced water is generated from the rocks across the lifetime of the well. Due to the low permeability of shale, it contains a very low water content and does not permit any flow and so produced water is not anticipated to arise from unconventional wells in the UK. Outside of the UK, treatment and/or disposal of produced water is a greater waste issue. Produced water is typically generated in much lower volumes than flowback fluid, estimated at an average of 57m<sup>3</sup> per year per well in the US.<sup>18</sup> Pads with multiple wells would therefore have corresponding increases in produced water requiring treatment or disposal.

<sup>14</sup> Environment Agency (2011) *Shale Gas North West- Monitoring of Flowback Water*. Available from [http://www.fraw.org.uk/files/extreme/envage\\_flowback\\_2011.pdf](http://www.fraw.org.uk/files/extreme/envage_flowback_2011.pdf) [Accessed October 2014].

<sup>15</sup> ENDS (2013) *UK Shale Gas and the Environment: Managing Contamination Risks*.

<sup>16</sup> Broderick J., *et al* (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/sites/default/files/coop\\_shale\\_gas\\_report\\_update\\_v3.10.pdf](http://www.tyndall.ac.uk/sites/default/files/coop_shale_gas_report_update_v3.10.pdf) [Accessed April 2015].

<sup>17</sup> Almond, S. Clancy, S.A. Davies, R.J. Worrall, F. (2014) *The flux of radionuclides in flowback fluid from shale gas exploitation*, in *Environ Science and Pollution Research International* 2014; 21(21): 12316–12324. Available from <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4200344/> [Accessed April 2015].

<sup>18</sup> European Parliament (2011) *Impacts of shale gas and shale oil extraction on the environment and on human health*. Available from <http://europeecologie.eu/IMG/pdf/shale-gas-pe-464-425-final.pdf> [Accessed April 2015].



Waste produced water also typically contains substances found in the rock formations, such as dissolved solids, gases, trace metals, naturally occurring radioactive elements, and organic compounds.<sup>5</sup> Small quantities of fracturing fluid may also be present depending how far through the well's lifetime the produced water occurs.

Flowback water requires storage prior to any treatment or disposal. In the US, holding ponds are used to store flowback water to allow the settlement of its contents. Settlement ponds have been the source of significant problems, including failure of the ponds resulting in surface water pollution and additional methane emissions. Open storage and settlement is not permitted in the UK, with storage of flowback water in tanks on site as part of a closed system prior to treatment or disposal.<sup>19</sup>

The disposal of flowback water simply by re-injecting it into the shale strata and storage of flowback water in open surface lagoons are widely adopted disposal methods in the US. However, reinjection without water treatment or blending with freshwater can result in blocking the underground fractures by the substances in the flowback water. Reinjection or open pit storage is not permissible in the UK under current groundwater protection legislation due to the risks of contamination. Direct discharge to surface water would also not be permitted in the UK due to the high salt content and presence of contaminants. The EA deems that although flowback fluid is a waste when it returns to the surface, if it can be treated to the point where it performs the same function as fresh injection fluid, it will no longer be a waste and could be used in well stimulation. The three main options for safe disposal in the UK are:

- ▶ On-site treatment with re-use of water and disposal of remaining liquids and solids to a suitable licensed waste treatment and disposal facility;
- ▶ Removal off site to a suitable licensed waste treatment and disposal facility; and
- ▶ Disposal to a special sewer with the permission of the relevant waste water utility company.<sup>19</sup>

The EA considers the reuse of flowback fluid following treatment and blending with fresh water to be the preferred and sustainable option for its management in the UK.<sup>20</sup> The EA considers the reuse of flowback fluid should be present in any waste management plan for the operational stage. The re-use of flowback water is however less likely during exploratory drilling and therefore it is assumed that it will require treatment and disposal at this stage.

If being disposed of at wastewater treatment works (WwTW), the high salinity and suspended materials such as heavy metals means that the fluid can cause damage to some elements of the WwTW, if not adequately equipped for treatment of this type of waste fluid. Lower volumes of waste flowback water would be generated during the exploratory phase, and it would therefore be a more significant issue during the longer term operational stages.<sup>6</sup> To avoid damaging the plant, a high level of dilution would typically be required during the water treatment process, particularly in areas where there are numerous wells generating waste water. A certain minimum flow volume to reach the necessary dilution of salt and other substances would generally only be available at larger WwTW, such as those near large population centres. If hydraulic fracturing takes place in a relatively rural location, plant of this scale may be a considerable distance from the fracturing site thus substantially increasing the transport distances if the waste flowback fluid is tankered to a WwTW in another part of the country.

Alternatively, some level of pre-treatment may be necessary if the local WwTW is not of sufficient size to provide appropriate dilution of pollutants.<sup>5</sup> Pre-treatment options include desalination to reduce salt content, which may be by evaporation, distillation, selective membranes, electric separation or chemical treatment, but these are often energy intensive and costly techniques. The brine slurry produced by the desalination process can be crystallised to allow disposal as solid waste. Chemical precipitation to remove suspended solids and substances such as magnesium, calcium, strontium, barium and radium is necessary prior to final discharge to surface waters or reuse, as is disinfection via filtration, ultraviolet (UV) light, chlorine, iodine, ozone or acid treatments.

During treatment of flowback water in WwTWs, NORM may accumulate in the sewage sludge rather than liquid effluent. Additional pre-treatment may therefore be required for NORM removal prior to the entry of

<sup>19</sup> DECC (2014) *Fracking UK Shale: Water*. Available from [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/277211/Water.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/277211/Water.pdf) [Accessed April 2015].

<sup>20</sup> Environment Agency (2013) *Onshore oil and gas exploratory operations: technical guidance, Consultation Draft*.



flowback water into the WwTW to avoid this, for example through acid-alkali treatment to precipitate the NORM out of solution for separate disposal.<sup>15</sup> This solid may be disposed of to landfill if NORM concentrations are sufficiently low. In the UK, radioactive flowback fluid remains classified as radioactive waste until final discharge from offsite effluent treatment works or until reuse as a fracturing fluid. If the flowback water is not above the threshold to be classed as radioactive waste, then NORM pre-treatment would not be required and the waste water could be processed as normal in a WwTW.

According to the EA, flowback water at Preese Hall was stored on site in double skinned tanks. It was then transported to the Davyhulme wastewater treatment work (WwTW). This WwTW treats other industrial effluents from the Manchester area and was considered by the Agency as capable of dealing with the levels of minerals contained in the flowback water from the Preese Hall site.

Removal of wastewater by road tanker or infrastructure to transport wastewater to nearby treatment facilities could require substantial infrastructure investment, as could construction of water treatment works on site.

There are alternatives to the use of water as a fracturing fluid, such as gels, carbon dioxide and nitrogen gas foams. The use of some of these alternative fluids, particularly propane-based liquid petroleum gas (LPG) and foam, could reduce the toxicity of wastewater as salts, heavy metals and NORM are not so easily picked up from the shale formations. Foam and LPG are commercially in use in some shale formations in the US and Canada. While this can decrease local water demand, alternatives may not be appropriate for all types of shale formation and there are potentially further cost and production considerations.<sup>21</sup> They would also present alternative waste streams which may have further waste disposal issues.

Poor management of waste flowback water and other chemicals used on site can lead to accidental spillage and contamination of soils, surface or groundwater if not appropriately contained. This may lead to contaminated materials being removed from site as waste. A 2011 MIT study of gas well drilling in the US found that a third of documented incidents between 2005 and 2009 related to accidental spills and leaks, and nearly 10% of incidents related to off-site disposal issues.<sup>22</sup>

Scale that accumulates inside pipes, treatment or storage tanks can include solidified NORM, so radioactive scale may be another waste stream which requires appropriate disposal off site. Scale principally consists of barium, calcium and strontium compounds, in addition to radioactive materials such as radium. These substances precipitate out of solution due to changes in temperature and pressure in the well.<sup>23</sup> However scale is not expected to be a significant waste stream, with relatively small amounts generated on a non-routine basis.<sup>6</sup>

Any natural gas that may arise from drilling and flowback fluid may be disposed of by flaring in the earlier exploration stages. Although this is an extractive waste, it is not considered to be a hazardous waste and would be likely to be considered a gaseous effluent, with highly flammable properties. The drill-out process which occurs after hydraulic fracturing can release further waste methane emissions. Leakages of methane and other gases may also occur from pumps, valves, compressors and other equipment which would be waste gases released to air.<sup>6</sup>

In the UK, flaring is regulated by DECC as part of a licence condition and it is DECC's established policy that flaring should be reduced to the economic minimum.<sup>24</sup> As an alternative to flaring, 'green completion' involves the capture of methane from the fracturing process for use or export off site. Although not occurring at all sites, a recent study in the US found that for sites that capture gas emissions from flowback water, 99% of the potential emissions were captured during the green completion process.<sup>25</sup> Green completions can

<sup>21</sup> European Commission Joint Research Centre (2013) *An overview of hydraulic fracturing and other formation stimulation technologies for shale gas production*. Available from [https://ec.europa.eu/jrc/sites/default/files/an\\_overview\\_of\\_hydraulic\\_fracturing\\_and\\_other\\_stimulation\\_technologies\\_%28%29.pdf](https://ec.europa.eu/jrc/sites/default/files/an_overview_of_hydraulic_fracturing_and_other_stimulation_technologies_%28%29.pdf) [Accessed April 2015].

<sup>22</sup> MIT (2011) *The Future of Natural Gas: An Interdisciplinary MIT Study*, as cited in RSBP (2014) *Hydraulic Fracturing for Shale Gas in the UK*. Available from [http://www.rspb.org.uk/Images/shale\\_gas\\_report\\_evidence\\_tcm9-365779.pdf](http://www.rspb.org.uk/Images/shale_gas_report_evidence_tcm9-365779.pdf) [Accessed April 2015].

<sup>23</sup> Royal Academy of Engineering and Royal Society (2012) *Shale Gas in the UK, A Review of Hydraulic Fracturing*. Available from <https://royalsociety.org/policy/projects/shale-gas-extraction/report/> [Accessed April 2015].

<sup>24</sup> DECC (2013) *About Shale Gas and Hydraulic Fracturing (Fracking)*. Available from [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/268017/About\\_shale\\_gas\\_and\\_hydraulic\\_fracturing\\_Dec\\_2013.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/268017/About_shale_gas_and_hydraulic_fracturing_Dec_2013.pdf) [Accessed April 2015].

<sup>25</sup> Allen, D.T., et al (2013) *Measurements of methane emissions at natural gas production sites in the United States*, Proceedings of the National Academy of Sciences of the United States of America, 110 (44), 17768-17773. Available from [www.pnas.org/cgi/doi/10.1073/pnas.1304880110](http://www.pnas.org/cgi/doi/10.1073/pnas.1304880110) [Accessed November 2014].

therefore significantly reduce the amount of waste methane generated from flowback fluid, however appropriate infrastructure for transport offsite may not be in place until later production stages. For the UK, MacKay and Stone (2013) recommended that green completions should be adopted at all stages following exploration and that emissions of waste methane should be reduced to as low a level as reasonably practicable (ALARP).<sup>26</sup> The UK Government supports this recommendation and specifies that DECC's licence conditions mean that in practice operators must use green completion techniques to achieve the licence requirements, as well as setting a requirement to use green completions as the 'best available technology' for production facilities.<sup>27</sup> Venting natural gas is not permitted in the UK except for safety reasons, as part of DECC's licence conditions.<sup>28</sup>

In 2011, it was estimated that 1.6% of the total natural gas extracted from a study of four wells in the US was released as a waste gas from flowback fluid, with 50% of methane emissions typically captured and flared across the US, with the rest vented to atmosphere.<sup>18</sup> A more recent study by Allen et al (2013) of 150 sites in the US found that flowback emissions have been reduced substantially through improved gas collection during flowback. Allen also identified that releases of methane from plant and equipment leaks were now the greatest contributors to methane emissions during well production. Overall, waste methane emissions during the hydraulic fracturing process were found to represent an average of 0.42% of gross gas production.<sup>25</sup> The climate change impacts of the methane releases are considered elsewhere in **Appendix B.5: Climate Change**.

Other waste that is likely to be generated on site includes: waste oils; paraffins; waxes; oil contaminated rags; used batteries; waste chemicals, scrap metals and used containers. Spill kit materials contaminated with oil and diesel from equipment spills and leaks may also arise as a waste stream. If occurring within the UK, many of these waste streams would be designated as hazardous waste requiring appropriate disposal at an EA licensed site.

Sanitary wastewater would also be generated from site facilities. Drilling sites may not be connected to the sewerage system so this waste may require alternate disposal means.

A summary of the waste streams expected to be generated by Cuadrilla for exploratory drilling and fracturing is set out in the below table. Note that the proposed waste recovery and disposal methods are based on the local waste infrastructure available to the project in the north-west of England, and may not be representative of waste facilities or the most suitable disposal route available elsewhere.

Table B6.3 Summary of waste streams for exploratory drilling and fracturing

Waste Stream	Category	Cuadrilla Planned Recovery/Treatment/Disposal Method
Polymer based water drilling muds	Non-hazardous	Recycled offsite where feasible. A small amount may be lost to formation. Residual waste to specialist disposal facility.
Drill cuttings used with polymer based water muds	Non-hazardous	Treatment at a specialist facility. Residual waste to specialist disposal facility.
Low-toxicity oil based emulsion drilling muds	Non-waste	Closed loop system, muds are reconditioned by the supplier for reuse. A small amount may be lost to formation.

<sup>26</sup> MacKay, D.J.C. and Stone, T.J. (2013) *Potential Greenhouse Gas Emissions Associated with Shale Gas Extraction and Use*. Report on behalf of DECC. Available from [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/237330/MacKay\\_Stone\\_shale\\_study\\_report\\_09092013.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/237330/MacKay_Stone_shale_study_report_09092013.pdf) [Accessed April 2015].

<sup>27</sup> DECC (2014) *The Government's Response to the MacKay-Stone Report: Potential greenhouse Gas Emissions Associated with Shale Gas Extraction and Use*. Available from [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/305811/140424\\_MacKay\\_Stone\\_Response\\_.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/305811/140424_MacKay_Stone_Response_.pdf) [Accessed April 2015].

<sup>28</sup> DECC (2014) *Fracking and Local Air Quality*. Available from [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/277219/Air.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/277219/Air.pdf) [Accessed April 2015].

Table B6.3 (continued) Summary of waste streams for exploratory drilling and fracturing

Waste Stream	Category	Cuadrilla Planned Recovery/Treatment/Disposal Method
Drill cuttings used with low-toxicity oil based emulsion muds	Hazardous	Treatment as hazardous waste. Residual waste to hazardous waste disposal facility.
Losses to formation	Non-hazardous / Hazardous	Cuadrilla unlikely to be able to recover losses to formation.
Cement waste from the well casing	Non-hazardous	Recycled where feasible. Residual waste to landfill.
Spacer fluid	Non-hazardous	Treatment offsite and disposal at a specialist site for liquids.
Any contaminated materials from remediating oil or diesel spills, oil from separators, various waste oils and lubricants	Hazardous	Treatment as hazardous waste. Recovery where feasible. Residual waste to hazardous waste disposal facility.
General waste e.g. paper, timber, scrap-metal, food waste	Non-hazardous	Recycling where feasible onsite. Materials Recovery Facility. Residual waste to landfill.
Wastewater (foul effluent)	Non-hazardous	Recovery at a local Wastewater Treatment Works.
Industrial wastewater (rainwater captured by the pad during drilling)	Non-hazardous	Recovery for treatment at a local Wastewater Treatment Works.
Flowback fluid	Radioactive – Non-hazardous	Reuse on site
Sand	Non-hazardous	Recycled into secondary aggregates
Solid scale	Radioactive Waste – Low Level Waste	Augean Low Level Waste facility
Materials and equipment contaminated by NORM	Radioactive Waste – Low Level Waste	Augean Low Level Waste facility
Surplus natural gas	Hazardous (highly flammable)	Flared onsite

Source: Cuadrilla Bowland Ltd (2014) *Temporary Shale Gas Exploration Preston New Road, Lancashire: Environmental Statement*.

Overall, activities during this stage are expected to generate volumes of waste, primarily from drill cuttings, spent drilling mud and flowback water, including some hazardous waste.

## Production Development

The range and type of effects associated with Stage 3 of the unconventional oil and gas exploration and production lifecycle would be similar to those identified under Stage 2. However, the area of land take required per well pad would be greater than that associated with the exploratory drilling stage, reflecting the need for additional infrastructure such as storage tanks and on-site pipelines. Additional wells would also be drilled. Additional activities could include the completion of road connections and the installation of pipelines required to collect natural gas for transfer to the existing natural gas pipeline infrastructure.

The extension of the pad is not expected to result in additional waste as the soil would be collected and stored in banks around the site perimeter. Once the well is decommissioned, the soil would be used to restore the site.

Drilling operations at this stage would generate similar waste streams to those expected at Stage 2 but the scale of activity would increase substantially through the use of multiple well pads. This would result in additional volumes of waste than expected under Stage 2, depending on the number of wells developed.

The reuse of exploratory wells for production would result in less drill waste being generated (than requiring all new wells to be completed), as it would not be necessary to drill the well from the surface again.

### Production/operation/maintenance

Once in production, the volumes of waste being generated typically are higher for unconventional wells than for conventional wells.

The reuse of fracturing fluid may be a more economically viable option during production, compared to the exploration stage. Recycling the wastewater through onsite treatment of fracturing fluid prior to reuse would reduce the volume of waste water generated.

With regard to unconventional wells, there is a strong likelihood they would be refractured to stimulate the flow of shale gas again. In the US, the frequency of refracturing is not certain and is estimated to be once per 5 – 10 years on average, if at all. AEA reports that it is uncertain whether the US approach is transferable to Europe, with an expected potential for wells to be refractured once every 10 years and a potential maximum well lifetime of 10 to 40 years for European operations.<sup>5</sup> Given the lack of data for well lifetimes and the large numbers of wells in the US that have been shut down within 10 years, the life span of wells is not certain at this time and estimates of up to 40 years may be optimistic.<sup>29</sup> For each refracturing that occurs, it would result in similar levels of flowback water being generated as estimated in Stage 3.

The build-up of potentially radioactive scale would occur in greater quantities during production than exploratory drilling, but would still remain a minor waste stream from the site.

If the site is not connected to the sewerage system, sanitary waste would also require collection, for example in a sealed cell tank for disposal to an approved location. This would vary by the number of employees on site and the duration of operations.

Rainwater may collect in site drainage ditches and sumps. If the collected water contains anything other than clean rainwater, in the UK this must be collected and disposed of as waste. The surface runoff water may be contaminated with oils and classed as hazardous waste.<sup>30</sup>

### Decommissioning of wells

There is a general requirement on operators to remove as much equipment and structures from the pad site as possible, with the exception of infrastructure required to ensure the well is safely plugged.

It is expected that a proportion of the well infrastructure could be recycled (although to some extent that will depend on the viability of future onshore operations) as well as functioning, efficiency and operational safety of the well infrastructure to be reused. Large waste streams are not expected therefore at this stage. Although some waste would be generated, and would need to be managed, these are expected to be negligible in scale.

### Site restoration and relinquishment

As with conventional oil and gas well pads, site restoration would involve the removal of all remaining surface structures and the excavation and transport of the concrete and hard core pad based used for the pad site, or other materials which were laid or used to prepare the pad site. It is assumed that these materials, once broken up and graded could be reused as construction aggregate.

Any clean aggregates and concrete would be expected to be reused or recycled off site within the UK. Materials from the pad surface such as liners may be recovered, disposed to landfill or treated as hazardous waste where contaminated by spills or leaks.<sup>6</sup>

<sup>29</sup> Hughes, J.D. (2014) *Drilling Deeper: A Reality Check on U.S. Government Forecasts for a Lasting Tight Oil & Shale Gas*, Post Carbon Institute.

<sup>30</sup> Cuadrilla Resources Ltd (2010) *Beaconsall Hydrocarbon Exploration Site, Planning Application July 2010*, Section 2 – Supporting Statement to the Application.

Historically, wells in the US were often poorly plugged with various unsuitable materials from the site, leading to potentially dangerous releases of gas or fluids from the well. Cement plugging is now most common for sealing wells.<sup>31</sup>

Soil that has been stored on site should be reused to restore the site to the previous land use (or to support the land use determined by the local planning authority). It is assumed that the soil would be free of any contamination that may have occurred during the exploration and/or production phase.

It is assumed that the site would be reseeded with an appropriate mix, compatible with existing land use (whether amenity greenspace, grazing or arable land). As appropriate, landscaping should also take place.

## 6.3 Mitigation Measures

The following section sets out the potential mitigation measures available at each stage of the project life cycle.<sup>6, 30, 32</sup>

### Non-intrusive Exploration

Materials used for the construction of access roads should be chosen dependant on their ability to be recycled into a product for which there is a viable market.

### Exploration drilling and hydraulic fracturing

- ▶ Planning resource management should be used to ensure that the minimum amount of waste is generated, for example by avoiding over-ordering supplies; correct storage of materials to avoid damage and wastage; use of suppliers that minimise packaging; and specification of materials, such as recycled aggregates for the well pad and access road construction or the use of reusable panels for temporary routes, where possible.
- ▶ Site Waste Management Plans should be put into place to ensure that all wastes produced during construction and pad preparation are handled according to regulatory requirements and best practice. Waste management planning should establish a clear strategy for wastes that will be generated including options for waste elimination, reduction, recycling, treatment and disposal. Waste should be considered at the design stage of the project to design out waste where possible.
- ▶ On-site waste management to separate waste streams such as timber, scrap metal and cardboard promotes reuse and recycling and helps reduce volumes of waste sent to landfill. Hazardous waste must be stored and disposed of separately to non-hazardous waste. Hazardous waste liquids should also be stored in secondary containment.
- ▶ All soils should be handled in suitable conditions (e.g. dry weather) and the most appropriate method of soil handling should be used. Soils should be stored in allocated heaps and protected from erosion, contamination or degradation. Different soil types should be stored separately e.g. topsoil, sub-surface material, and the length of time soils are stored should be minimised where possible.
- ▶ Treat drilling muds to clean the mud for reuse in order to reduce the total volume required. Mud cleaning can include the use of cyclones and shaker tables to remove sand, silt and solids.<sup>33</sup> Muds should be disposed of once they can no longer be cleaned and reused. Mud disposal routes can include further separation into waste water for treatment, oil for energy recovery and

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<sup>31</sup> Technology Subgroup of the Operations & Environment Task Group (2011) *Paper #2-25: Plugging and Abandonment of Oil and Gas Wells*. Available from [https://www.npc.org/Prudent\\_Development-Topic\\_Papers/2-25\\_Well\\_Plugging\\_and\\_Abandonment\\_Paper.pdf](https://www.npc.org/Prudent_Development-Topic_Papers/2-25_Well_Plugging_and_Abandonment_Paper.pdf) [Accessed April 2015].

<sup>32</sup> Environment Agency (2013) *Onshore Oil and Gas Exploratory Operations: Technical Guidance (Consultation Draft)*.

<sup>33</sup> Weatherford (2011) *Drilling Fluids and Waste Management Services*. Available from <http://www.weatherford.com/dn/wft166679> [Accessed November 2014].



solid waste for processing and disposal, if appropriate treatment plants are accessible.<sup>34</sup> Return any unused drilling muds to the vendor.

- ▶ Use non-hazardous drilling muds where feasible to reduce the environmental risks associated with oil based muds and to improve recycling opportunities for drilling muds and cuttings. Water based drilling muds should always be used when drilling through shallow soils or local aquifers.
- ▶ Ensure that cement slurry injection is managed by an experienced and competent contractor to help minimise the proportion of cement returning to the surface as waste.
- ▶ Minimise the volume of water used per fracturing stage to the minimum needed for the nature and geology of the shale formation, in order to reduce the volume of flowback fluid generated. For example, Cuadrilla's exploratory drilling in Preston New Road, Lancashire UK, proposes to use 765m<sup>3</sup> water during fracturing rather than the more typical 1,000m<sup>3</sup> to reduce flowback fluid.<sup>6</sup>
- ▶ Store flowback fluids within double skinned tanks and bunded storage facilities on site, rather than open holding ponds.
- ▶ If feasible at exploration stage, treat flowback fluid so that it can be reused in the hydraulic fracturing process, for example through separation to remove sand, oil and gas, plus ultraviolet (UV) disinfection. UV disinfection would reduce the quantity of chemical biocides required.
- ▶ Sand separated through the treatment of flowback fluid can be removed from site and recycled into aggregates.
- ▶ Undertake analysis to assess the existence and extent of NORM during the exploratory phase in order to determine the likely requirement for wastewater treatment.
- ▶ Ensure that flowback fluid containing NORM is treated using an approach that ensures environmental protection, and is not disposed of at wastewater treatment works that are unable to process radioactive waste. Options could include pre-treatment with acid-alkali to precipitate out NORM for disposal or treatment at a wastewater treatment site licensed to accept radioactive waste.
- ▶ Consider the use of reverse osmosis or evaporation and crystallisation to reduce levels of Total Dissolved Solids (TDS) in wastewater, as wastewater treatment plants may not be designed to remove these substances. Elevated TDS levels may affect the functioning of the wastewater plant and potentially contaminate any receiving waters after discharge.
- ▶ Seek to avoid treatment offsite of flowback and produced water to reduce transport (if not connected to an appropriate waste water treatment plant by pipelines); however, before progressing consider additional energy consumption implications of any proposed onsite treatment. Should vehicle transport off site be required, promote sustainable transport options to transport and treat water generated during this stage.
- ▶ Use green completion techniques to capture natural gas for use on or offsite. If this is not possible, install an engine to burn the gas and recover energy. If flaring is the only option available, ensure that the natural gas is burned at temperatures above 800°C to ensure complete combustion.
- ▶ To avoid the risk of spills entering the wider environment and potentially causing contamination of soil and other materials which may have to be disposed of as hazardous waste, seal the site with an impermeable membrane underneath well pads and use bunds to contain liquid substances.
- ▶ Rainwater collected on the surface of the pad should be regularly tested to determine whether it is uncontaminated and can be discharged from site or used within the hydraulic fracturing

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<sup>34</sup> Enviroco (2014) *Drilling Mud Treatment Plant*. Available from <http://www.enviroco.co.uk/capabilities/services/oil-gas/mtp/> [Accessed November 2014].





process, or whether it requires collection and removal from site as hazardous waste e.g. if contaminated with oil/chemicals.

## Production Development

In addition to the mitigation measures listed for exploration drilling and hydraulic fracturing:

- ▶ Site Waste Management Plans should be extended to cover the management of waste during stage 3 operations. Waste management planning should establish a clear strategy for wastes that will be generated including options for waste elimination, reduction, recycling, treatment and disposal.
- ▶ Good practice guidance in the protection of soil materials should be followed.
- ▶ Promote best practice in selected methods to transport and treat wastewater generated during this stage.

## Production/operation/maintenance

In addition to the mitigation measures listed for exploration drilling and hydraulic fracturing:

- ▶ Connect the well to the gas main as soon as possible to enable collection and use of waste methane produced, or store the gas and export off site. Alternatively, an engine could be installed to burn waste methane and recover energy for use in any future onsite activities (such as the refracking that maybe required).
- ▶ Ensure that there is sufficient storage capacity on site for waste flowback fluid if there is a risk of the production of fluid exceeding the treatment capacity of local facilities. Operations may need to be suspended in the event that no treatment or storage capacity is available.
- ▶ Promote best practice in selected methods to transport and treat wastewater generated during this stage.

## Decommissioning of wells

- ▶ A Waste Management Plan should be adopted prior to decommissioning to ensure that all plant and infrastructure that is required to be decommissioned is recycled.

## Site restoration and relinquishment

- ▶ The decommissioning Waste Management Plan should be extended and adopted prior to site restoration to ensure that all plant and infrastructure that is required to be decommissioned is recycled.
- ▶ Stockpiled soils should be reused for land reclamation as soon as practicable.
- ▶ Previously excavated materials from the project construction stage should be reused on site where feasible.

## 6.4 Regulatory Framework

### International/European

The **Waste Framework Directive** 75/442/EEC as amended by 91/156/EEC, 91/92/EEC and 2008/98/EC provides the overarching framework for waste management at the EU level. It relates to waste disposal and the protection of the environment from harmful effects caused by the collection, transport, treatment, storage and tipping of waste. In particular, it aims to encourage the recovery and use of waste in order to conserve natural resources. The key principles of the Directive include the 'Waste Management Hierarchy' which stipulates waste management options based on their desirability. In order, these are: prevention; preparing

for re-use; recycling; other recovery, e.g. energy recovery; and disposal. Key objectives are to reduce the adverse impacts of the generation of waste and the overall impacts of resource use. This should be done through a variety of mechanisms, including:

- ▶ By 2020, requiring member states to recycle 50% of their household waste and 70% of their non-hazardous construction and demolition waste;
- ▶ Applying the waste hierarchy - promoting waste minimisation followed by reuse and recycling, other recovery (such as energy recovery) and disposal - as a priority order in waste prevention and management legislation and policy;
- ▶ Ensuring that four specified materials (paper, metal, plastics and glass) are collected separately by 2015;
- ▶ Taking measures as appropriate to promote the re-use of products and preparing for re-use activities; and
- ▶ Extending the self-sufficiency and proximity principles to apply to installations for recovery of mixed municipal waste from households.

The Directive was transposed into English legislation through the Waste (England and Wales) Regulations 2011 (SI2011 No.988).

A compromise agreement was reached between the Council of Environment Ministers and the European Parliament in June 2008 on revisions to the Waste Framework Directive. The main changes include EU-wide targets for reuse and recycling 50% of household waste by 2020, and for reuse, recycling and recovery of 70% of construction and demolition waste by 2020. In this context, the **Landfill Directive 99/31/EC** (European Commission, 1999) focuses on waste minimisation and increasing levels of recycling and recovery. The overall aim of the Directive is to prevent or reduce as far as possible negative effects on the environment, in particular the pollution of surface water, groundwater, soil and air and on the global environment, including the greenhouse effect as well as any resulting risk to human health from the landfilling of waste, during the whole lifecycle of the landfill. The Directive sets the target of reducing biodegradable municipal waste landfilled to 35% of that produced in 1995 by 2020. The **Mining Waste Directive 2006/21/EC** aims to prevent or reduce as far as possible the adverse effects on the environment and any resultant risks to human health from the management of waste from the extractive industries. The Directive sets out how to achieve this aim by providing for measures, procedures and guidance on how extractive industries should be managed.

The **Environmental Impact Assessment Directive 2011/92/EU** aims for the environmental impacts from certain projects to be identified and for mitigation measures to be proposed. Environmental Impact Assessments (EIAs) are not mandated for all shale gas operations and would be necessary when operations exceed 500,000m<sup>3</sup> gas extraction or are deemed likely to have significant environmental impacts, which could include impacts from the generation and disposal of waste, among others.

The **Water Framework Directive 2000/60/EC** aims to protect and enhance water quality. It includes measures that relate to waste flowback water, such as not permitting the reinjection of flowback water containing hazardous substances for disposal in rock formations. The **Urban Waste Water Directive 97/271/EEC** concerns the discharge of industrial wastewater such as flowback fluid into urban wastewater treatment plants, requiring pre-treatment to avoid adverse effects on the treatment plant and the environment.

The **Basel Convention** came into force in 1992 and is a global agreement, ratified by several member countries and the European Union, for addressing the problems and challenges posed by hazardous waste. The key objectives of the Basel Convention are:

- ▶ To minimise the generation of hazardous wastes in terms of quantity and hazardousness;
- ▶ To dispose of them as close to the source of generation as possible; and
- ▶ To reduce the movement of hazardous wastes.

The **EU Thematic Strategy on the Prevention and Recycling of Waste (2002-2012)** is a long-term strategy aims to help Europe become a recycling society that seeks to avoid waste and uses waste as a resource.

There are a number of **Producer Responsibility Directives** relating specifically to consumer products. Their purpose is to require businesses to reuse, recover and recycle waste which comes from products they produce, and each Directive sets national targets for recovery and recycling of these wastes.

The **World Summit on Sustainable Development (2002)** in Johannesburg proposed broad-scale principles which should underlie sustainable development and growth including an objective on greater resource efficiency.

The **European Sustainable Development Strategy (2006)** includes sustainable consumption & production and conservation & management of natural resources as key challenge areas.

## UK

The **Environmental Permitting (England and Wales) Regulations 2010** sets up a pollution control regime, and means that anyone who treats, deposits, recovers, or disposes of controlled waste must do so in accordance with the conditions of an environmental permit or an exemption. Permits are also required for operations that generate certain wastes. This includes the management of mining waste such as flowback fluid and waste gases, and any areas designated for the deposit of mining wastes. The waste operator would need to provide a Waste Management Plan as part of the permit application. The Plan must set out objectives to prevent or reduce the production of extractive waste; encourage recovery of waste; and ensure safe disposal. An industrial emissions permit would be required for operations that flare more than 10 tonnes of gas per day. Additionally, a permit for the temporary storage and disposal of radioactive waste such as flowback fluid containing NORM may be necessary.

The **Waste (England and Wales) Regulations 2011** implement the revised EU Waste Framework Directive 2008/98, which sets requirements for the collection, transport, recovery and disposal of waste. They require organisations to confirm that they have applied the waste management hierarchy when transferring waste; amend the system for waste carrier and broker registration (introduced in the **Control of Pollution Act 1974**); and exclude some categories of waste from waste controls. The **Waste (England and Wales) (Amendment) Regulations 2012** relate to the co-mingled collection of waste and require the separate collections of waste paper, metal, plastic and glass in England from 1<sup>st</sup> January 2015 (or confirmation that the waste contractor can adequately separate co-mingled waste streams).

Under the **Environmental Protection (Duty of Care) Regulations**, persons concerned with controlled waste are under a duty of care to:

- ▶ Prevent any other person committing the offence of depositing, disposing or recovering controlled waste without an environmental permit or in a manner likely to cause harm to health or the environment;
- ▶ Prevent waste escaping through appropriate and secure storage and transportation;
- ▶ Ensure that waste is transferred to an authorised person or to a person authorised to transport waste; and
- ▶ Ensure the waste is accompanied by a written description (a waste transfer note). The note must include a description of the waste and details of the parties involved in the transfer. It must also include the relevant six figure List of Waste codes.

The **List of Waste (England) Regulations 2005** provide a system of classification for all wastes and determines whether they are hazardous. Each waste has a six-digit identification code as set out in the Regulations.

Hazardous waste is defined as waste possessing one or more of the hazardous properties set out in the Hazardous Waste Directive, e.g. explosive, toxic, oxidising, flammable, or irritant. Under the **Hazardous Waste (England & Wales) Regulations 2005**, producers of hazardous waste are required to notify their premises to the environmental regulators. All hazardous waste movements must be accompanied by

Hazardous Waste Consignment Notes containing written information about the waste and its movements. It also requires hazardous and non-hazardous wastes (and different types of hazardous waste) not to be mixed. This transposes the requirements of the EU Hazardous Waste Directive 91/689/EEC into national law.

The **Landfill Tax Regulations 1996** aim to discourage landfilling and promote those waste management options which are further up the waste management hierarchy, such as waste reduction and recycling. The **Environmental Permitting Regulations** also include restrictions on waste accepted by landfill and includes a requirement for waste pre-treatment prior to landfill through physical, thermal, chemical or biological processes (including sorting) in order to reduce its volume or hazardous nature, facilitate its handling or enhance recovery. Liquid wastes are also banned from landfill.

UK Government's Sustainable Development Strategy: Securing the Future (2005) and the UK's Shared Framework for Sustainable Development, One Future - Different Paths (2005) includes sustainable Consumption and Production as one of four priorities and considers the five guiding principles:

- ▶ Living within Environmental Limits;
- ▶ Ensuring a Strong, Healthy and Just Society;
- ▶ Achieving a Sustainable Economy;
- ▶ Using Sound Science Responsibly; and
- ▶ Promoting Good Governance.

In February 2011, the Coalition Government published its vision for sustainable development and a package of measures to deliver it through the Green Economy, action to tackle climate change, protecting and enhancing the natural environment, fairness and wellbeing and building a Big Society. **Mainstreaming Sustainable Development (2011)** is a refreshed vision and builds on commitments and principles that underpinned the UK's 2005 Sustainable Development strategy by recognising the needs of the economy, society and the natural environment, alongside the use of good governance and sound science.

The **Waste Management Plan for England (2013)** provides a planning framework to meet the waste management needs of local areas, in order to support the objectives and provisions of the revised Waste Framework Directive (2008/98/EC). It sets out the high level arrangements for waste and the approach for assessing the need for new waste infrastructure.

The **Waste Prevention Programme for England (2013)** was launched in December 2013 as a requirement of the revised Waste Framework Directive. It sets out the Government's view of the key roles and actions which should be taken to move towards a more resource efficient economy. As well as describing the actions the Government is taking to support this move, it also highlights actions businesses, the wider public sector, the civil society and consumers can take to benefit from preventing waste.



# 7 Cultural Heritage

## 7.1 Introduction

Cultural heritage, including architectural and archaeological heritage, within this context is defined as below-ground and upstanding evidence of past human activity and encompasses artefacts, buried and underwater archaeological sites, earthworks, buildings, battlefields, historic gardens, historic landscapes, wrecks, hedgerows and ancient woodland. Cultural heritage assets may also include land, buildings and structures that have, for example, an important cultural meaning/use, artistic significance or scientific value. There are links between the cultural heritage topic and other topics in the study, specifically landscape and land use (as part of soils and geology).

## 7.2 Assessment of Effects

This section comprises of the review of the likely effects on cultural heritage arising from the potential activities associated with the six main stages of unconventional oil and gas exploration and production. **Table B7.1** presents a summary of the key stages of exploration, production and decommissioning.

Table B7.1 Unconventional Oil and Gas Exploration and Production Lifecycle and Key Activities

Stage	Activities
1	<p><b>Non-intrusive exploration</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Site identification, selection, characterisation;</li> <li>▶ Seismic surveys; and</li> <li>▶ Securing of necessary development and operation permits.</li> </ul>
2	<p><b>Exploration drilling and hydraulic fracturing</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Pad preparation road connections and baseline monitoring;</li> <li>▶ Well design and construction and completion;</li> <li>▶ Hydraulic fracturing; and</li> <li>▶ Well testing including flaring.</li> </ul>
3	<p><b>Production development</b>, including :</p> <ul style="list-style-type: none"> <li>▶ Pad preparation and baseline monitoring;</li> <li>▶ Facility construction and installation;</li> <li>▶ Well design construction and completion;</li> <li>▶ Hydraulic fracturing;</li> <li>▶ Well testing, possibly including flaring;</li> <li>▶ Provision of pipeline connections; and</li> <li>▶ (Possibly) re-fracturing.</li> </ul>



Table B7.1 (continued) Unconventional Oil and Gas Exploration and Production Lifecycle and Key Activities

Stage	Activities
4	<p>Production/operation/maintenance, including:</p> <ul style="list-style-type: none"> <li>▶ Gas/oil production;</li> <li>▶ Production and disposal of wastes/emissions;</li> <li>▶ Power generation, chemical use and reservoir monitoring; and</li> <li>▶ Environmental monitoring and well integrity monitoring.</li> </ul>
5	<p><b>Decommissioning of wells</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Well plugging and testing;</li> <li>▶ Site equipment removal; and</li> <li>▶ Environmental monitoring and well integrity monitoring.</li> </ul>
6	<p><b>Site restoration and relinquishment</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Pre-relinquishment survey and inspection; and</li> <li>▶ Site restoration and reclamation.</li> </ul>

Note: Exploration wells most usually move from Stage 2 to Stage 4, though some may be used for long-term production testing and some may be retained and their sites redeveloped as a production project. For the purposes of this review, the appraisal stage (a term commonly used in industry) spans Stages 2 and 3

In the United Kingdom, there is no statutory requirement to employ any specific methodology for the assessment of impacts on heritage assets, and consequently reference is made to guidance documents from various sources<sup>1</sup>. However, a broad approach which seeks to capture likely effects and address them is as follows<sup>2</sup>:

- ▶ Identify the baseline heritage assets and their setting;
- ▶ Assess the significance/value of the baseline assets and their settings;
- ▶ Identify and define the magnitude of impact and the severity of the effects;
- ▶ Identify mitigation required and its methodology in terms of spatial extent, timeframe for implementation and techniques to be implemented; and
- ▶ Assess the development impact and its effect on the significance of the asset taking into consideration any mitigation proposed (residual effects).

In determining the nature and extent of likely impacts, the following criteria<sup>3</sup> can be used to grade the significance of assets as set out in **Table B7.2**.

<sup>1</sup> Institute for Archaeologists (2014) *Standards and guidance for archaeological desk-based assessments*. Available from <http://www.archaeologists.net/codes/ifa> [Accessed October 2014]; Department for Transport (2014) *Design manual for roads and bridges Vol. 11, section 3, part 2*. Available from <http://www.dft.gov.uk/ha/standards/ghost/dmr/vol11/section3.htm> [Accessed October 2014]; English Heritage (2012) *The setting of heritage assets*. Available from <http://www.english-heritage.org.uk/publications/setting-heritage-assets/setting-heritage-assets.pdf> [Accessed October 2014].

<sup>2</sup> Cuadrilla Bowland Ltd (2013) *Lancashire Shale Gas Exploration: Grange Hill, Singleton, Lancashire Environmental Impact Assessment Scoping Report*. Available from [http://planningregister.lancashire.gov.uk/Attachments/6358/2013-07-09\\_GH\\_Scoping\\_Issue.pdf](http://planningregister.lancashire.gov.uk/Attachments/6358/2013-07-09_GH_Scoping_Issue.pdf) [Accessed October 2014].

<sup>3</sup> Derived from: Cuadrilla Bowland Ltd (2014) *Temporary Shale Gas Exploration, Preston New Road, Lancashire: Environmental Statement* p.95. Available from [http://www.cuadrillaresources.com/wp-content/uploads/2014/07/PNR\\_ES\\_Vol1\\_Environmental\\_Statement.pdf](http://www.cuadrillaresources.com/wp-content/uploads/2014/07/PNR_ES_Vol1_Environmental_Statement.pdf) [Accessed October 2014].

Table B7.2 Cultural Heritage significance and typical descriptors

Asset significance	Typical descriptors
Very high	Assets of acknowledged international importance such as World Heritage Sites Assets that contribute to acknowledged international research objectives
High	Nationally important assets Assets with potential to contribute to national research objectives
Medium	Regionally important assets Assets with potential to contribute to regional research objectives
Low	Assets compromised by poor preservation and/or poor survival of contextual associations Assets of limited value, but with potential to contribute to local research objectives
Negligible	Assets with no or very little surviving heritage interest

Effects can be either direct or indirect in character<sup>4</sup>. Direct effects will result from activities associated with construction of the well-pad, access track and seismic arrays involving removal of topsoil and excavations. Indirect effects could arise from changes to local patterns of drainage potentially affecting buried deposits distant from the site. Effects can be temporary or permanent in nature, be adverse or beneficial. Adverse effects will detract from the value of the cultural heritage asset itself, or its patterns or components. Beneficial effects could arise through increased understanding of the asset, improved setting and public access.

Likely effects can be determined according to a combination of the significance of the asset and the magnitude of change, as set out in **Table B7.3**<sup>5</sup>.

Table B7.3 Cultural Heritage magnitude of change

Magnitude of change	Description of change
Major	Complete destruction/demolition of a site or feature. Change to the site or feature resulting in a fundamental change in our ability to understand and appreciate the heritage resource and its historical context and setting.
Moderate	Change to the site or feature resulting in an appreciable change in our ability to understand and appreciate the heritage resource and its historical context and setting.
Minor	Change to the site or feature resulting in a small change in our ability to understand and appreciate the heritage resource and its historical context and setting.
Negligible	Negligible or no material change to the site or feature, or change in our ability to understand and appreciate the heritage resource and its historical context and setting.
No change	No change

<sup>4</sup> See Cuadrilla Bowland Ltd (2014) p.104.

<sup>5</sup> Derived from Cuadrilla Bowland Ltd (2014) p.95.

In turn, the likely significance of effects can be gauged according to the five point scale set out in Table 7.4<sup>6</sup> where neutral and slight adverse effects are not judged to be significant.

**Table B7.4 Cultural Heritage significance of effects**

Significance of effect	Effect
Very large adverse	Partial or total loss of a site identified as being of very high importance.
Large adverse	Result in total, or almost total, loss of heritage assets. Be highly intrusive and would serious damage the setting of the heritage resource such that its context is seriously compromised and can no longer be appreciated or understood. Be strongly at variance with the form, scale and pattern of a heritage resource. Be in serious conflict with national policies for the protection of the heritage resource.
Moderate adverse	Be out of scale or at odds with the form, scale, pattern and character of a heritage resource. Be intrusive in the setting (context) and adversely affect the appreciation and understanding of the resource. Result in a loss of features such that the integrity of the heritage resource is compromised, but not destroyed. Be in conflict with local or regional policies for the protection of heritage assets.
Slight adverse	Have a detrimental impact on the context of a heritage feature such that its integrity is compromised and appreciation and understanding of it is diminished. Not fit comfortably with the form, scale, pattern and character of a heritage resource. Be in conflict with local policies for the protection or enhancement of the heritage asset.
Neutral	Maintain existing historic features. Have no appreciable impacts, either beneficial or adverse on any known or potential heritage assets. Result in a balance of beneficial and adverse impacts. Not result in severance or loss of integrity, context or understanding within a historic landscape. Not be in conflict with policies for the protection or enhancement of the heritage asset.

### Non-intrusive Exploration

It is assumed that the activities associated with this stage (site identification, selection and characterisation and the securing of regulator approval) would be largely desk-based. Consequently, no significant effects on cultural heritage would be anticipated from these activities.

However, there potentially could be disturbance effects associated with seismic testing, such as on fragile above or below ground buildings and artefacts. However, the potential impact of these activities on cultural heritage assets remains untested and therefore has uncertain impacts in the short or longer term.

Vibroseis is a common method of seismic survey and typically involves 3-5 large truck mounted vibrator units which sub-sonically vibrate the ground while a number of support vehicles record the returning shock waves for analysis. Surveys tend to be spatially restricted due to the requirement for roads or other hard surfaces accessible by vehicle. Where roads have to be constructed to facilitate access to sites, any adverse effects would be temporary with land restored following completion of the surveys. Where shot-hole techniques are utilised (which involve the use of explosions as a source of seismic energy), the requirement for large

<sup>6</sup> Derived from Cuadrilla Bowland Ltd (2014) p.96.

vehicular access would be likely to be reduced whilst it would be expected that shot holes would be infilled after use.

Installation of arrays typically involves excavation of a pit to a depth of 0.80m and consequently the effects on unrecorded archaeological assets would be limited to the area of the pit, with the resulting magnitude of effects negligible<sup>7</sup>.

### Exploration drilling and hydraulic fracturing

There would be the potential for the loss or damage to cultural heritage features and landscapes associated with preparation for drilling, although site investigation should have largely anticipated these effects. The introduction of new elements into existing views could also have a negative effect on the setting of above-ground historic or archaeological features or landscapes<sup>8</sup>.

There would be the potential for well pad construction and drilling activities to result in the loss or damage to subsurface or buried archaeology. The effects principally arise from topsoil clearance and excavations which could expose or remove features or artefacts of potential interest. The effects are likely to be greatest where the excavations are deepest (for example in the drilling cellar or drainage ditches) and least where only minor excavation is required such as for access roads<sup>9</sup>.

The potential for effects would depend upon the proximity of any investigations or works to cultural heritage or archaeological sites, features or landscapes, and their current condition and sensitivity.

It is important to note that the potential effects on cultural heritage assets described above would be similar to those associated with the construction of conventional oil and gas well pads as well as other development projects.

### Production Development

There would be the potential for the loss or damage to cultural heritage features and landscapes associated with preparation for drilling (such as through site expansion), although site investigation should have anticipated these effects. The introduction of new elements into existing views could also have a negative effect on the setting of above-ground historic or archaeological features or landscapes<sup>10</sup>.

There would be the potential for well pad construction and drilling activities, such as the disposal of drill cuttings<sup>11</sup>, to result in the loss or damage to subsurface or buried archaeology.

The potential for effects would depend upon the proximity of any investigations or works to cultural heritage or archaeological sites, features or landscapes, and their current condition and sensitivity.

### Production/operation/maintenance

Subject to appropriate mitigation identified as part of Stages 1-3, no effects on above-ground cultural heritage or archaeological sites or features are anticipated as a result of operational activities as no further surface disturbance will occur. Nevertheless, risks have been cited<sup>12</sup> relating to potential negative effects on unrecorded cultural heritage artefacts (archaeological deposits and areas of high paleoenvironmental potential) as well as building foundations and fabric as a result of water abstraction and consequent depletion of groundwater, particularly in periods of water stress. However, local abstraction is considered unlikely due to regulatory requirements related to abstraction within the UK where it is likely that the majority of water supply will be via the mains.

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<sup>7</sup> Cuadrilla Bowland Ltd (2014) p.103.

<sup>8</sup> See AEA (2012) *Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe: AEAT, report for the European Commission, 2012*. Available from <http://ec.europa.eu/environment/integration/energy/pdf/fracking%20study.pdf> [Accessed May 2013].

<sup>9</sup> Cuadrilla Bowland Ltd (2014) p.93 & p.104.

<sup>10</sup> See: AEA (2012) p.xi.

<sup>11</sup> See: AEA (2012) p.37/38.

<sup>12</sup> English Heritage (2013) *Hydro-fracturing Issues Report* (Unpublished Draft).

Over time, the growth of visual screening could help to reduce visibility into the site and hence potential impacts on cultural heritage assets and their settings as well as historic landscapes.

### Decommissioning of wells

No effects on cultural heritage features or landscapes are anticipated as a result of decommissioning, including subsurface and buried archaeological remains as these will have been identified in previous stages.

### Site restoration and relinquishment

No effects on cultural heritage features or landscapes are anticipated as a result of decommissioning, including subsurface and buried archaeological remains as these will have been identified in previous stages.

As part of site restoration, there could be opportunities to enhance the setting of heritage features and landscapes through landscape design.

## 7.3 Mitigation Measures

The following section sets out the potential mitigation measures available at each stage of the project life cycle.

### Non-intrusive Exploration

- ▶ Regular monitoring of the effects of seismic survey activity on cultural heritage assets should be undertaken;
- ▶ Sites selected should be of no cultural heritage value, and the presence of any sensitive assets in the vicinity identified through desk-based assessment and surveys as required;
- ▶ Planning for operational site design and layout, in liaison with local and national experts, should take account of potentially vulnerable cultural heritage assets and their settings, including historic landscapes, which could be affected by construction and operational activities;
- ▶ Forward planting to screen the site could be required to reduce potential visual impacts on cultural heritage assets; and
- ▶ Identification of appropriate access routes would help to minimise potential negative effects on historic or archaeological features such as listed buildings, caused by transport pollution and vibration associated with lorry movements<sup>13</sup>.

### Exploration drilling and hydraulic fracturing

- ▶ Prior to any works on site, a desk study and site walkover should be undertaken to determine the historic and archaeological value of the sites and potential need for further site evaluation through trial trenching or more specific geophysical surveys.
- ▶ Consultation with established bodies charged with cultural heritage protection should be undertaken during the planning and permitting process to help identify existing and potential assets in the vicinity of proposed activity (including drill pad sites, pipelines, roads and transportation routes)<sup>14</sup>.

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<sup>13</sup> IOD (2012) *Getting Shale Gas Working*. Available from <http://www.iod.com/influencing/policy-papers/infrastructure/infrastructure-for-business-getting-shale-gas-working> [Accessed November 2014].

<sup>14</sup> Eshleman K & Elmore A (2013) *Recommended Best Management Practices for Marcellus Shale Gas Development in Maryland*. Available from

- ▶ Close monitoring during topsoil stripping and excavation works should be undertaken to identify unexpected features or artefacts. This can involve mapping and recording of features which could require further investigation<sup>15</sup>.
- ▶ Where potential impacts are identified the construction should be altered to minimise impacts, and if retention is not possible, consideration should be given to moving features or undertaking detailed excavation and recording.

### Production Development

- ▶ Prior to any works on site, a desk study and site walkover should be undertaken to determine the historic and archaeological value of the sites and potential need for further site evaluation through trial trenching or more specific geophysical surveys;
- ▶ Close monitoring during topsoil stripping and excavation works should be undertaken to identify unexpected features or artefacts; and
- ▶ Where potential impacts are identified the construction should be altered to minimise impacts, and if retention is not possible, consideration should be given to moving features or undertaking detailed excavation and recording.

### Production/operation/maintenance

- ▶ The effects of production activities should be closely monitored for adverse and cumulative impacts if there are likely to concentrations of activity in a locality.

### Decommissioning of wells

- ▶ Prior to decommissioning, opportunities for landscape enhancement should be investigated, particularly if operations are in the vicinity of historic landscapes.

### Site restoration and relinquishment

- ▶ Prior to decommissioning, opportunities for landscape enhancement should be investigated, particularly if operations are in the vicinity of historic landscapes.

## 7.4 Regulatory Framework

### International/European

The *World Heritage Convention* aims to promote co-operation amongst nations to protect heritage that is of such outstanding value that its conservation is important for current and future generations; and established a register of World Heritage Sites. It is intended that properties on the World Heritage List will be conserved for all time. Member states commit themselves to ensure the identification, protection, conservation, and presentation of World Heritage properties.

The World Heritage Committee's *Operational Guidelines for the Implementation of the World Heritage Convention (2008)* set out: the procedure from the inscription of properties on the World Heritage List and the List of World Heritage in Danger; the protection and conservation of World Heritage properties; the granting of International Assistance under the World Heritage Fund; and the mobilisation of national and international support in favour of the Convention.

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[http://www.mde.state.md.us/programs/Land/mining/marcellus/Documents/Eshleman\\_Elmore\\_Final\\_BMP\\_Report\\_22113\\_Red.pdf](http://www.mde.state.md.us/programs/Land/mining/marcellus/Documents/Eshleman_Elmore_Final_BMP_Report_22113_Red.pdf) [Accessed October 2014].

<sup>15</sup> Cuadrilla Bowland Ltd (2014) p.105.



The *UNESCO Convention for the Protection of the Archaeological Heritage of Europe (revised)* is a Europe-wide international treaty which establishes the basic common principles to be applied in national archaeological heritage policies. It supplements the general provisions of the *UNESCO World Heritage Convention (1972)* and aims to protect archaeological heritage as a source of the European collective memory and as an instrument for historical and scientific study. It sets out a framework which requires the member states to:

- ▶ Maintain an inventory of archaeological heritage and designated protected monuments and areas;
- ▶ Create archaeological reserves; and
- ▶ For finders of any element of archaeological heritage to report and make it available to the competent authority.

The European Convention on the Protection of the Archaeological Heritage (1992) made a number of important agreements including setting the definition of archaeological heritage as: “all remains and objects and any other traces of mankind from past epochs...shall include structures, constructions, groups of buildings, developed sites, moveable objects, monuments of other kinds as well as their context, whether situated on land or under water”.

The European Union Strategic Environmental Assessment Directive (2001/42/EC) at Annex I provides guidance related to the information that should be reported in the strategic environmental assessment. Impacts that should be covered are stated in Annex I (f): “*the likely significant effects (1) on the environment, including on issues such as biodiversity, population, human health, fauna, flora, soil, water, air, climatic factors, material assets, cultural heritage including architectural and archaeological heritage, landscape and the interrelationship between the above factors.*”

Article 3 of the Environmental Impact Assessment Directive (2011/92/EU) sets out what should be assessed in an EIA. It states: “The environmental impact assessment shall identify, describe and assess in an appropriate manner ... the direct and indirect effects of a project on the following factors:

- (a) Human beings, fauna and flora;
- (b) Soil, water, air, climate and the landscape;
- (c) Material assets and the cultural heritage; and
- (d) The interaction between the factors referred to in points (a), (b) and (c).”

## UK

The Department for Culture, Media and Sport White Paper *Heritage Protection for the 21<sup>st</sup> Century (2007)* sets out a strategy for protecting the historic environment, based on three core principles: developing a unified approach to the historic environment; maximising opportunities for inclusion and involvement; and supporting sustainable communities by putting the historic environment at the heart of an effective planning system.

The National Planning Policy Framework (2012) sets out the principles for planning in the United Kingdom which include the stipulation that planning should: conserve heritage assets in a manner appropriate to their significance. The objective of the policies is to maintain and manage change to heritage assets in a way that sustains and, where appropriate, enhances its significance, which may be archaeological, architectural, artistic or historic. This significance may derive not only from its physical presence but also from its setting. When determining applications for development, planning authorities are required to have regard to:

- ▶ The desirability of sustaining and enhancing the significance of all heritage assets (whether designated or not) and putting them to viable uses consistent with their conservation;
- ▶ The positive contribution that conservation of heritage assets can make to sustainable communities, including their economic vitality; and



- ▶ The desirability of new development making a positive contribution to local character and distinctiveness.

The draft *Heritage Protection Bill* contains provisions to unify the designation and consent regimes for terrestrial heritage assets, and transfer responsibility for designation of these assets. It also contains provisions to reform the marine heritage protection regime in England and Wales by broadening the range of marine historic assets that can be protected. The draft Bill is based on the proposals set out in the White Paper, *Heritage Protection for the 21<sup>st</sup> Century (2007)*, and is one element of a wider programme of on-going heritage protection reforms. There are however, no current plans to enact the Bill and it is not known whether its provisions will become statute.

The *Ancient Monuments and Archaeological Areas Act (1979)* provides for the scheduling of ancient monuments and offers the only legal protection specifically for archaeological sites. The *Planning (Listed Buildings and Conservation Areas) Act (1990)* outlines the level of protection received by listed buildings, scheduled monuments and buildings within Conservation Areas.

There are a number of other Acts which afford protection to cultural and historical assets, including the *Protection of Wrecks Act (1973)*, which provides protection for shipwrecks of historical, archaeological or artistic value; the *Protection of Military Remains Act (1986)*, which provides protection for the wreckage of military aircraft and designated military vessels, and the *Treasure Act (1996)*, which sets out procedures for dealing with finds of treasure, its ownership and rewards, in England, Wales and Northern Ireland.



# 8 Landscape

## 8.1 Introduction

Landscape in this context is defined by The European Landscape Convention as ‘an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors’. This definition is stated as covering natural, rural, urban and peri-urban (i.e. the urban-rural fringe) and includes land, inland water and marine areas. For the purposes of this study, landscape is taken to apply to rural areas, and townscape to urban areas. Visual effects are those effects that influence how people perceive a landscape or townscape, such as the erection of a building or structure.

## 8.2 Assessment of Effects

This section comprises a review of the likely effects on landscape arising from the potential activities associated with the six main stages of unconventional oil and gas exploration and production. **Table B8.1** presents a summary of the key stages of exploration, production and decommissioning.

Table B8.1 Unconventional Oil and Gas Exploration and Production Lifecycle and Key Activities

Stage	Activities
1	<p><b>Non-intrusive exploration</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Site identification, selection, characterisation;</li> <li>▶ Seismic surveys; and</li> <li>▶ Securing of necessary development and operation permits.</li> </ul>
2	<p><b>Exploration drilling and hydraulic fracturing</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Pad preparation road connections and baseline monitoring;</li> <li>▶ Well design and construction and completion;</li> <li>▶ Hydraulic fracturing; and</li> <li>▶ Well testing including flaring.</li> </ul>
3	<p><b>Production development</b>, including :</p> <ul style="list-style-type: none"> <li>▶ Pad preparation and baseline monitoring;</li> <li>▶ Facility construction and installation;</li> <li>▶ Well design construction and completion;</li> <li>▶ Hydraulic fracturing;</li> <li>▶ Well testing, possibly including flaring;</li> <li>▶ Provision of pipeline connections ; and</li> <li>▶ (Possibly) re-fracturing.</li> </ul>

Table B8.1(continued) Unconventional Oil and Gas Exploration and Production Lifecycle and Key Activities

Stage	Activities
4	<p><b>Production/operation/maintenance</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Gas/oil production;</li> <li>▶ Production and disposal of wastes/emissions;</li> <li>▶ Power generation, chemical use and reservoir monitoring; and</li> <li>▶ Environmental monitoring and well integrity monitoring.</li> </ul>
5	<p><b>Decommissioning of wells</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Well plugging and testing;</li> <li>▶ Site equipment removal; and</li> <li>▶ Environmental monitoring and well integrity monitoring.</li> </ul>
6	<p><b>Site restoration and relinquishment</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Pre-relinquishment survey and inspection; and</li> <li>▶ Site restoration and reclamation.</li> </ul>

Note: Exploration wells most usually move from Stage 2 to Stage 4, though some may be used for long-term production testing and some may be retained and their sites redeveloped as a production project. For the purposes of this review, the appraisal stage (a term commonly used in industry) spans Stages 2 and 3

### Non-intrusive Exploration

Stage 1 of the unconventional oil and gas exploration and production lifecycle comprises non-intrusive activities. Site identification, selection and characterisation and the securing of regulator approval would be largely desk-based and in consequence, no effects on landscapes are anticipated from this activity.

Vibroseis is a commonly used method of seismic survey and involves the employment of large vibrator unit vehicles as well as support vehicles for data recording. Construction of temporary tracks/roads may be required to facilitate site access and which could result in the fragmentation of local landscapes, particularly where new roads are of a significant length. However, new tracks/roads would be temporary and land would be restored following completion of surveys. In some cases, it may be necessary to use the shot-hole survey method. This involves the drilling of a hole with a small diameter for the insertion of explosives. The shot-holes are infilled, once the explosives have been detonated.

Overall, the effects on landscapes and visual amenity would be localised and of a temporary nature, occurring only during seismic surveys, and as such are of a minimal impact.

### Exploration drilling and hydraulic fracturing

The activity associated with this stage would mainly take place on site with some associated activity such as the construction of road connections located off-site. Like conventional oil and gas activities, as well as other types of development, activity associated with pad preparation, road access and well construction would have short and medium-term impacts on visual amenity and landscapes.

Further visual impacts will result from the presence of well heads and drilling rigs, with drilling operations lasting from 3 – 5 months per well, comprising up to 3 months for the vertical well and up to two months for the horizontal well<sup>1</sup>). The drilling rig would be in the range of 30-50m high<sup>2</sup> and could result in locally

<sup>1</sup> See: Cuadrilla Bowland Ltd (2014) *Temporary Shale Gas Exploration, Preston New Road, Lancashire: Environmental Statement* p.26 at: [http://www.cuadrillaresources.com/wp-content/uploads/2014/07/PNR\\_ES\\_Vol1\\_Environmental\\_Statement.pdf](http://www.cuadrillaresources.com/wp-content/uploads/2014/07/PNR_ES_Vol1_Environmental_Statement.pdf) [Accessed October 2014].

significant effects depending on the character and sensitivity of the receiving landscape and the extent to which such landscape changes are visible to communities. However, due to the relatively short duration of the phase, these effects would be temporary<sup>3</sup>.

The visual impact of a well during drilling and fracturing operations is illustrated in Figures B8.1 and B8.2<sup>4</sup>, although these can vary by country. Environmental regulations in the United Kingdom, for example, preclude the use of holding ponds for water meaning that tanks are used instead. Figure B8.3 illustrates an exploratory drilling operation in Lancashire, UK and the use of water tanks, contrasting with the example from the United States in **Figure B8.2**.

Figure B8.1 A shale gas site in Pennsylvania during drilling<sup>5</sup>



<sup>2</sup> See: Cuadrilla Bowland Ltd (2014) p.39.

<sup>3</sup> AEA (2012) *Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe: AEAT, report for the European Commission p.xi*. Available from <http://ec.europa.eu/environment/integration/energy/pdf/fracking%20study.pdf> [Accessed April 2015].

<sup>4</sup> See also Marcellus Shale (undated) *Marcellus Air Over Ohio's Utica Shale*. Available from [http://www.marcellus-shale.us/MARCELLUS-AIR\\_OHIO.htm](http://www.marcellus-shale.us/MARCELLUS-AIR_OHIO.htm) [Accessed April 2015].

<sup>5</sup> Ricardo-AEA (2013) *Unconventional Gas in England: Description of infrastructure and future scenarios p.30*. Available from <http://www.ricardo-aea.com/cms/assets/Uploads/Misc-uploads/ED58661-scenarios030214v14.pdf> [Accessed October 2014].



Figure B8.2 A US shale gas site during a single hydraulic fracturing operation<sup>6</sup>



Legend: 1. Wellhead and frack tree with 'Goat Head'; 2. Flow line for flowback & testing; 3. Sand separator for flowback; 4. Flowback tanks; 5. Line heaters; 6. Flare stack; 7. Pump trucks; 8. Sand hogs; 9. Sand trucks; 10. Acid trucks; 11. Frack additive trucks; 12. Blender; 13. Frack control and monitoring centre; 14. Fresh water impoundment; 15. Fresh water supply pipeline; 16. Extra tanks; 17. Line heaters; 18. Separator-metre skid; 19. Production manifold.

Figure B8.3 Hydraulic fracturing at Preese Hall, Lancashire UK<sup>7</sup>



<sup>6</sup> New York State Department of Environmental Conservation (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, September 2011*. Available from <http://www.dec.ny.gov/energy/75370.html> [Accessed October 2014].

<sup>7</sup> Energy-pedia (2011) *UK: Cuadrilla Resources releases report on unusual seismic activity related to Lancashire shale gas drilling*. Available from <http://www.energy-pedia.com/news/united-kingdom/cuadrilla-resources-releases-report-on-unusual-seismic-activity-related-to-lancashire-shale-gas-drilling> [Accessed April 2015].

The average area covered by a pad for unconventional oil and gas exploration is between 1 and 2 hectares with site clearing (vegetation, soil layers) likely to be required at this stage. Additional clearing may be required for the provision of service roads.

Flaring associated with testing may result in visual impacts. The effect will be dependent on location, height, duration and timing of the flare. However, within the UK licence requirements ensure that flaring is kept to the economic minimum. Furthermore, within the UK, any effects will be minimised through the use of best available technology (BAT), required as part of the permitting process, which will include stack design which would minimise visual intrusion effects. It is assumed that night light pollution resulting from other construction activities would be mitigated through appropriate measures such as restricted working hours and shielding of emergency lighting to minimise disturbance.

Public access to open spaces and the countryside is unlikely to be affected from the activity due to the small area (1 – 2 ha) of the site and the fact that activities would take place on the site.

Chemical storage tanks and plants associated with hydraulic fracturing would result in additional elements on site. Furthermore water storage tanks may be required, particularly in remote areas with limited or no connection to water mains. These elements would contribute to the visual intrusion associated with this stage.

The exploration phase would lead to adverse effects on the landscape and visual impacts. Effects would be less significant where development takes place in an industrial setting.

## Production Development

The production development stage would include similar activities to those under stage 2. This would include pad preparation; however, the average area covered by the well pad would be increased to 2-3 hectares. The expansion of land-take associated with this phase would increase potential visual impacts, particularly where this would involve clearing of high standing vegetation such as trees and shrubs. The use of heavy plant, stockpiles, fencing, site buildings etc could potentially result in adverse visual intrusion during site preparation, particularly in sensitive areas of high landscape value, or in close proximity to residential areas. However, these operations are likely to proceed sequentially as a shale gas play is developed which would reduce the potential for cumulative effects which could result from simultaneous development of a number of pads in a given area, but would equally tend to make the impacts a longer-term feature in the landscape<sup>8</sup>.

Chemical storage tanks and plants associated with hydraulic fracturing would result in additional elements on site. Furthermore, as more wells are drilled, additional water storage tanks may be required, particularly in remote areas with limited or no mains water connection. These elements would contribute to the visual intrusion associated with this stage.

Like conventional oil and gas production, additional construction activity would be required for facility provision and installation of pipeline connections. The effects on the landscape resulting from the construction of pipelines could be significant but would be short term and are likely to be reversed once habitat restoration has been completed. Furthermore, the significance of effects would depend on the width of the development corridor (which in itself is dependent on the pipeline diameter), length and location. Effects are likely to be more significant if the pipeline is routed through protected landscapes. **Figure B8.4** illustrates the visual impact of pipeline laying operations.

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<sup>8</sup> AEA (2012) p.34.



Figure B8.4 Pipeline construction in the NE United States<sup>9</sup>

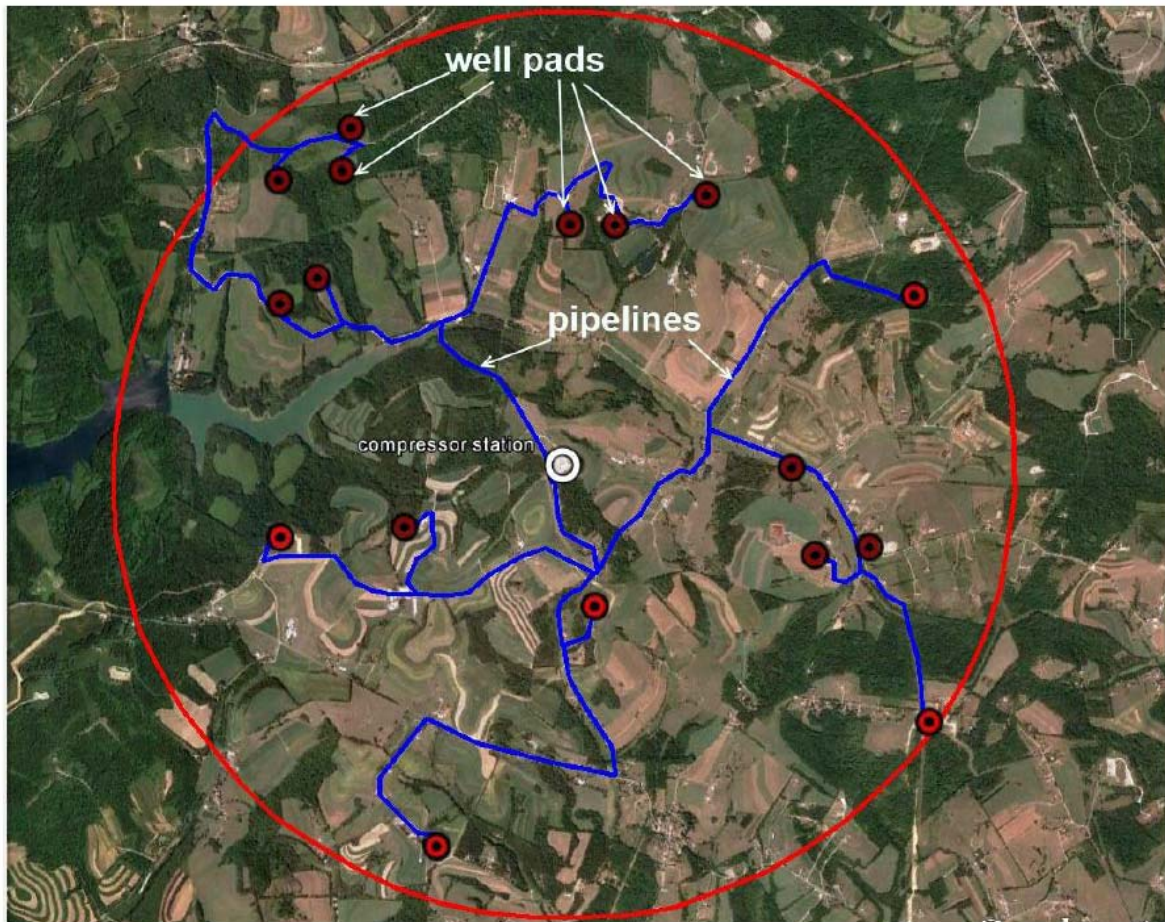


The presence of the pipeline would have short-term adverse effects and potential medium term impacts given the removal of a significant swathe of vegetation. Depending on the sensitivity of the landscape, significant effects could occur, although these would be dependent on routing, corridor length and width and the speed of restoration and re-vegetation.

The potential cumulative visual effects of well development are potentially significant, where a network of wells and associated pipelines and roadways could affect a wide area. **Figure B8.5** shows a centralised compressor station located on the Marcellus Shale at Washington County, Pennsylvania together with well pads located within a four mile radius. An indicative, 16 mile pipe network layout for the field is also shown, based on the assumption that the pipe network follows the access roads to the well pads, and then follow existing roads and/or forest clearings.

<sup>9</sup> Ricardo-AEA (2013) p.22.

Figure B8.5 A local network of shale gas wells in the NE United States<sup>10</sup>



Over a wider area, the cumulative impact could (depending on topography and vegetation cover) be significant with a well density of one per 1.6km<sup>2</sup>, as in the example shown in **Figure B8.6**.

<sup>10</sup> Ricardo-AEA (2013) p.21.



Figure B8.6 A local network of shale gas wells in the NE United States (57 wells covering 90sqkm)<sup>11</sup>



In conclusion, production development could lead to negative effects on landscapes due to the development size of pads and the development of the associated infrastructure. These effects could potentially be significant depending on the distribution and density of pads, the phasing of their development, the character and sensitivity of the receiving landscape and the extent to which such landscape changes are visible to communities<sup>12</sup>.

### Production/operation/maintenance

There would be no additional effects resulting from this stage under the assumption that production, operation and maintenance would take place on the existing site. This stage does not involve the introduction of additional infrastructure which could have implications on the landscape. However, there may be some short term effects associated with wells that are re-fractured. It is likely that residual effects on the landscape would remain in the long-term and may result in a permanent change of landscape and visual amenity for local communities. The degree of perceived intrusion is likely to be lessened through the maturing of landscaping and re-vegetation. In some cases it may be possible to minimise effects through mitigation measures, such as screening through existing features or planting and landscaping. Effects resulting from the construction of the pipeline have been assessed as neutral in the medium and long term as habitats recover and corridor vegetation matures.

Figures B8.7 and B8.8 illustrate pad production facilities and the effect of the removal of the infrastructure which was required during the drilling and fracturing phase.

<sup>11</sup> Ricardo-AEA (2013) p.38.

<sup>12</sup> European Commission Joint Research Centre (2012) *Shale Gas for Europe – main environmental and social considerations: a literature review*. Available from <http://publications.jrc.ec.europa.eu/repository/bitstream/11111111/26691/1/lbna25498enn.pdf> [Accessed October 2014].

Figure B8.7 A well pad in production in the NE United States<sup>13</sup>



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<sup>13</sup> Ricardo-AEA (2013) p.6.



Figure B8.8 A shale gas production facility in the NE United States<sup>14</sup>



Gas processing plants (for the compression of produced gas prior to transportation) which will serve a number of wells will in themselves have a different, potentially more intrusive, visual impact, as illustrated in **Figure B8.9**. These facilities serve significant hinterland and vary greatly in scale and visual impact<sup>15</sup>.

<sup>14</sup> European Commission Joint Research Centre (2012) p.31.

<sup>15</sup> See: Marcellus Shale (undated) *Our look at the Majorsville Gas Plant*. Available from [http://www.marcellus-shale.us/Majorsville\\_Gas-plant.htm](http://www.marcellus-shale.us/Majorsville_Gas-plant.htm) [Accessed April 2015]; Stell, J. (undated) *Marcellus and Utica shales attract more gas processing infrastructure*, in Gas Processing News. Available from <http://www.gasprocessingnews.com/features/201410/marcellus-and-utica-shales-attract-more-gas-processing-infrastructure.aspx> [Accessed April 2015]; Smith, C.E. (2014) *Wealth of gas processing, pipeline projects planned for Marcellus-Utica region*, in UOGR. Available from <http://www.ojg.com/articles/uogr/print/volume-2/issue-1/marcellus/wealth-of-gas-processing-pipeline-projects-planned-for-marcellus-utica-region.html> [Accessed April 2015].

Figure B8.9 Gas processing and cryogenic plant, Pennsylvania<sup>16</sup>

### Decommissioning of wells

Decommissioning of wells and removal of site equipment would involve some construction activity. The activity would be short-term and take place on the existing site. Consequently no additional effects on landscape or visual impacts are anticipated.

### Site restoration and relinquishment

Site restoration and reclamation would take place on the existing site with the aim to restore the original condition.

It may not be possible to remove all well equipment from the site. However, remaining structures would be small scale and would not affect the general landscape or have visual impacts.

Long-term effects on the landscapes have been anticipated to be neutral under the assumption that the original state of the site can be restored and that remaining structures would be negligible.

Potential for the enhancement of landscapes has been identified where the original site character is of low value.

A helpful summary<sup>17</sup> of the likely landscape impacts set out above is reproduced in **Table B8.2**. Note that some of these aspects could be specific to the United States context for which they have been developed.

<sup>16</sup> Ricardo-AEA (2013) p.25.

<sup>17</sup> New York State Department of Environmental Conservation (2011) .

Table B8.2 Summary of New Landscape Features and Potential Visual Impacts

Description of Activity	Description of Typical New Landscape Features	Description of Potential Visual Impacts
On-site Well Pad Construction	<ul style="list-style-type: none"> <li>▶ Newly created well pads - open, level areas averaging approximately 3.5 acres in size</li> <li>▶ Newly created linear features such as access roads and connecting pipelines</li> <li>▶ Newly created water impoundment areas (if necessary)</li> <li>▶ Construction equipment, including bulldozers, graders, backhoes, and other large equipment for clearing, cutting, filling and grading activities</li> <li>▶ Trucks for hauling equipment and materials</li> <li>▶ Worker vehicles</li> </ul>	<ul style="list-style-type: none"> <li>▶ Direct impacts - on the existing visual setting of a well location</li> <li>▶ Indirect impacts - on the existing visual setting of areas in the vicinity of a well location, including views that contain a well location</li> <li>▶ Temporary or short-term duration - during the weeks or months while construction is underway</li> <li>▶ Negative - because of the introduction of new features into the landscape</li> <li>▶ Site-specific - within views that contain individual well locations</li> <li>▶ Cumulative - within views of areas or regions that contain concentrations of well locations</li> </ul>
On-site Well Drilling	<ul style="list-style-type: none"> <li>▶ Drill rigs of varying heights and dimensions</li> <li>▶ Auxiliary on-site equipment such as storage tanks for water, fuel, and drilling mud; generators; compressors; solids control equipment; a choke manifold; an accumulator; pipe racks; and the crew's office space</li> <li>▶ Trucks for hauling equipment and materials</li> <li>▶ Worker vehicles</li> </ul>	<ul style="list-style-type: none"> <li>▶ Direct impacts - on the existing visual setting of a well location</li> <li>▶ Indirect impacts - on the existing visual settings of areas surrounding a well location, including views that include a well location</li> <li>▶ Temporary - during the weeks while drilling is underway</li> <li>▶ Periodic - during the times when drilling may occur over a three-year period following the date that the initial drilling on a well site commences</li> <li>▶ Negative - throughout the duration of drilling, primarily because of the high visibility of drilling activities from surrounding vantage points</li> <li>▶ Site-specific - within views that contain individual well locations</li> <li>▶ Cumulative – within views of areas or regions that contain concentrations of well locations</li> </ul>

Table B8.2 (continued) Summary of New Landscape Features and Potential Visual Impacts

Description of Activity	Description of Typical New Landscape Features	Description of Potential Visual Impacts
On-site Well Fracturing	<ul style="list-style-type: none"> <li>▶ On-site equipment such as storage tanks for water, fuel, and fracturing additives; compressors; cranes; pipe racks; and the crew's office space</li> <li>▶ Trucks, including tractor trailers and other large trucks for hauling sand and fracturing additives, pipe-hauling trucks, welding and other mechanical support trucks</li> <li>▶ Worker vehicles</li> </ul>	<ul style="list-style-type: none"> <li>▶ Direct impacts – on the existing visual setting of a well location</li> <li>▶ Indirect impacts - on the existing visual settings of areas surrounding a well location, including views that include a well location</li> <li>▶ Temporary or short-term duration – during the weeks while hydraulic fracturing is underway</li> <li>▶ Periodic - during the times when fracturing may occur over the lifetime of the well(s)</li> <li>▶ Negative - throughout their duration, primarily because of the high visibility of fracturing activities from surrounding vantage points.</li> <li>▶ Site-specific - within views that contain individual well locations</li> <li>▶ Cumulative – within views of areas or regions that contain concentration of well locations</li> </ul>
Well Production	<ul style="list-style-type: none"> <li>▶ Operating well pads - open, level areas averaging approximately 0.5 to 1.0 acre in size, maintained in grassy or gravelled conditions</li> <li>▶ Wellhead locations and small aboveground facilities for the pumping and transfer of product into gas lines.</li> <li>▶ Access road maintained in gravelled condition</li> <li>▶ Connecting pipeline right-of-way maintained with grassy vegetation</li> </ul>	<ul style="list-style-type: none"> <li>▶ Direct impacts - on the existing visual setting of a well location</li> <li>▶ Indirect impacts - on the existing settings within viewsheds that contain a well location</li> <li>▶ Long-term duration - during the years while active well sites remain viable</li> <li>▶ Negative - during short-term period of initial development</li> <li>▶ Neutral - during long-term period of production over a potential 30-year period</li> <li>▶ Site specific - within views that contain individual well locations</li> <li>▶ Cumulative – within views of areas or regions that contain concentrations of well locations</li> </ul>

Table B8.2 (continued) Summary of New Landscape Features and Potential Visual Impacts

Description of Activity	Description of Typical New Landscape Features	Description of Potential Visual Impacts
On-site Well Site Reclamation	<ul style="list-style-type: none"> <li>▶ Initial bare areas resulting from the removal of wellheads and small aboveground facilities used during production; re-contouring to pre-existing terrain conditions; and re-vegetation efforts</li> <li>▶ Subsequent vegetated areas reverting to pre-existing vegetation patterns and species</li> </ul>	<ul style="list-style-type: none"> <li>▶ Direct impacts - on the existing visual setting of a well location</li> <li>▶ Indirect impacts - on the existing settings within viewsheds that would contain a well location</li> <li>▶ Temporary to short term - during removal of well equipment and structures, re-contouring terrain, and replanting of vegetation</li> <li>▶ Periodic and long-term - during periodic inspection or monitoring and implementation of any corrective actions to facilitate successful re-vegetation for several months to as long as one to three years</li> <li>▶ Neutral to beneficial - as vegetation succession proceeds</li> <li>▶ Site specific - within views that contain individual well locations</li> <li>▶ Cumulative – within views of areas or regions containing concentrations of well locations</li> </ul>
On-site Well Site Reclamation	<ul style="list-style-type: none"> <li>▶ Initial bare areas resulting from the removal of wellheads and small aboveground facilities used during production; re-contouring to pre-existing terrain conditions; and re-vegetation efforts</li> <li>▶ Subsequent vegetated areas reverting to pre-existing vegetation patterns and species</li> </ul>	<ul style="list-style-type: none"> <li>▶ Direct impacts - on the existing visual setting of a well location</li> <li>▶ Indirect impacts - on the existing settings within viewsheds that would contain a well location</li> <li>▶ Temporary to short term - during removal of well equipment and structures, re-contouring terrain, and replanting of vegetation</li> <li>▶ Periodic and long-term - during periodic inspection or monitoring and implementation of any corrective actions to facilitate successful re-vegetation for several months to as long as one to three years</li> </ul>



Table B8.2 (continued) Summary of New Landscape Features and Potential Visual Impacts

Description of Activity	Description of Typical New Landscape Features	Description of Potential Visual Impacts
		<ul style="list-style-type: none"> <li>▶ Neutral to beneficial - as vegetation succession proceeds</li> <li>▶ Site specific - within views that contain individual well locations</li> <li>▶ Cumulative – within views of areas or regions containing concentrations of well locations</li> </ul>
Off-site periodic and temporary influx of specialized workforces at various phases of development	<ul style="list-style-type: none"> <li>▶ Increased use of local recreational vehicle or other camping areas (areas with cabins or designated for tent camping) for temporary or seasonal housing.</li> <li>▶ Increased local worker traffic during and after working hours</li> </ul>	<ul style="list-style-type: none"> <li>▶ Direct impacts - on the existing visual setting of off-site housing locations and on local roads</li> <li>▶ Indirect impacts - on the existing settings within viewsheds that would contain off-site housing and local roads</li> <li>▶ Temporary and periodic - during specific phases of well development (construction, drilling, fracturing, and reclamation)</li> <li>▶ Neutral to negative - occupancy of existing offsite housing locations would be consistent with capacity, but local traffic may result in congestion during and after work hours</li> <li>▶ Site-specific – at specific housing locations and along local roads</li> </ul>
Off-site contractor yards or equipment storage areas or other staging areas	<ul style="list-style-type: none"> <li>▶ Increased traffic and activity associated with construction and use of new contractor yards, equipment storage areas or other staging areas</li> <li>▶ Increased traffic and activity associated with use of existing contractor yards, equipment storage areas, or other staging areas</li> </ul>	<ul style="list-style-type: none"> <li>▶ Direct impacts - on the existing visual setting of an off-site yard, storage area, or staging area</li> <li>▶ Indirect impacts - on the existing settings within viewsheds that contain an off-site yard, storage area, or staging area</li> <li>▶ Temporary and periodic - during specific phases of well development (construction, drilling, fracturing, and reclamation)</li> </ul>



Table B8.2 (continued) Summary of New Landscape Features and Potential Visual Impacts

Description of Activity	Description of Typical New Landscape Features	Description of Potential Visual Impacts
		<ul style="list-style-type: none"> <li>▶ Negative - due to the appearance and movement of high numbers of specialized and large equipment and vehicles</li> <li>▶ Site specific – at specific off-site yard, storage area, or staging area locations</li> </ul>

### 8.3 Mitigation Measures

The following section sets out the potential mitigation measures available at each stage of the project life cycle.

#### Non-intrusive Exploration

None identified.

#### Exploration drilling and hydraulic fracturing

- ▶ Site selection to avoid visual intrusion onto sensitive receptors<sup>18</sup>, based on an assessment of landscape and visual impact to judge the relationship between the magnitude of the effects (nature-geographical extent-duration) and the sensitivity (low-medium-high) of the receptor(s)<sup>19</sup>;
- ▶ Creation of bunds to help screen operations using stored topsoil as well as targeted planting of vegetation which would contribute to long-term screening<sup>20</sup>;
- ▶ Best practice construction techniques such as minimising the vertical height of drilling equipment (typically 30-50m high) and site screening through existing features or use of planting and landscaping;
- ▶ Optimise the phasing of the development of well pads to minimise cumulative impacts; and
- ▶ Light pollution should be mitigated by restricting working hours to daylight hours and by site screening to avoid light pollution to the surrounding area.

#### Production Development

- ▶ Best practice construction techniques such as minimising the vertical height of drilling equipment and site screening through existing features or use of planting and landscaping<sup>21</sup>; and
- ▶ Design measures to minimise effects resulting from pipelines. This could include measures such as routing along existing roads, minimising corridor width and maximising the speed of restoration and re-vegetation where feasible.

<sup>18</sup> See: Cuadrilla Bowland Ltd (2014) p. 429.

<sup>19</sup> See: Cuadrilla Bowland Ltd (2014) pp.392/393.

<sup>20</sup> See: Cuadrilla Bowland Ltd (2014) pp. 429/430.

<sup>21</sup> See Celtique (2012) *Environmental Statement Chapter 14 for exploratory drilling at Wood Barn Farm, Adversane Lane, Broadford Bridge, Billingshurst, West Sussex*. Available from <http://buildings.westsussex.gov.uk/ePlanningOPS/tabPage3.jsp?apllid=1421> [Accessed October 2014].

## Production/operation/maintenance

- ▶ Site screening (existing or through planting and landscaping) should be used to mitigate long-term residual adverse effects.

## Decommissioning of wells

- ▶ A study of the surrounding landscape character and sensitivity<sup>22</sup> should be undertaken prior to decommissioning to identify measures which would allow efficient site restoration as well as opportunities for the enhancement of landscapes.

## Site restoration and relinquishment

- ▶ Remaining structures should be incorporated into site design during restoration and reclamation.

# 8.4 Regulatory Framework

## International

The **European Landscape Convention** is principally directed at the national level, but emphasises the importance of landscape as a cultural as well as an aesthetic asset. The convention also calls for improved public involvement in landscape matters. The UK became a signatory to the European Landscape Convention in 2006.

## UK

In the UK, there are numerous Acts governing the protection of the countryside, landscape and natural environment. The National Parks and Access to the Countryside Act 1949 makes provision for National Parks, confers powers for the establishment and maintenance of nature reserves, makes provision for the recording, creation, maintenance and improvement of public paths and for securing access to open country and confers further powers for preserving and enhancing natural beauty. National Parks are areas of relatively undeveloped and scenic landscape. Designation as a national park may include substantial settlements and human land uses which are often integral parts of the landscape. Land within a national park remains largely in private ownership. Each National Park is operated by its own national park authority, with two 'statutory purposes':

- ▶ To conserve and enhance the natural beauty, wildlife and cultural heritage of the area; and
- ▶ To promote opportunities for the understanding and enjoyment of the parks.

AONBs are areas of high scenic quality that have statutory protection in order to conserve and enhance the natural beauty of their landscapes. AONB landscapes range from rugged coastline to water meadows to gentle lowland and upland moors. Natural England has a statutory power to designate land as Areas of Outstanding Natural Beauty.

The Countryside and Rights of Way Act 2000 increased the duty of provision of public access to the countryside and strengthened legislation relating to Sites of Special Scientific Interest (SSSIs). In particular, it requires public bodies to further the conservation and enhancement of SSSIs both in carrying out their operations, and in exercising their decision making functions.

Section 50 of the **Infrastructure Act 2015** inserts an amendment to the Petroleum Act 1998 regarding safeguards for onshore hydraulic fracturing. These include a commitment that "hydraulic fracturing will not take place within other protected areas", which will be defined in regulations issued by the Secretary of State for Energy and Climate Change. It is noted however, that in the originally proposed amendment at the third reading of the Bill, protected areas included:

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<sup>22</sup> See: Cuadrilla Bowland Ltd (2014) pp. 392/393.

- ▶ Special areas of conservation under the Conservation (Natural Habitats, &c) Regulations 1994,
- ▶ Special protection areas under the Wildlife and Countryside Act 1981,
- ▶ Sites of special scientific interest under the Wildlife and Countryside Act 1981,
- ▶ National parks under the National Parks and Access to the Countryside Act 1949,
- ▶ The Broads under the Norfolk and Suffolk Broads Act 1988, and
- ▶ Areas of outstanding natural beauty under the Countryside and Rights of Way Act 2000.

The Marine and Coastal Access Act 2009 seeks to ensure clean healthy, safe, productive and biologically diverse oceans and seas, by putting in place better systems for delivering sustainable development of marine and coastal environment.

Other relevant Acts include:

- ▶ The *1967 Forestry Act (as amended 1999)* restricts and regulates the felling of trees. The *1968 Countryside Act* enlarges the function of the Agency established under the National Parks and Access to the Countryside Act 1949, to confer new powers on local authorities and other bodies for the conservation and enhancement of natural beauty and for the benefit of those resorting to the countryside;
- ▶ The *1986 Agriculture Act (with numerous revisions)* covers the provision of agricultural services and goods, agricultural marketing compensation to tenants for milk quotas, conservation and farm grants; and
- ▶ The *Commons Act 2006*, which protects common land and promotes sustainable farming, public access to the countryside and the interests of wildlife.

## England

The Natural Environment and Rural Communities (NERC) Act 2006 implements key elements of the Government's Rural Strategy published in July 2004. The NERC Act is designed to help achieve a rich and diverse natural environment and thriving rural communities through modernised and simplified arrangements for delivering Government policy. The NERC Act established a new independent body - Natural England - responsible for conserving, enhancing, and managing England's natural environment for the benefit of current and future generations. The Act made amendments to both the Wildlife and Countryside Act 1981 and the Countryside and Rights of Way Act 2000, which further enhance provisions to biodiversity generally and SSSIs in particular.

The National Planning Policy Framework (2012) includes strong protections for valued landscapes and townscapes as well as recognising the intrinsic character and beauty of the countryside. The importance of planning positively for high quality design is underlined and local and neighbourhood plans are expected to "develop robust and comprehensive policies that set out the quality of development that will be expected for the area". Planning policies and decisions are expected to respond to local character and history, and reflect the identity of local surroundings and materials, while not preventing or discouraging appropriate innovation. The Framework states (paragraph 64) that: "Permission should be refused for development of poor design that fails to take the opportunities available for improving the character and quality of an area and the way it functions".

The Framework has a number of specific requirements relating to planning and landscape including a clear expectation that the planning system should contribute to and enhance the natural and local environment by protecting and enhancing valued landscapes. Local planning authorities are expected to set criteria based policies against which proposals for any development on or affecting protected landscape areas will be judged. In doing so, distinctions should be made between the hierarchy of international, national and locally designated sites and "great weight" should be given to "conserving landscape and scenic beauty in National Parks, the Broads and Areas of Outstanding Natural Beauty". Local planning authorities in their plan-making are expected to take account of climate change and changes to landscape and contain a clear strategy for enhancing the natural, built and historic environment. Where appropriate, "landscape character



assessments should also be prepared, integrated with assessment of historic landscape character, and for areas where there are major expansion options assessments of landscape sensitivity”.

With regard to mineral extraction, the Framework notes that when determining planning applications, local planning authorities should give great weight to the benefits of the mineral extraction, including to the economy. However, the Framework also places a duty on local planning authorities to ensure that there are no unacceptable adverse impacts on the natural and historic environment and to take into account the cumulative effect of multiple impacts from individual sites and/or from a number of sites in a locality. The Framework makes explicit reference to unconventional hydrocarbons; it states that mineral planning authorities should clearly distinguish between the three phases of development (exploration, appraisal and production) and address constraints on production and processing within areas that are licensed for oil and gas exploration or production.

Planning Practice Guidance for Onshore Oil and Gas (2013) provides advice on the planning issues associated with the extraction of hydrocarbons. It will be kept under review and should be read alongside other planning guidance and the NPPF. The guidance identifies a range of issues that mineral planning authorities may need to address. Those particularly relevant to landscape include: visual intrusion into the local setting and the wider landscape caused by the placement of any building or structure within the application site area; lighting; landscape character; and site restoration and aftercare.



# 9 Health

## 9.1 Introduction

Human health includes the potential for negative effects on public health and site workers as a result of shale gas activities. This includes the impact of emissions to air and releases to water, noise and flood risk among others.

There are links between the human health topic and other topics in the study, specifically air and water.

## 9.2 Assessment of Effects

This section comprises of the review of the likely effects on health arising from the potential activities that could take place in the six main stages of unconventional oil and gas exploration and production. **Table B9.1** presents a summary of the key stages of exploration, production and decommissioning.

Table B9.1 Unconventional Oil and Gas Exploration and Production Lifecycle and Key Activities

Stage	Activities
1	<p><b>Non-intrusive exploration</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Site identification, selection, characterisation;</li> <li>▶ Seismic surveys;</li> <li>▶ Securing of necessary development and operation permits.</li> </ul>
2	<p><b>Exploration drilling and hydraulic fracturing</b>, including:</p> <ul style="list-style-type: none"> <li>▶ Pad preparation road connections and baseline monitoring;</li> <li>▶ Well design and construction and completion;</li> <li>▶ Hydraulic fracturing;</li> <li>▶ Well testing including flaring.</li> </ul>
3	<p><b>Production development</b>, including :</p> <ul style="list-style-type: none"> <li>▶ Pad preparation and baseline monitoring;</li> <li>▶ Facility construction and installation;</li> <li>▶ Well design construction and completion;</li> <li>▶ Hydraulic fracturing;</li> <li>▶ Well testing, possibly including flaring</li> <li>▶ Provision of pipeline connections</li> <li>▶ (Possibly) re-fracturing.</li> </ul>



Table B9.1 (continued) Unconventional Oil and Gas Exploration and Production Lifecycle and Key Activities

Stage	Activities
4	<b>Production/operation/maintenance</b> , including: <ul style="list-style-type: none"> <li>▶ Gas/oil production;</li> <li>▶ Production and disposal of wastes/emissions;</li> <li>▶ Power generation, chemical use and reservoir monitoring;</li> <li>▶ Environmental monitoring and well integrity monitoring.</li> </ul>
5	<b>Decommissioning of wells</b> , including: <ul style="list-style-type: none"> <li>▶ Well plugging and testing;</li> <li>▶ Site equipment removal;</li> <li>▶ Environmental monitoring and well integrity monitoring.</li> </ul>
6	<b>Site restoration and relinquishment</b> , including: <ul style="list-style-type: none"> <li>▶ Pre-relinquishment survey and inspection;</li> <li>▶ Site restoration and reclamation.</li> </ul>

Note: Exploration wells most usually move from Stage 2 to Stage 4, though some may be used for long-term production testing and some may be retained and their sites redeveloped as a production project. For the purposes of this review, the appraisal stage (a term commonly used in industry) spans Stages 2 and 3

## Non-intrusive Exploration

Site identification, selection and characterisation and the securing of regulator approval would be expected to be largely desk based. As a result, no effects on health are expected from these activities.

Seismic surveys (most commonly vibroseis and shot hole techniques) may generate noise. However, noise levels are expected to be low and emissions temporary such that no health impacts would be expected. There may also be an increase in vehicular movements to conduct the seismic surveys, although any increase would be very small and therefore unlikely to affect human health.

## Exploration drilling and hydraulic fracturing

### Pad preparation

Activities associated with pad preparation, such as excavation, earth moving, the use of machinery and vehicle transport could potentially affect sensitive residential areas within close proximity to well pad sites due to the generation of noise, vibration and dust. Depending on the level of noise and proximity to receptors, noise in particular has the potential to cause annoyance, affect sleep and performance, with children particularly vulnerable to the effects.<sup>1</sup> However, impacts are likely to be similar to those associated with general construction activity and would occur over a relatively short time period. For example, estimates by Cuadrilla in respect of a proposed temporary shale gas exploration site in Lancashire, England indicate that site preparation and construction of the well pad and access track would take up to two months.<sup>2</sup>

<sup>1</sup> Stansfeld, S.A. and Matheson, M.P. (2003) *Noise pollution: non-auditory effects on health*, British Medical Bulletin, 68, 243–257. Available from <http://bmb.oxfordjournals.org/content/68/1/243.full> [Accessed April 2015].

<sup>2</sup> Cuadrilla Bowland Ltd (2014) *Temporary Shale Gas Exploration Preston New Road, Lancashire: Environmental Statement*. Available from [http://www.cuadrillaresources.com/wp-content/uploads/2014/07/PNR\\_ES\\_Vol1\\_Environmental\\_Statement.pdf](http://www.cuadrillaresources.com/wp-content/uploads/2014/07/PNR_ES_Vol1_Environmental_Statement.pdf) [Accessed October 2014].

Construction and preparation of the pad may be used as a focus for anti-fracking sentiment and may be subject to protest action from opposition groups and local communities. This could potentially increase the fear of crime through the fear of vandalism and personal injury as a result of an influx of a large number of people into a local area. In the UK, there have also been reports that recent protests against hydraulic fracturing have involved small levels of violence.<sup>3</sup>

## Drilling

Drilling is an activity with significantly high noise levels, with continuous operations each day over a period of several weeks or months. For construction equipment used in the preparatory stages, the maximum calculated composite noise level at 75m is 70dBA. For horizontal drilling, the maximum noise level is 64dBA.<sup>4</sup> Depending on the distance from the noise source, any attenuation and ambient noise levels, noise at 64dBA could disturb local residents, particularly in sensitive areas and noise controls would be necessary. As the oil and gas sector already has widely used noise controls, it is anticipated that effects can largely be avoided if the installation is properly designed and managed.

In this respect, the drilling of exploratory wells at the proposed Cuadrilla site in Lancashire is expected to take place across approximately five months for the vertical and horizontal sections of the first well (for a depth of 3,500m and lateral distance of 2,000m), with subsequent well drilling expected to take three months each. Drilling works would include construction activities such as casing and cementing as well as the drilling itself. Diesel generators are likely to be used to power the drilling rigs. Cuadrilla indicate that three generators would be used 24 hours per day during drilling operations at its Lancashire site generating a noise level of 39 dBL<sub>Aeq</sub> at receptors situated at a distance of 380m from the well pad boundary. Whilst Cuadrilla view these levels as unlikely to be significant<sup>5</sup>, Lancashire County Council have deferred making a decision on the planning application due to concerns over localised noise impacts<sup>6</sup>

The extended duration of drilling relative to conventional oil and gas exploration would involve increased emissions of pollutants such as particulate matter (PM<sub>10</sub>), nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO), volatile organic compounds (VOCs) and sulphur dioxide (SO<sub>2</sub>) from diesel fumes generated from well drilling equipment. These substances can all cause adverse health effects, particularly for the respiratory system. PM<sub>10</sub> comprises of small airborne particles which are less than 10 micrometres in diameter. These particles can enter the respiratory tract and have the potential to cause damage to lung tissue, affect breathing and the respiratory system and cause cancer. NO<sub>x</sub> includes reactive gases such as nitrogen dioxide (NO<sub>2</sub>), which can irritate the lungs. NO<sub>x</sub> also contributes to smog and ground level ozone (O<sub>3</sub>) formation which can cause further potential health impacts such as reducing lung function and causing respiratory inflammation. SO<sub>2</sub> also affects breathing and respiratory systems, and can aggravate existing cardiovascular disease.<sup>7</sup> VOCs can cause slightly wider health effects, such as irritation of eyes, nose and throat; headaches and nausea; and damage to kidneys, liver and the central nervous system.<sup>8</sup> Carbon monoxide is a toxic gas which displaces oxygen in the blood, which can cause nausea, headaches and dizziness, and is ultimately fatal at high concentrations. The potential for the emissions to have a negative impact on local populations will depend on a site's proximity to residential areas, and the sensitivity of receptors, such as those with pre-existing respiratory conditions.

Drilling of unconventional wells is expected to result in drill cuttings with an average volume of 270m<sup>3</sup> per well, for a well of 2,100m depth and an additional lateral section of 1,200m.<sup>9</sup> Geological formations contain naturally occurring radioactive materials (NORM) such as radium, strontium and potassium. There is therefore the potential for these cuttings to have elevated levels of radioactivity which could lead to health

<sup>3</sup> The Telegraph (2014, 04 May) *Anti-fracking protest 'turns violent'*. Available from <http://www.telegraph.co.uk/news/uknews/crime/10806262/Anti-fracking-protest--turns-violent.html> [Accessed November 2014].

<sup>4</sup> AEA (2012) *Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe: AEAT, report for the European Commission, 2012*. Available from <http://ec.europa.eu/environment/integration/energy/pdf/fracking%20study.pdf> [Accessed May 2013].

<sup>5</sup> Cuadrilla Bowland Ltd (2014) Appendix F – Air Quality.

<sup>6</sup> BBC News (2015) *Cuadrilla fracking applications: Lancashire County Council defer decision*. Available from <http://www.bbc.co.uk/news/uk-england-lancashire-31007062> [Accessed April 2015].

<sup>7</sup> United States Environmental Protection Agency (2014) *Health Effects of Air Pollution*. Available from <http://www.epa.gov/region07/air/quality/health.htm> [Accessed November 2014].

<sup>8</sup> United States Environmental Protection Agency (2012) *Volatile Organic Compounds*. Available from <http://www.epa.gov/iaq/voc.html> [Accessed November 2014].

<sup>9</sup> AEA (2012).

concerns if workers were exposed. NORM levels are dependent on local geology, and may or may not be present at levels high enough to require protection for workers. However, Public Health England's (2014) review of the available evidence on potential public health impacts of shale gas extraction states that levels are usually similar to those in the ground beneath, and are not of specific concern.<sup>10</sup> Established procedures are in place to address radiological risks should they be required, and as such a minimal impact on health is expected.

### Hydraulic fracturing

Hydraulic fracturing is expected to generate the loudest levels of noise of all the activities during the exploratory stage (90dBA at 75m distance) based on the need to use generators to inject high volumes of water to achieve the required pressure. This operation would take several days per frack. Effective noise abatement measures are expected to reduce the impact, but there is potential for this noise to disturb local residents if activities are undertaken within close proximity to residential areas.<sup>9</sup> Noise could be particularly disturbing for local residential receptors during evenings, night time and weekends, during which time the effects from noise could be significant.<sup>11</sup> High noise levels would also affect site workers, and without appropriate protective measures and equipment could result in hearing loss and tinnitus.<sup>12</sup>

Emissions of diesel fumes from fracturing fluid pumps could potentially have a negative impact on local air quality<sup>13</sup>, in a similar way as the drilling process. Emissions are likely to include PM, NO<sub>x</sub>, CO, VOCs and SO<sub>2</sub>. Furthermore, the on-site handling of proppant sand during the fracturing fluid make up operation could lead to generation of significant levels of dust as 0.25% of total sand may be emitted to the air,<sup>14</sup> roughly equivalent to 25-100m<sup>3</sup> of sand emitted per well.<sup>15</sup> The long term inhalation of elevated concentrations of dust can result in health effects such as lung cancer, asthma and Chronic Obstructive Pulmonary Disorder (breathing problems resulting from lung damage), and for sand in particular, this can also lead to the lung disease silicosis.<sup>16</sup> Working outside is not necessarily adequate protection for workers handling and working with dusty materials, and protective measures and equipment may be required.

There is a risk of hydraulic fracturing causing water supply contamination (and generating emissions to air), principally due to spills but also due to the leakage of fracturing fluid and methane as a result of inadequacies in well cementing or the movement of contaminants through existing faults or porous rocks to groundwater resources (although the latter has not been observed in practice and would be very unlikely). In addition, other substances such as trace elements, NORM and organic material may be contained in flowback water which, if not managed and treated, could cause contamination. There have been concerns in the US regarding contamination of drinking water supplies, but issues have typically arisen from private borehole supplies in remote areas, which may have limited water treatment and quality testing. In the UK, 99% of drinking water is mains water supplied by water companies, which is rigorously monitored and treated to ensure adequate water quality. These mains supplies are considered to be at low risk of impacting public health due to the regulatory requirements for the provision of safe drinking water supplies. However, private supplies in the UK may be at greater risk of pollution from shale gas activities.<sup>10</sup>

A study of the flux of radioactivity in flowback fluid from shale gas development in the Carboniferous, Bowland Shale, UK; the Silurian Shale, Poland; and the Carboniferous Barnett Shale, US by Almond *et al*

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<sup>10</sup> Public Health England (2014) *Review of the Potential Public Health Impacts of Exposures to Chemical and Radioactive Pollutants as a Result of Shale Gas Extraction*. Available from [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/332837/PHE-CRCE-009\\_3-7-14.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/332837/PHE-CRCE-009_3-7-14.pdf) [Accessed April 2015].

<sup>11</sup> Cuadrilla Bowland Ltd (2014).

<sup>12</sup> Health and Safety Executive (2014) *Noise at Work: Key Messages*. Available from <http://www.hse.gov.uk/NOISE/keyfacts.htm> [Accessed November 2014].

<sup>13</sup> Lechtenböhmer *et al.* (2011) *Impacts of shale gas and shale oil extraction on the environment and on human health*. Available from <http://europeecologie.eu/IMG/pdf/shale-gas-pe-464-425-final.pdf> [Accessed April 2015].

<sup>14</sup> Kellam (2012) *Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe*. Cited in AEA (2012).

<sup>15</sup> Based on 5,000-20,000m<sup>3</sup> of water used per well within fracturing fluid and the fluid being composed of 98-99% of water, and 1-1.9% proppant. See King (2012) *Hydraulic Fracturing 101*. *Journal of Petroleum Technology*, April 2012 p34-42. Available from [http://fracfocus.org/sites/default/files/publications/hydraulic\\_fracturing\\_101.pdf](http://fracfocus.org/sites/default/files/publications/hydraulic_fracturing_101.pdf) [Accessed April 2015].

<sup>16</sup> Health and Safety Executive (2014) *Dust*. Available from <http://www.hse.gov.uk/construction/faq-dust.htm> [Accessed November 2014].

(2014)<sup>17</sup> found that levels of NORM in flowback water are much higher than found in groundwater, but well below permitted UK exposure limits such that they are unlikely to pose a threat to human health<sup>18</sup>.

The hydraulic fracturing process is also highly water intensive. Water consumption requirements will vary according to local geology, however a four well exploration site in Lancashire, UK, estimated that approximately 90,000m<sup>3</sup> of water would be required. The level of water consumption required has the potential to reduce water availability, with the potential for detrimental impacts on public water supplies and health.<sup>9</sup> This could be significant in water stressed areas.

**Appendix B.3 Water and Appendix B.5 Waste** provide further detail on the risks of water contamination and water consumption and the presence of NORMs in flowback water.

Public perception of the impacts of hydraulic fracturing can affect mental, physical and emotional wellbeing. This can exacerbate or trigger health effects caused by anxiety or changes in behaviour arising from people's belief about the project. This can be alleviated through good use of information campaigns, provision of evidence on known risks, and monitoring of issues that may present a real or perceived health risk.<sup>11</sup>

### Well completion

As the fracturing fluid returns to the surface, it contains natural gas and small amounts of VOCs. The extent of emissions to air would depend on the nature and composition of shale gas at a particular drilling location and the well completion method. The release of methane in enclosed areas can present a hazards and health risk due to its potentially explosive nature depending on concentrations and the presence of any ignition source, however this would not be anticipated at an open well site.<sup>10</sup>

Geological disturbance caused by hydraulic fracturing may create pathways for the release of other gases apart from shale gas. Radon has been highlighted as a particular concern because high levels of radon in poorly ventilated areas can increase the risk of lung cancer.<sup>19</sup> Radon is a radioactive gas released from rocks such as shale, granite and limestone. The level of radioactivity when radon escapes to open areas is generally low, but can build up to several thousand Becquerel per cubic meter in enclosed areas (compared to average indoor radon concentrations of 20 Bq.m<sup>-3</sup> in the UK for example).<sup>10</sup> If new pathways were created as a result of hydraulic fracturing that led to the accumulation of radon in buildings and homes, this could have a negative impact on human health. Given that radon is colourless and odourless these levels could build up undetected. However, the likelihood of new pathways being created is exceptionally low and the scale of such releases, if they occur, likely to be small. Sound well integrity should prevent the transmission of radon from rocks into the well bore. As radon is soluble, it is also present in flowback fluid and may be released to air at the surface. There have not been measurements for the radon content or the release of radon from flowback fluid, however this could elevate radon levels in the immediate area around the wellhead.

The presence of radioactive substances such as radium in flowback fluid may also result in the wastewater being classed as radioactive waste, requiring appropriate controls and disposal (see **Appendix B.6 Waste**). This may include radioactive tracers, if used to monitor the fracturing process.<sup>10</sup> Radioactive scale and wastewater sludge may also be generated and require safe disposal as radioactive waste.

The noise levels which would be generated through flaring during well completion are uncertain. However noise from flares can be minimised through appropriate flare design and it is not expected to have a negative impact on local communities. Flaring would primarily result in the production of carbon dioxide (CO<sub>2</sub>) but also NO<sub>x</sub>, SO<sub>2</sub>, CO, and PM, as well as methane and VOCs in the event of incomplete combustion, which could affect local air quality and potentially the health of sensitive local receptors.<sup>20</sup> Emissions to air during

<sup>17</sup> Almond, S. Clancy, S.A. Davies, R.J. Worrall, F. (2014) *The flux of radionuclides in flowback fluid from shale gas exploitation*, in *Environ Science and Pollution Research International* 2014; 21(21): 12316–12324. Available from <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4200344/> [Accessed April 2015].

<sup>18</sup> Durham Energy Institute (2014) *How radioactive is fracking flowback water?* DEI Briefing Note No. 905: Autumn 2014. Available from <https://www.dur.ac.uk/resources/refine/NORMRB.pdf> [Accessed April 2015].

<sup>19</sup> National Cancer Institute (2011) *Radon and Cancer*. Available from <http://www.cancer.gov/cancertopics/factsheet/Risk/radon> [Accessed September 2013].

<sup>20</sup> MacKay, D.J.C. and Stone, T.J. (2013) *Potential Greenhouse Gas Emissions Associated with Shale Gas Extraction and Use*. Report on behalf of DECC. Available from

flaring may be a greater issue during the exploratory stages, as there is less likely to be gas collection infrastructure in place compared to the later production stages. Cuadrilla anticipates flaring to take place during an initial test period for 90 days in respect of its proposed exploratory site in Lancashire. 'Green completions' (or reduced emissions completion (REC)) which capture the methane rather than flaring the gas are preferable, and would have health benefits from the reduced emissions to air.<sup>21</sup> Green completions are discussed further in **Appendix: B.5 Climate Change**.

Leakages (fugitive emissions) of methane and other pollutants such as NO<sub>x</sub>, CO and hydrocarbons may occur during well completion and well production from pumps, valves, pressure relief valves, flanges, agitators and compressors.<sup>9</sup> Glycol dehydrators, used to remove water from the natural gas stream, are a further source of methane emissions and benzene, toluene, ethylbenzene and xylene (BTEX). During the exploration stages, there may also be smaller, less robust gas pipeline infrastructure in place connecting the well to the main gas pipeline, compared to later stages, which may therefore result in fugitive emissions during the transport of gas off site through the temporary pipelines. Fugitive emissions may include methane, ethane, CO<sub>2</sub>, hydrogen sulphide, nitrogen and helium, in addition to volatile and semi-volatile organic compounds and naturally occurring radioactive material (NORM).<sup>9</sup> However, it is anticipated that fugitive emissions are less likely from more robust pipeline infrastructure put in place during later production stages. Emissions of VOCs releases can also occur from storage tanks and oil tanks.

### HGV movements

HGV movements would be required to transport materials to and from a well pad site during each of the activities under this stage. The number of movements could be more substantial if the water required for hydraulic fracturing and flowback is tankered to/from site. In respect of its proposed site in Lancashire, Cuadrilla estimate that vehicle movements would peak at 250 truck movements per day during the most intense periods, although this would only be sustained at this level for a few days at a time.

HGV movement may generate emissions and dust potentially affecting those with respiratory problems as well as noise and vibrations which may cause stress and anxiety to residents principally alongside local transport networks. The principal emissions from diesel and petrol engines are CO, NO<sub>x</sub>, un-burnt hydrocarbons and PM. However, the potential for negative health impacts would depend on numerous factors such as the proximity of HGV routes to residential or other sensitive areas and the existing background levels of pollution.

### Worker health and safety

As with any construction activities, there are health and safety risks for workers on site. The UK has a robust regulatory regime for health and safety at work, requiring risk assessment, appropriate control measures, monitoring and enforcement. The UK health and safety regulatory regime takes a goal based approach, in which regulators set goals to be achieved and operators are responsible for how to achieve them. The regime includes the approach to reduce risks to a level 'as low as reasonably practicable'. The approach in other countries, such as the US, is more prescriptive and sets specific standards that must be met.<sup>22</sup> Provided relevant UK health and safety legislations are followed (including the Construction (Design and Management) CDM Regulations 2007) and Borehole Sites & Operations Regulations (1995) then it is assumed that such risks would be eliminated, avoided or reduced to an acceptable minimum, in line with other construction and oil and gas activities.

## Production Development

Most of the activities associated with stage 3 (i.e. - pad preparation, well construction and hydraulic fracturing) are expected to be largely similar to stage 2. However, the scale, magnitude and duration of impact at this stage is expected to be greater given the need to drill, complete and hydraulic fracture a

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[https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/237330/MacKay\\_Stone\\_shale\\_study\\_report\\_09092013.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/237330/MacKay_Stone_shale_study_report_09092013.pdf) [Accessed April 2015].

<sup>21</sup> DECC (2014) *Fracking and Local Air Quality*. Available from [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/277219/Air.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/277219/Air.pdf) [Accessed April 2015].

<sup>22</sup> Royal Academy of Engineering and Royal Society (2012) *Shale Gas in the UK, A Review of Hydraulic Fracturing*. Available from <https://royalsociety.org/policy/projects/shale-gas-extraction/report/> [Accessed April 2015].



greater number of wells. In addition, there would be the need for provision of pipeline connections which would further increase the scale of activity required.

### Production/operation/maintenance

There is expected to be a minimal level of ongoing noise from the wellhead installations during production and at a level unlikely to have any negative impact on local populations.

Wells may be refractured during their lifetime to stimulate the flow of gas. In the US, the frequency of re-fracturing is not certain and is estimated to be once per 5 – 10 years on average, if at all. For the purposes of their report, AEA (2012) assumed that a well would be re-fractured between 0 and 4 times over a well lifetime of up to 40 years. Due to refracturing, associated health risks are likely to be similar to those identified during stages 2 and 3 although AEA (2012) note that, whilst wells would be monitored during re-fracturing, there is uncertainty with respect to the risks associated with re-fracturing on well integrity. Notwithstanding, during production it is expected that the integrity wells would be tested and any potential failure of the well would be monitored, and remedial measures would be implemented to address any issues identified using established industry processes. This, alongside with the assumption that wells will be located an adequate distance from drinking water, should result in a minimal risk.

Transportation of materials and equipment during the production and maintenance phase is expected to be minimal in the most part. By this stage, it is anticipated that water pipelines would be connected to the site to provide water and remove waste water from the fracturing process. This would substantially reduce vehicle movements and associated exhaust emissions compared to exploration and test stages where water may be tankered on and off site. Additionally, if a power connection is in place on the site during long-term production, emissions from diesel generators to pump fracturing fluid into the well may no longer arise.

Well pad sites may be subject to residual protest action from opposition groups and local communities. This could potentially increase the fear of crime through the fear of vandalism and personal injury as a result of an influx of a large number of people into a local area, although this is expected to be a much lower risk than compared to previous stages. There may also be continued mental health impacts caused by elevated health concerns. In this respect, a study of health concerns in communities living on the Marcellus Shale, US by Ferrar *et al* (2013) found that stress was a frequently reported health impact<sup>23</sup>. Similarly, a wide-ranging health impact assessment (HIA) undertaken by the Colorado School of Public Health<sup>24</sup> to address community concerns about health impacts of natural gas development and production in Battlement Mesa, US identified psychological impacts (such as depression, anxiety and stress) amongst residents.

Radon can be present in natural gas, typically at levels of approximately 200 Bq.m<sup>-3</sup>, although US studies have shown average radon levels of 1,370 Bq.m<sup>-3</sup>, ranging up to 95,300 Bq.m<sup>-3</sup>. Even at these high levels, delivery of natural gas to customers is still only expected to produce indoor radon concentrations of 20 Bq.m<sup>-3</sup> (comparable to UK averages). Radon levels in delivered gas would depend on transit times and processing, as a short delivery time would give less opportunity for the radioactive gas to decay (half-life of 3.8 days) and increase the risk of radon exposure.<sup>10</sup>

### Decommissioning of wells

Health and safety risks associated with the decommissioning process will be similar to those encountered on a conventional demolition site (e.g. risks related to the use of heavy machinery, excavation and lifting) and it is assumed that all standard precautions would be taken to safeguard workers and the public.

HGV movements required to remove site equipment from site may generate emissions and dust potentially affecting those with respiratory problems as well as noise and vibrations which may cause stress/anxiety to residents principally alongside local transport networks. .

<sup>23</sup> Ferrar KJ, Kriesky J, *et al* (2013) *Assessment and longitudinal analysis of health impacts and stressors perceived to result from unconventional shale gas development in the Marcellus Shale region*. International Journal of Occupational and Environmental Health 19(2): 104–12.

<sup>24</sup> Colorado School of Public Health (2011) *Battlement Mesa Health Impact Assessment (2nd Draft)*. Available from <http://www.garfield-county.com/environmental-health/battlement-mesa-health-impact-assessment-draft2.aspx> [Accessed April 2015].



As with any demolition site, there is a risk of accidental discharges of demolition-related materials to water, air or land and potential for the creation of new pollution pathways for existing contaminants on the site. However, it is considered that the probability of such effects occurring is low and pollution control management procedures would be adopted to help mitigate this risk.

Following production, wells must be properly closed with cement plugs and/or mechanical barriers in the wellbore to eliminate the pathway to the surface or freshwater sources. The inadequate sealing of wells could therefore result in subsurface pathways for contaminant migration leading to groundwater pollution and potentially surface water pollution. This risk is discussed further in **Appendix B3: Water and Flood Risk**.

### Site restoration and relinquishment

Activities during site restoration and reclamation include landscaping, planting and re-vegetation. This, alongside with associated vehicle movements for transportation of materials such as topsoil, may generate noise, vibration, dust or emissions to air. The potential for health impacts will depend on the level of restoration and reclamation required as well as the distance of residential areas from site. However, this is considered to be minimal.

## 9.3 Mitigation Measures

The following section sets out the potential mitigation measures available at each stage of the project life cycle.<sup>9, 10, 11, 22, 25</sup> Mitigation measures presented in **Appendix B.3: Water and Flood Risk** and **Appendix B.4: Air** are also relevant

### Non-intrusive Exploration

- ▶ Sites selected should avoid residential and other sensitive areas.

### Exploration drilling and hydraulic fracturing

- ▶ Operators should be required to carry out a comprehensive high-level assessment of environmental risks, including risks to human health, and to consult with stakeholders including local communities, as early as practicable in the development of their proposals.<sup>26</sup>
- ▶ Operators should seek to limit noise, dust and mobilisation of any contaminants during construction as part of a Construction Environmental Management Plan (CEMP).
- ▶ Measures should be implemented to reduce dust generation such as the use of different proppants if feasible.
- ▶ Speed limits (circa 15 – 20 mph) should be adopted on sites to reduce dust.
- ▶ Noise modelling should be undertaken in advance of works to enable appropriate mitigation measures to be put in place.
- ▶ Noise controls should be implemented during the drilling process to avoid adverse health effects. Controls may include:
  - ▶ good design and management of equipment;
  - ▶ positioning of equipment on site to screen it from receptors; selection of plant and construction methods to reduce noise and vibration;
  - ▶ fit and maintain exhaust silencers for site vehicles;

<sup>25</sup> Celtique Energie Weald Ltd (2013) *Northup Field, Wisborough Green, Planning Application, Environmental Statement*.

<sup>26</sup> As detailed in written ministerial statement by Edward Davey (2012) *Exploration of Shale Gas*. Available from [http://webarchive.nationalarchives.gov.uk/20121217150421/http://www.decc.gov.uk/en/content/cms/news/wms\\_shale/wms\\_shale.aspx](http://webarchive.nationalarchives.gov.uk/20121217150421/http://www.decc.gov.uk/en/content/cms/news/wms_shale/wms_shale.aspx) [Accessed September 2013].

- ▶ limit drill pipe cleaning ('hammering') to certain daytime hours, and use rubber hammer covers on the sledges when clearing pipes;
  - ▶ use compressors and generators with lined and sealed acoustic covers;
  - ▶ use higher or larger-diameter stacks for any flaring operations at the exploratory stage ('green completions' which capture the methane for use should be implemented in preference to flaring when appropriate infrastructure is in place);
  - ▶ reduce noise from air rotary drilling discharge pipes through actions such as orientation away from noise receptors and use of a large-diameter discharge line;
  - ▶ switch off vehicles and machinery when not in use;
  - ▶ use electric pumps;
  - ▶ use sound barriers to supplement noise attenuation from natural features; and
  - ▶ limit noise generating activities to weekdays e.g. between 7am to 7pm to avoid causing disturbance at weekends and at night.
- ▶ Sites layouts should be planned to avoid the need for vehicle reversing manoeuvres and associated reversing alarms.
  - ▶ Appropriate limits on maximum noise levels should be set and noise monitoring undertaken to demonstrate compliance with limits.
  - ▶ Hearing and breathing protection for site operatives should be provided where needed.
  - ▶ Controls, such as safety equipment and radiological protection, should be implemented for site operatives and visitors on site.
  - ▶ Adequate separation between drinking water sources and drilling areas should be adopted (these will differ depending on geological characteristics at site and in the surrounding area). No drilling should take place within areas with vulnerable groundwater that are used for potable water supplies.
  - ▶ Wells should be adequately cased and sealed to avoid migration of methane or contaminants out of the well bore and into other geological formations.
  - ▶ Spill prevention and pollution control measures should be implemented on site to avoid accidental discharges/manage their impact.
  - ▶ HGV routing should seek to avoid residential areas and existing areas of poor air quality.
  - ▶ If activities are within a radon affected area, monitoring of radon levels should be undertaken and appropriate precautions implemented if levels are found to be elevated.
  - ▶ Safety management plans should be implemented which include mitigation measures and monitoring programmes. A mechanism should also be put in place to audit the site's risk management processes.
  - ▶ The following hierarchal approach to addressing hazards should be followed where possible: eliminate hazards through design; where hazards cannot be designed out they should be isolated or protection to workers and the public should be provided; where the hazard cannot be avoided by protection or isolation, its effects should be mitigated through design, process changes and management control measures.
  - ▶ Site specific emergency response procedures should be put in place in consultation with emergency services.
  - ▶ Close consultation and full exchange of information with the local community is essential, liaison with the local police and authorities, and the use of appropriate on-site security should minimise the risk of negative consequences of protest action, such as an increase in fear of crime.

- ▶ The provision of clear and accurate and consistent information, including evidence of known risks should be maintained.
- ▶ Monitoring programmes should be implemented for environmental factors which may present health risks (or perceived health risks) to alleviate anxiety in local communities.

### Production Development

As for exploration drilling.

### Production/operation/maintenance

As above for exploration drilling, in addition to:

- ▶ Undertake regular monitoring and testing of well integrity.

### Decommissioning of wells

As for exploration drilling, in addition to:

- ▶ Well design and methods of plugging should minimise the risk of contamination. Monitoring should be undertaken to detect any release of contaminants to groundwater.

## 9.4 Review of Regulatory Framework

The regulatory framework for the control of water quality, emissions to air and treatment of wastewater are set out in **Appendices B.3 Water and Flood Risk**, **B.4 Air**, and **B.6 Waste and Resource Use**, respectively. The regulatory review below includes items which are additional to the water, air and waste regulatory regimes.

### International/European

The World Health Organization (WHO)<sup>27</sup> states that “*health promotion goes beyond health care. It puts health on the agenda of policy makers in all sectors and at all levels*”; consequently, healthy public policy has been a main goal of health development in many countries. The **Canadian Lalonde Report (1974)** identified four health fields independently responsible for individual health: environment, human biology, lifestyle and health care organisation.

The WHO **Children’s Environment and Health Action Plan for Europe (CEHAPE) (2004)** was launched in June 2004 and signed by all 53 Member States of the WHO European Region. The aim of the CEHAPE is to protect the health of children and young people from environmental hazards.

The European Union (EU) has a Programme for Community action in the field of Health (2008-2013) and, on 23<sup>rd</sup> October 2007 the Commission adopted a new overarching Health Strategy ‘**Together for Health - A Strategic Approach for the EU 2008-2013**’. Community Action focuses on tackling health determinants which are categorized as: personal behaviour and lifestyles; influences within communities which can sustain or damage health; living and working conditions and access to health services; and general socio-economic, cultural and environmental conditions. A review in 2011 determined that the principles and objectives of this strategy would remain valid across the next decade to support the **Europe 2020** growth strategy. **Investing in Health – Commission Staff Working Document (2013)** sets out how health investment contributes to the Europe 2020 objectives of smart, sustainable and inclusive growth.

The **Strategic Environmental Assessment (SEA) Directive** specifically requires the consideration of: “the likely significant effects on the environment, including on issues such as ..., human health ...” (European Parliament and the Council of the European Union, 2001). The **SEA Protocol (United Nations Economic Commission for Europe, 2003)** implements the political commitments made at the Third European

<sup>27</sup> See WHO (1986) *Ottawa Charter adopted at the First International Conference on Health Promotion in 1986*. Available from <http://www.who.int/healthpromotion/conferences/previous/ottawa/en/index3.html> [Accessed April 2015].

Conference on Environment and Health and uses the term 'environment and health' throughout. It indicates that health authorities should be consulted at the different stages of the process and so goes further than the SEA Directive. Once ratified, it will require changes to the SEA Directive to require that health authorities are statutory consultees.

The WHO publication *Health Impact Assessment in Strategic Environmental Assessment (2001)* provides a review of Health Impact Assessment concepts, methods and practice to support the development of a protocol on SEA to the Espoo Convention, which adequately covers health impacts.

There is a Europe-wide directive relating to drilling safety, the *Mineral-Extracting Industries - Drilling Directive (92/91/EEC)*, which sets out the minimum requirements for improving the health and safety of works in the mineral extractive industries. Additionally, the *Ionising Radiation Directive (96/29/Euratom)* lays down safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation, including radon gas.

## UK

Many of the UK policies and strategies regarding health are aimed at understanding trends and the nature of health issues, understanding the links between health issues and other related factors (such as economic status, etc.), and, primarily, at reducing the inequalities in health. Whilst some applicable policies/strategies are contained within adopted strategies, many of the Government's objectives and intended actions are contained within White Papers and guidance papers.

The *Children and Young People's Health Outcomes Strategy* was launched in 2012 through a new Forum which makes key recommendations regarding the need for system changes and opportunities to influence the health and care system.

There is a range of regulation in place specifically to manage occupational health and safety. This regulation is primarily based on the overarching *Health and Safety at Work etc Act 1974*, which sets out general duties of employers to protect employees and other persons. There are numerous supporting regulations, with a key piece of legislation being the *Management of Health and Safety at Work Regulations 1999*. This requires a risk assessment to be carried out to identify the nature and levels of risk associated with a work activity, and appropriate precautions to be implemented to eliminate or control these risks. A proportionate response according to the risk is required, with the higher the level of risk identified through the assessment, the greater the measures that will be needed to reduce it. Additional regulations under the Act include the *Borehole Site and Operations Regulations 1995*, which are concerned with the health and safety management of oil and gas sites, and the *Offshore Installations and Wells (Design and Construction, etc) Regulations 1996*, which relate to the integrity of all wells drilled for petroleum extraction (including shale gas). The *Construction (Design and Management) Regulations 2007* are also in place to improve health and safety at construction sites, with legal duties placed on a range of parties, including designers, clients, contractors and workers.

The Health and Safety Executive (HSE) is responsible for the inspection and regulation of workplaces to ensure the health and safety of workforces and others affected by work activities. For shale gas operations, the HSE will assess well designs prior to construction, monitor well operations during construction, and undertake site inspections of well integrity during the operational phase.<sup>28</sup> Any major incidents relating to well integrity would have to be reported by operators to the HSE under the *Reporting of Injuries Diseases and Dangerous Occurrences Regulations 1995*.

The *Environmental Protection Act 1990* defines what constitutes a statutory nuisance, which includes 'any noise emitted from premises [including land] so as to be prejudicial to health or a nuisance' and 'noise that is prejudicial to health or a nuisance and is emitted from a vehicle, machinery or equipment in a street'. Under Part III of the Act, local authorities or private individuals may take action to secure abatement of any such nuisance. There are also provisions for preventing a nuisance occurring or an intermittent nuisance recurring. Only one person need be affected for action to be possible.

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<sup>28</sup> The Environment Agency and the Health and Safety Executive (2012) *Working together to Regulate Unconventional Oil and Gas Developments*. Available from <http://www.hse.gov.uk/aboutus/howwework/framework/aa/hse-ea-oil-gas-nov12.pdf> [Accessed April 2015].



# Appendix C

## EU “Acquis Communautaire” Relating to Shale Gas



Abbreviation	Directive/Regulation
AUTOMOTIVE	Regulation (EC) No 595/2009 of the European Parliament and of the Council of 18 June 2009 on type-approval of motor vehicles and engines with respect to emissions from heavy duty vehicles (Euro VI) and on access to vehicle repair and maintenance information and amending Regulation (EC) No 715/2007 and Directive 2007/46/EC and repealing Directives 80/1269/EEC, 2005/55/EC and 2005/78/EC (OJ L 188, 18.7.2009, p. 1–13)
AQD	Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe (OJ L 152, 11.6.2008, p. 1–44)
BRP	Regulation (EU) No 528/2012 of the European Parliament and of the Council of 22 May 2012 concerning the making available on the market and use of biocidal products (OJ L 167, 27.6.2012, p. 1–123) Directive 98/8/EC of the European Parliament and of the Council of 16 February 1998 concerning the placing of biocidal products on the market (OJ L 123, 24.4.1998, p. 1–63)
EIAD	Directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment (OJ L 26, 28.1.2012, p. 1–21)
ELD	Directive 2004/35/CE of the European Parliament and of the Council of 21 April 2004 on environmental liability with regard to the prevention and remedying of environmental damage (OJ L 143, 30.4.2004, p. 56–75)
END	Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise - Declaration by the Commission in the Conciliation Committee on the Directive relating to the assessment and management of environmental noise (OJ L 189, 18.7.2002, p. 12–25)
GD	Council Directive 80/68/EEC of 17 December 1979 on the protection of groundwater against pollution caused by certain dangerous substances (OJ L 20, 26.1.1980, p. 43–48)
GWD	Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration (OJ L 372, 27.12.2006, p. 19–31)
HLD	Directive 94/22/EC of the European Parliament and of the Council of 30 May 1994 on the conditions for granting and using authorizations for the prospection, exploration and production of hydrocarbons (OJ L 164, 30.6.1994, p. 3 -8)
IED	Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) (OJ L 334, 17.12.2010, p. 17–119)
IPPCD	Directive 2008/1/EC of the European Parliament and of the Council of 15 January 2008 concerning integrated pollution prevention and control (OJ L 24, 29.1.2008, p. 8–29)
MWD	Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries and amending Directive 2004/35/EC (OJ L 102, 11.4.2006, p. 15–34)
NATURA2000	Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (OJ L 206, 22.7.1992, p. 7–50) Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds (OJ L 20, 26.1.2010, p. 7–25)
NORMS	Council Directive 96/29/Euratom of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation (OJ L 159, 29.6.1996, p. 1–114)
NRMMD	Directive 97/68/EC of the European Parliament and of the Council of 16 December 1997 on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery (OJ L 59, 27.2.1998, p. 1–86)
OMND	Directive 2000/14/EC of the European Parliament and of the Council of 8 May 2000 on the approximation of the laws of the Member States relating to the noise emission in the environment by equipment for use outdoors (OJ L 162, 3.7.2000, p. 1–78)
PAEID	Directive 2003/4/EC of the European Parliament and of the Council of 28 January 2003 on public access to environmental information and repealing Council Directive 90/313/EEC (OJ L 41, 14.2.2003, p. 26-32)
REACH	Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC (OJ L 396, 30.12.2006, p. 1–849)
SEAD	Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment (OJ L 197, 21.7.2001, p. 30-37)





Abbreviation	Directive/Regulation
SEVESO II	Council Directive 96/82/EC of 9 December 1996 on the control of major-accident hazards involving dangerous substances (OJ L 10, 14.1.1997, p. 13–33)
SEVESO III	Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC (OJ L 197, 24.7.2012, p. 1–37)
SHPWEI	Council Directive 92/91/EEC of 3 November 1992 concerning the minimum requirements for improving the safety and health protection of workers in the mineral- extracting industries through drilling (eleventh individual Directive within the meaning of Article 16 (1) of Directive 89/391/EEC) (OJ L 348, 28.11.1992, p. 9-24)
UWWDD	Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment (OJ L 135, 30.5.1991, p. 40–52)
WD	Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (OJ L 312, 22.11.2008, p. 3–30)
WFD	Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (OJ L 327, 22.12.2000, p. 1–73)
WSR	Regulation (EC) N° 1013/2006 of the European Parliament and of the Council of 14 June 2006 on shipments of waste (OJ L 190, 12.7.2006, p. 1-98)

