RICARDO-AEA

Shale gas risk assessment for Maryland

Report for Chesapeake Climate Action Network
and Citizen Shale

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Executive summary

This study provides an assessment of the potential environmental risks and impacts associated with the development of shale gas resources in Maryland. This assessment built on a risk assessment for the development of unconventional hydrocarbons in Europe, carried out by a consortium led by Ricardo-AEA. This approach enables a systematic evaluation of all potentially significant environmental aspects, at all relevant phases of the development of shale gas resources, and takes account of impacts associated with both individual wells/wellpads, and developments across Garrett and Allegany Counties, the parts of Maryland where shale gas resources could potentially be developed.

As a strategic risk assessment, this study does not take account of site-specific controls which may be applied at individual developments. Its value is therefore in identifying the key environmental risk issues which state policy-makers should take into account when taking a decision with regard to the potential development of shale gas resources in the state.

The preliminary risk assessment is summarised in Table ES1 below. This table highlights that the majority of issues under consideration continue throughout the lifetime of shale gas development. The table also highlights the uncertainties associated with the post-abandonment phase. Further research in this area is recommended.

One issue was identified as “very high” using this approach:

- Land-take during site preparation (cumulative)

“High” significance issues and risks were also identified in relation to groundwater contamination, surface water contamination, water resources, emissions to air, biodiversity, noise, visual impacts and traffic. As would be expected, risks were generally higher when considering cumulative impacts of development of multiple well pads.

A number of issues were identified as being “not classifiable” due to a lack of relevant data, particularly those associated with the post-abandonment phase.

The main causes of impacts and risks were as follows:

- The use of more significant volumes of water and chemicals compared to conventional gas extraction
- Lower gas yields per well, combined with increased economic cost of extracting shale gas resulting in a commercial requirement to carry out an intensive and widespread program of shale gas development.
- The challenge of ensuring the integrity of wells and other equipment throughout the lifetime of the plant
- The challenge of ensuring that spillages of chemicals and waste waters with potential environmental consequences are avoided
- The challenge of identification and selection of optimum geological sites, based on a geological risk assessment, and the likely dispersion and fate of any fracturing fluid that remains underground after hydraulic fracturing operations are completed.
- The potential toxicity of chemical additives and the challenge to develop greener alternatives
- The unavoidable requirement for transportation of equipment, materials and wastes to and from the site
- The unavoidable requirements for use of plant and equipment during well construction, hydraulic fracturing and downstream operations. This equipment necessarily requires space to be sited and operated, and results in unavoidable emissions to air and noise impacts

A proposed Liquefied Natural Gas facility at Cove Point, Calvert County MD will also be evaluated in a similar manner, although this facility is not directly linked to the development of shale gas resources in Maryland.

Table ES1: Summary of preliminary risk assessment

Environmental aspect	**Project phase**							
	Site identification and preparation	**Well design drilling, casing, cementing**	**Fracturing**	**Well completion**	**Production**	**Well abandonment and post-abandonment**	**Downstream infrastructure**	**Overall rating across all phases**
Individual site								
Groundwater contamination	Not applicable	Low	Moderate-**High**	**High**	Moderate-**High**	Not classifiable	Low	**High**
Surface water contamination	Low	Moderate	Moderate	**High**	Low	Not applicable	Low	**High**
Water resources	Not applicable	Not applicable	Low	Not applicable	Low	Not applicable	Not applicable	Low
Release to air	Low	Moderate	Moderate	Moderate	Moderate	Low	Moderate-**High**	Moderate
Land take	Moderate	Not applicable	Not applicable	Not applicable	Moderate	Not classifiable	Low	Moderate
Risk to biodiversity	Moderate	Low	Low	Low	Moderate	Not classifiable	Not classifiable	Moderate
Noise impacts	Low	Moderate	**High**	Not classifiable	Low	Not applicable	Moderate	**High**
Visual impact	Moderate	Moderate	Low	Not applicable	Low	Low-moderate	Low	Moderate
Seismicity	Not applicable	Not applicable	Low	Low	Not applicable	Not applicable	Not applicable	Low
Traffic	Low	Low	Moderate	Low	Low	Not applicable	Low	Moderate

Environmental aspect	**Project phase**							
	Site identification and preparation	**Well design drilling, casing, cementing**	**Fracturing**	**Well completion**	**Production**	**Well abandonment and post-abandonment**	**Downstream infrastructure**	**Overall rating across all phases**
Cumulative								
Groundwater contamination	Not applicable	Low	**High**	**High**	**High**	Not classifiable	Low	**High**
Surface water contamination	Moderate	Moderate	Moderate-**High**	**High**	Moderate	Not applicable	Moderate	**High**
Water resources	Not applicable	Not applicable	**High**	Not applicable	**High**	Not applicable	Not applicable	**High**
Release to air	Low	**High**	**High**	**High**	**High**	Moderate	**High**	**High**
Land take	**Very high**	Not applicable	Not applicable	Not applicable	**High**	Not classifiable	Low	**Very High**
Risk to biodiversity	**High**	Low	Moderate	Moderate	**High**	Not classifiable	**High**	**High**
Noise impacts	Low	Moderate	**High**	Not classifiable	Low	Not applicable	Moderate	**High**
Visual impact	**High**	**High**	Moderate	Not applicable	Moderate	Low-moderate	**High**	**High**
Seismicity	Not applicable	Not applicable	Low	Low	Not applicable	Not applicable	Not applicable	Low
Traffic	Moderate	Moderate	**High**	Moderate	Low	Not applicable	Low	**High**

Not applicable: Impact not relevant to this stage of development
Not classifiable: Insufficient information available for the significance of this impact to be assessed

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Appendices

1 Introduction

1.1 Study overview

Executive Order 01.01.2011.11 of the State of Maryland set up an Advisory Commission to assist policymakers in deciding whether and how gas production from the Marcellus Shale in Maryland can be accomplished. As part of its work program, the Advisory Commission is considering risks of impacts to public health, safety, the environment and natural resources. The Executive Order requires the Advisory Commission to produce two reports:

- A report on best practices for shale gas exploration and production
- A report on short-term, long term and cumulative effects of shale gas exploration and production

In respect of the first reporting requirement, a review of candidate best management measures has been prepared by Eshleman and Elmore (2013 PR). This report was reviewed by the Maryland Department of the Environment (MDE). During the course of this review, all of the recommendations in Dr. Eshleman's report were considered. Following the completion of this review, MDE published its Best Practices report in draft for public comment (Maryland Department of the Environment and Department of Natural Resources 2013 PR).

The MDE Best Practices Report sets out those measures which the Department proposes to implement in order to ensure that shale gas can be properly regulated in order to provide adequate protection for the environment

The aim of this study was to assess the potential environmental risks and impacts associated with the development of shale gas resources in Maryland. This assessment built on a risk assessment for the development of unconventional hydrocarbons in Europe, carried out by a consortium led by Ricardo-AEA (European Commission 2012 PR). This approach enables a systematic evaluation of all potentially significant environmental aspects, at all relevant phases of the development of shale gas resources, and takes account of impacts associated with both individual wells/wellpads, and developments across a region such as Garrett and Allegany Counties.

Environmental aspects considered	Project phases considered
Groundwater contamination	Site identification and preparation
Surface water contamination	Well design drilling, casing, cementing
Water resources	Fracturing
Release to air	Well completion
Land take	Production
Risk to biodiversity	Well abandonment and post-abandonment
Noise impacts	Construction & operation of downstream infrastructure
Visual impact	Overall rating across all phases
Seismicity	
Traffic	

This study does not address climate/carbon footprint issues. The assessments contained in the European Commission study were comprehensively re-evaluated in the light of data relevant to the situation in Maryland and the objectives of this study. The risk assessment was carried out in two stages.

- Stage 1: Firstly, the risks associated with development of shale gas resources in Maryland were evaluated on the basis of existing legislative and regulatory provisions: that is, without taking account of the potential benefits of the Best Practice Measures set out in the MDE report.
- Stage 2: Secondly, the risks associated with development of shale gas resources in Maryland were estimated on the assumption that the Best Practice Measures set out in the MDE report would all be in place (Maryland Department of the Environment and Department of Natural Resources, 2013).

This report is set out as follows.

In chapter 2, an introduction to the risk assessment methodology is provided. Chapter 2 also sets out the information resources which were used to adapt the risk assessments and ensure that they are applicable to Maryland.

Chapter 3 provides an evaluation of the environmental and health risks potentially associated with shale gas extraction, on the basis of existing legislative and regulatory provision.

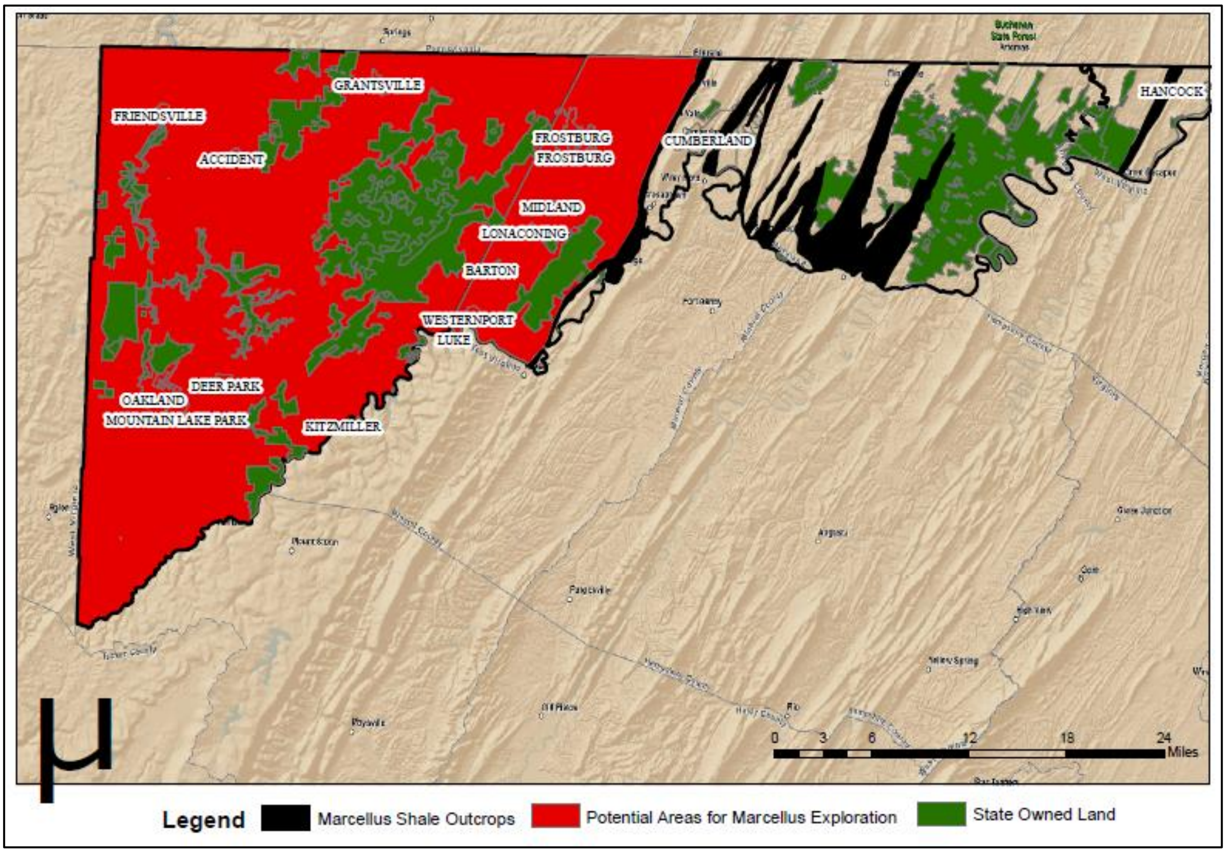
Chapter 4 provides a revised evaluation of the risks described in Chapter 3, taking account of the Best Practice Measures set out in the MDE report.

The study conclusions and recommendations are set out in Chapter 5.

1.2 Shale gas in Maryland

The Marcellus Shale extends into the western end of the state of Maryland. Shale gas extraction could potentially occur in Garrett County, and in the west of Allegany County, as shown in Figure 1.

Figure 1: Potential areas for Marcellus Shale exploration



Source: Maryland Department for the Environment

The US Geological Survey estimated that the entire Marcellus Shale in the Appalachian basin contains approximately 80 trillion cubic feet of gas, together with approximately 3 billion barrels of natural gas liquids (USGS 2012a NPR). Further gas reserves may be available in the east of the State (USGS 2012b NPR), but assessment of potential impacts associated with exploitation of these resources does not form part of the present study.

The Energy Information Administration estimated that the State of Maryland had an unproved Technically Recoverable Resource (TRR) of 646 billion cubic feet, as of 1 January 2010 (EIA 2012 NPR). The University of Maryland provided unpublished advice to the Maryland Department of the Environment that the likely quantity of extractable gas in Garrett County Marcellus Shale was in the range 1 to 8 trillion cubic feet, and in Allegany County, 0.5 to 4 trillion cubic feet (these estimates were described as “for comparative analysis only”).

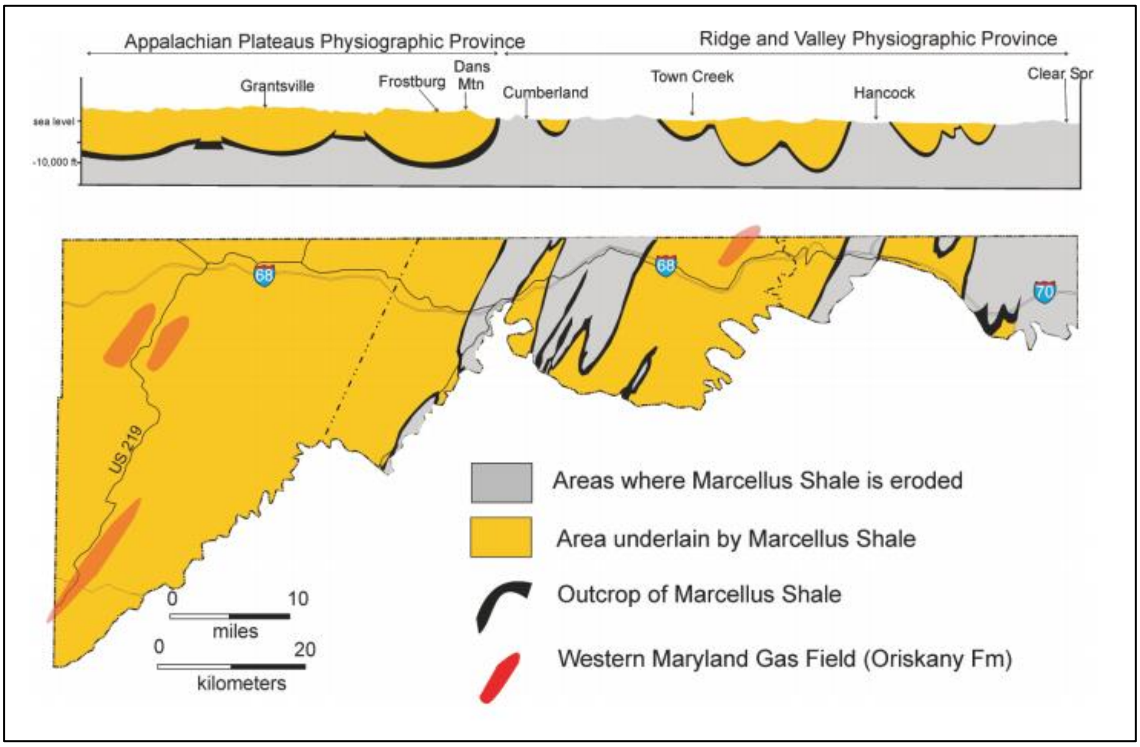
Sage Policy Group Inc. (2012 NPR) conducted an analysis of the shale gas resources in Maryland. This study estimated that total production between 2016 and 2045 could be in the range 390 to 1,300 billion cubic feet, based on USGS estimates of 700 to 2,400 billion cubic feet of gas in place in the Maryland Marcellus Shale. This range is consistent with the EIA estimate of 646 billion cubic feet, and lower than the range of 1.5 to 12 trillion cubic feet quoted by the University of Maryland. Sage Policy Group Inc. estimated that a total of 200 to 670 gas wells may be drilled to recover the anticipated quantity of gas.

1.3 The Marcellus Shale formation in Maryland

Within Garrett County and the western portion of Allegany County, the Marcellus is between 5,000 and 9,000 feet deep and between 150 to 200 feet thick (Maryland Geological Survey, undated).

However, in the eastern part of the Appalachian Plateau Physiographic Province the Marcellus Shale outcrops at the surface (see Figure 2 below). As this coincides with the boundary of the zone of potential exploration shown in Figure 1, this means that, in the area approaching the western boundary of the exploration zone, the depth to the Marcellus shale will be significantly less than 5000 feet, rising to the surface at the outcrop shown in Figure 2 below.

Figure 2: Marcellus shale in Western Maryland



2 Risk assessment methodology

To ensure the most efficient delivery of this project, the European Commission study was used as the starting point for the analysis of environmental and health risks and impacts posed by shale gas development. The risk assessment considered the range of impacts identified in the European Commission study, together with the addition of impacts associated with downstream infrastructure.

2.1 Literature review and analysis

The first stage was to identify and review new information relevant to this project, over and above the extensive information database already established for the existing risk assessment for unconventional hydrocarbons.

New published scientific research was identified and evaluated. The European Commission study reviewed research published up to April 2012. Recently published reports, review articles and other publications were reviewed to identify relevant new research. A search of published scientific literature was carried out using the www.sciencedirect.com database, together with Google Scholar. Additionally, a search of recent publications under the auspices of the Society of Petroleum Engineers was carried out. The most relevant and useful publications for our analysis. This process resulted in the identification of 20 additional publications for consideration in this study.

In parallel with this, information relevant to the geological, environmental and regulatory setting in Maryland, and specifically in Garrett and Allegany Counties was gathered. An extensive information request was provided to relevant regulatory authorities and data providers. The information provided and used in this study was discussed with the relevant bodies, and refined to focus on data which were available and relevant to the focus of this study.

2.2 Environmental risk assessment

2.2.1 Study approach and limitations

When considering environmental risks and impacts, it is important to consider the probability and severity of a possible event. King (2012 PR) suggested categorising events according to the significance of impacts on people and the environment, and according to experience of the frequency of their occurrence, consistent with more general guidance on environmental risk assessment (e.g. UK Department for Environment, Transport and the Regions, 2011 NPR).

The study uses a preliminary risk screening approach to enable the environmental and health risks identified in this study to be prioritised. This review considered all potential issues identified during the literature review, discussion with consultees, and from the knowledge of the project team. The review focused in particular on the issues which differ for oil and gas extraction from the Marcellus shale using hydraulic fracturing, compared to "conventional" oil and gas extraction.

The strategic risk screening approach was applied by developing criteria for evaluating the potential significance and likelihood of impacts occurring. Each potential issue was considered against these criteria to the extent permitted by the available information. The limits of this risk screening exercise are acknowledged, considering notably the absence of systematic baseline monitoring for the reference sites elsewhere in the US (from which most of the examined literature sources come from), the lack of comprehensive and centralised data on well failure and incident rates, and the need for further research on a number of possible effects, including long term impacts. Greater weight was given to information available in independently peer reviewed publications, the number of which is limited.

Ideally, a comparison of risks and impacts with conventional gas extraction would be made on the basis of the impacts per unit of energy extracted. Data on the scale of impacts and their frequency are not available or sufficiently robust to enable this analysis to be carried out for the majority of potential impacts under consideration. New York State DEC (2011, p5-139) quotes a range of 2.3 to 9.9 bcf/well Estimated Ultimate Recovery (EUR), based on optimum conditions for the Marcellus Shale in Pennsylvania. The US EIA (2010 NPR) provided an EUR per well for Maryland of 0.21 bcf/well for the Marcellus Shale Foldbelt, and 0.52 bcf/well for the Marcellus Shale Interior. These gas volumes may not be economically recoverable in practice. For comparison, a review carried out by Massachusetts Institute of Technology (MIT undated NPR) indicated that EUR for conventional wells is typically in the range 1 to 8 bcf per well. Hence, it is likely that more wells would be needed to extract unconventional gas compared to conventional gas.

Having identified the relevant information for this study, a systematic update was carried out to the previous risk assessment (European Commission, 2012). In the European Commission study, each environmental aspect was analysed at each stage of the implementation of a shale gas exploration/exploitation project.

These analyses were systematically revisited in relation to the conditions prevailing in the state of Maryland, and specifically Garrett and Allegany counties. Where relevant, the analyses took account of the geological, environmental, population, legal and regulatory conditions in Garrett and Allegany counties.

The discussion of each issue was updated and adapted in order to be applicable to the potential development of Marcellus Shale gas resources in Maryland, and based on current science. The analysis continued to draw extensively on the key US references identified in the 2012 study. In carrying out this update and revision to the preceding study, a science-led approach was adopted, acknowledging any potentially significant areas of uncertainty or disagreement in relation to the science.

The resultant risk assessment, set out in Section 3 of this report, is designed to complement the proposed scope and approach of the Draft Work Plan developed for a similar study proposed to be carried out on behalf of the State Governor's Commission.[1]

2.2.2 Downstream infrastructure

In addition to the seven project stages identified in the 2012 risk assessment, the study also evaluated the risks associated with the development of downstream infrastructure. For the purpose of this study, "downstream infrastructure" was defined as plant and equipment used for the transportation and processing of natural gas downstream of shale gas wellpads. Hence, the downstream infrastructure analysed includes: gathering and mains pipelines; gas clean-up plants; compressor stations, liquefaction plants, fractionation plants; water treatment infrastructure, new road connections and traffic associated with downstream operations.

The infrastructure requirements associated with shale gas developments are described, and the potential scale of infrastructure required in Maryland is set out, drawing on evidence from the development of Marcellus Shale in Pennsylvania, and estimates of shale gas reserves in Maryland. The risk assessment identified any residual environmental risks, impacts and uncertainties associated with the development of downstream infrastructure.

The study will consider issues associated with the Dominion Cove Liquefied Natural Gas export facility that has been proposed in Cove Point, Maryland. This facility will not be

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[1] "*Draft Work Plan: Marcellus Shale Risk Assessment*," dated 20 September 2013

directly linked to the development of shale gas resources in the state, and consequently the analysis of the Cove Point facility will be reported as Appendix 1 to this report.

2.2.3 Management practices

The risk assessment was carried out on the basis of two scenarios. Firstly, it was assumed that controls normally applied in the oil and gas extraction industry would be applied to shale gas extraction (Scenario 1). Hence, national and state regulations and standards were assumed to apply across the shale gas extraction process.

As a separate scenario, it was assumed that the Best Management Practices identified by the Maryland Department of Environmental Protection (Maryland DEP 2014 PR) would be applied (Scenario 2). The risk assessment was repeated on the assumption that these BMPs would be in place, in order to investigate whether they would provide sufficient protection in respect of the key environmental risks identified. The aim of the risk assessment for Scenario 2 was to identify whether the key potential impacts would be fully addressed, partially addressed, or not addressed by the identified BMPs.

2.2.4 Study scope and boundaries

The US Department of Energy identified four major areas of concern for potential human and ecosystem impacts with regard to the use of hydraulic fracturing for shale gas production (SEAB, 2011a NPR):

- Possible pollution of drinking water from methane and chemicals used in fracturing fluids;
- Air pollution;
- Community disruption during shale gas production; and
- Cumulative adverse impacts

The potential significance of local effects, together with cumulative and regional effects of multiple drilling, hydraulic fracturing, production and delivery activities on the environment was also highlighted by the International Energy Agency (2012 NPR p14), which noted in particular the potential cumulative effects on water use and quality, land use, air quality, traffic and noise as well as the issue of waste water management.

New York State DEC (2011 PR p11-2 to 11-9) identified impacts associated with the following resources:

- Potential effects on people (e.g. via noise, radioactive materials, air emissions)
- Water resources
- Sensitive ecosystems and species
- Air quality
- Visual quality of the landscape
- Transportation

The USEPA (2011a PR p viii) focused specifically on the relationship between hydraulic fracturing and drinking water resources.

The range of potential hazards identified in these key references were considered systematically at each stage of the hydraulic fracturing process, to enable the risks associated with each aspect of hydraulic fracturing and Marcellus shale gas exploitation to be characterised in a strategic manner, considering the limits of the exercise, as indicated below.

The activities identified by King (2012 PR) as potentially significant are:

- transport of fracturing materials to the well
- the specific act of fracturing
- recovery of hydraulic fracturing wastewater from the well ; and
- the transport of wastewater from the well

The range of impacts considered in the present study was derived from the aggregated range of issues identified in the above review studies. The study considers the direct environmental and health issues associated with these aspects of shale gas extraction. The study is not a “life-cycle” assessment, and consequently the risks associated with secondary processes are outside the scope of the study (e.g. the specific risks/impacts, resources and energy consumed in order to manufacture sand and other proppants, gravel, stone and chemical additives for well pad construction; or to construct and maintain road and pipeline infrastructure; or to produce fracturing fluids).

The potential impacts associated with traffic have been highlighted as a distinct issue from the impacts associated with the gas extraction process itself and associated infrastructure. Some of the impacts associated with traffic (such as emissions of air pollution, noise impacts and land take) can be expected to be similar in nature to those of the gas extraction process, whereas others (such as impacts on community severance or accident risks) differ in nature. The nature of the sources and the relevant control measures are sufficiently different for it to be useful to consider traffic-related impacts as a distinct but related issue.

This study is not designed to draw conclusions on the potential significance of hazards posed by specific installations. The approach taken is to draw on published information in relation to environmental and health risks, and make a preliminary judgment in terms of the potential significance of the hazards under consideration for the use of HVHF in Europe. The basis for reaching each preliminary judgment is set out in the text following each classification in the Section 4.

2.2.5 Well lifetime and re-fracturing

Conventional and unconventional gas well production rates tend to drop after a period of time. An operator may choose to re-fracture the well, in order to increase the gas flow rate. As discussed in Chapter 3, this may take place approximately once every 10 years, or between 0 and 4 times over a well lifetime of up to 40 years. Industry reports suggest that the requirement for re-fracturing is generally reducing, because of improved ability to target fracturing activities [REF]; however, the frequency of re-fracturing is an area of uncertainty.

Although important in terms of potential risks and impacts in practice, the evaluation in this chapter is not strongly sensitive to the assumed frequency of re-fracturing, because the study is designed to be applicable to a wide range of circumstances involving the potential for development of multiple well pads in a local area such as a municipality, and across the wider area of Garrett and Allegany Counties.

2.2.6 Cumulative impacts

The development of shale gas plays opens the possibility of development of gas extraction infrastructure over a wide area. Consequently, cumulative risks need to be taken into account in the risk assessment. This was carried out by separately evaluating the risks posed by development of individual installations, and the risks posed by development of an entire shale gas play. The area of Garrett County is approximately 660 square miles, and as shown in Figure 1 above, shale gas infrastructure may be required across the full extent of this area and part of Allegany County.

The current trend towards the use of multi-well pads, in which up to 10 wells may be placed on a single pad mitigates these impacts to some extent. New York State (2011 PR p5-23) indicates that one well pad may allow approximately 640 acres of shale formation to be accessed. This would correspond to a typical separation between well pads of approximately 1 mile. Over an area of approximately 800 square miles, this would correspond to approximately 800 multi-well installations, occupying approximately 1.2% of the land area. This is comparable to the total of approximately 710 shale gas wells drilled in Pennsylvania during 2009 (Cuadrilla Resources Ltd 2011 NPR p12). The potential for cumulative effects was assessed on the basis of development of this scale. The rate of well pad development is likely to be determined by the availability of plant and equipment, as well as external economic considerations such as the price of gas and competitive position with regard to other unconventional hydrocarbon opportunities.

2.3 Risk prioritisation framework

A strategic risk prioritisation approach has been adopted to enable potential impacts to be evaluated.

King (2012 PR) sets out a useful basis for risk prioritisation in the context of shale gas development. This follows established principles of screening and prioritisation for environmental risk and impact assessment and management (e.g. UK Department for Environment, Transport and the Regions, 2000 NPR).

The risk prioritisation was carried out by classifying environmental hazards and hazards for people on the following basis:

- **Slight:** Slight environmental effect– e.g. a planned or unplanned discharge which does not result in exceedances of an environmental quality standard
- **Minor:** Minor environmental effect – e.g. a planned or unplanned discharge which could result in exceedances of an environmental quality guideline in the immediate vicinity of the release point, but which would not be expected to have significant environmental or health effects
- **Moderate:** Localized environmental effect – e.g. a discharge or incident resulting in potential effects on natural ecosystems in the vicinity of the release point or incident; ongoing effects on people in the vicinity of a site due to impacts such as noise, odour or traffic
- **Major:** Major environmental effect – e.g. an ongoing discharge resulting in persistent exceedances of an environmental quality standard; permanent degradation of a protected habitat
- **Catastrophic:** Massive environmental effect – e.g. a pollution incident resulting in harm to the health of members of the public over a wide area due to contamination of drinking water supplies; accident resulting in death or serious injury to workers and/or members of the public.
- **No data:** Insufficient data to allow a preliminary judgment to be reached

The frequencies or probabilities of hazards occurring were classified on the following basis (adapted from King, 2012 PR):

- **Rare:** Encountered rarely or never in the history of the industry; not forecast to be encountered under foreseeable future circumstances in view of current knowledge and existing controls on oil and gas extraction.
- **Occasional:** Encountered several times in this industry; could potentially occur under foreseeable future circumstances if management or regulatory controls fall below best practice standards
- **Periodic:** Occurs several times a year in this industry; a short-term impact would be expected to occur with the use of hydraulic fracturing for hydrocarbon operations

- **Frequent/definite:** Occurs several times a year at a specific site; a long-term impact would be expected to occur with the use of hydraulic fracturing for hydrocarbon operations
- **No data:** Insufficient data to allow a preliminary judgment to be reached

In environmental risk assessment studies of hazard significance and probability, it is often necessary to use some judgment because of uncertainty associated with the evidence base. This was the case for the present study. The frequency or probability of hazards occurring was estimated from reported analysis of hydraulic fracturing activities in the field where this was available. As indicated above, independent and comprehensive information for instance on well failures and incident rates is limited, which makes this risk prioritisation exercise a preliminary one, pending additional data. Indeed the absence of evidence of hazards does not necessarily mean evidence of the absence of hazards. Where expert judgment needed to be used, this was noted in the text.

Considering the hazard significance and associated probability enables risks to be prioritised and screened, as set out in Table 1 (adapted from King 2012 PR , after DeMong et al., 2010 PR).

Table 1: Risk ranking table

Probability classification	**Hazard classification**					
	Slight	**Minor**	**Moderate**	**Major**	**Catastrophic**	**No data**
Rare	Low	Low	Moderate	Moderate	High	Not classifiable
Occasional	Low	Moderate	High	High	Very high	
Periodic/short term definite	Low	Moderate	High	Very high	Very high	
Frequent/long-term definite	Moderate	High	Very high	Very high	Very high	
No data	Not classifiable					

Where more than one scenario is envisaged, the combination giving rise to the highest ranking is presented. Risks can then be screened and prioritised as follows:

- Green: Low risk
- Yellow: Moderate risk
- Orange: High risk
- Red: Very high risk

This approach is useful for evaluating individual risks, and has been applied in the following sections to characterise the potential risks which could occur if specific mitigation in relation to the risks posed by shale gas extraction is not carried out.

2.4 Legal setting

2.4.1 Permitting procedures

The Code of Maryland Regulations (COMAR) Chapter 26.19.01 set out controls on the environmental impacts of development of the State's hydrocarbon resources.

COMAR 26.19.01.06 sets the basis for permitting of hydrocarbon development in Maryland. A permit is required prior to wellpad preparation, drilling, re-drilling or exploration. An environmental assessment is required to accompany the permit application, although the regulation is not specific as to what is required. Insurance is required in relation to public health and property risks resulting from accidents. A performance bond of up to $100,000 per well is required. Applicants are required to provide confirmation that all zoning requirements have been met, together with a statement of all other federal, State, county, and local permits and approvals required, and their status. Applicants are required to provide a set of management plans:

- A sediment and erosion control plan
- A stormwater management plan
- A reclamation plan for restoring the well site (this includes a plan for disposal of well cuttings)
- A pit design plan designed to prevent any drilling liquid from coming into contact with any other waters
- A spill prevention, control, and countermeasures plan

Additional locational information is needed to undertake directional drilling, as will be the case for shale gas facilities. A detailed map is required, showing key features including water wells, other well bores and occupied properties within 2,640 feet of the well head. The regulation gives the Department of the Environment the option of requiring “other relevant materials and documents considered necessary.” A permit is also required for seismic activities (26.19.01.03), and for activities involving the use of explosives (26.19.01.04).

COMAR 26.19.01.02 requires an operator to immediately report to the Natural Resources Police Force any occurrence which creates an environmental or safety hazard. Procedures for well plugging and abandonment are set out in COMAR 26.19.01.12.

COMAR 26.19.01.09 sets out the criteria for Approval of Drilling and Operating Permit. This includes Clause E on the separation of gas wells, which states: “*The Department may not issue a permit to drill and complete a gas well closer than 2,000 feet to an existing gas well unless the Department of Environment is provided with credible geologic evidence of reservoir separation to warrant granting an exception.*” As the Marcellus Shale is the target reservoir and would not be separated, under the existing regulation it would not be possible to complete a standard well pad with multiple directional boreholes. We understand that the Maryland Department of the Environment has recognised this issue and, therefore, for the basis of this study and report we have assumed that a permit for a multi-borehole wellpad could be issued in future based on an amended regulation.

2.4.2 Land use planning procedures

The State of Maryland entrusts local jurisdictions with land use planning authority to guide growth and development through the Land Use Article of the Maryland Annotated Code (www.maryland.gov). There is a presumption that permissions for change of land use will be in accordance with the relevant County Comprehensive Plan.

2.4.3 Groundwater contamination

Primary control of groundwater contamination risks associated with shale gas development in Maryland would be via the permitting processes, as set out in Section 2.4.1 above.

The 1996 Amendments to the Safe Drinking Water Act requires jurisdictions to develop and implement source water assessment programs to evaluate the safety of all public drinking water systems (Allegany County, 2010). These are carried out by the Maryland Department of the Environment. Maps of the contributing areas for water supply sources are prepared, and potential contamination risks are identified, together with recommendations for protecting these sources.

2.4.4 Surface water contamination

The control of surface water contamination risks is likely to be via the permitting processes, as set out in Section 2.4.1 above.

COMAR 26.08.04.01-1 sets out the permitting requirements for discharges of water effluent. This regulation requires preliminary plans and specifications for new facilities to be submitted to the DOE, to enable the Department to evaluate the proposed facility. An applicant may be required to provide additional reports, specifications, plans, or other information on the existing or proposed pollution control program.

2.4.5 Water resources

COMAR Section 26.17.06.04 sets out the procedures for applying for a permit to appropriate and use water resources. Applicants are required to provide the following information:

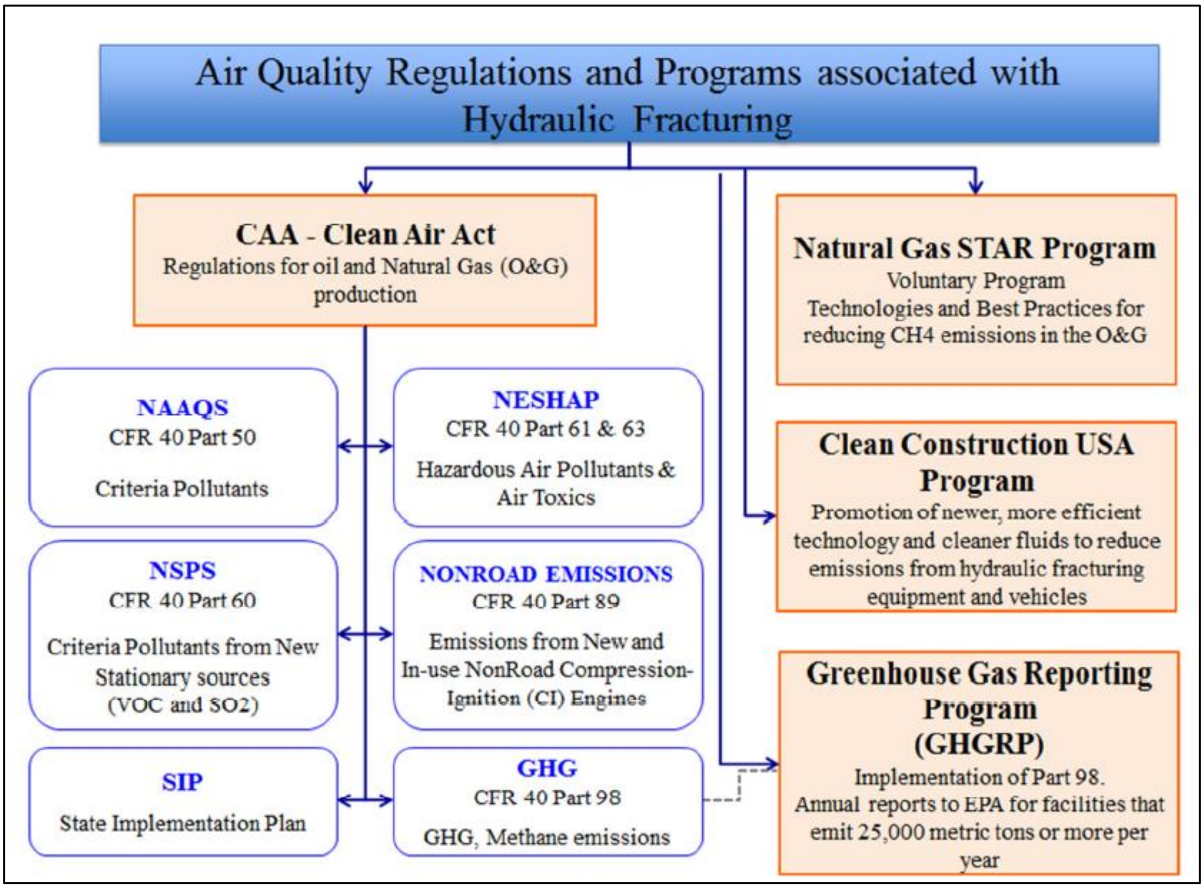
- The specific water use or uses
- A map showing the location of the proposed appropriation or use, and the area or structure in which the water use will occur
- The anticipated average and maximum appropriation quantities
- Plans and specifications for any facility or structure requiring a permit.

If a requested appropriation or use is for more than an annual average of 10,000 gallons per day, there are additional public notification requirements

2.4.6 Release to air

The regulatory situation with regard to emissions to air is summarised in Figure 3 (Rodriguez and Ouyang 2013 PR).

Figure 3: Regulation of emissions to air from hydraulic fracturing



This Act requires major pollution sources to comply with National Emissions Standards for Hazardous Air Pollutants (NESHAPs) via the application of Maximum Achievable Control Technology. However, the thresholds set in the Clean Air Act, and the absence of a requirement for aggregation of oil and gas wells and associated infrastructure under the terms of this act, mean that shale gas infrastructure normally falls outside the scope of this part of the Clean Air Act. In April 2012, the EPA published legislation which prohibits venting or flaring of emissions during completion by 2015 (40 CFR Parts 60 and 63). Operators will be required to use Reduced Emissions Completions to capture completion emissions rather than venting or flaring them. This is expected to result in a significant reduction in emissions of methane and volatile organic compounds (EPA 2012b; Litovitz et al. 2013 PR).

In general, states are free to administer their own regulations as long as they follow the minimum requirements of applicable federal regulations. Consequently, different states apply the regulations through programs of greater or lesser effective degrees of stringency. Some states have specific rules related to hydraulic fracturing, while others regulate it solely under their general oil and gas permitting requirements.

Emissions from engines used to operate compression or drilling plant would be regulated under 40 CFR Part 60, Subpart JJJJ, IIII, Standards of Performance for Stationary Spark Ignition (SI) Compression Ignition (CI) Internal Combustion Engines (ICE). (New York State 2011 PR p6-94).

Air emissions legislation for construction plant is set in 40 CFR part 1039. The EPA provides a summary of emissions limits at http://www.epa.gov/otaq/standards/nonroad/nonroadci.htm.

2.4.7 Risk to biodiversity

Development is limited by regulation in some areas. COMAR 26.23.02.01 restricts development in wetland areas, or in buffer zones surrounding non-tidal wetland areas. An application for a regulated activity in a wetland must include information relating to the proposed development, together with the identification of wetlands known or believed to have significant plant or wildlife value, and field survey information. The applicant must provide details of alternative sites considered, and there must be a demonstrable public need for the development. The applicant must set out mitigation measures, and provide evidence that the regulated activity will not cause or contribute to a degradation of water quality standards.

Certain wetlands with rare, threatened, endangered species or unique habitat can be identified as Wetlands of Special State Concern under COMAR 26.23.06.01 and .02. These areas are afforded protections including a 100 foot buffer from development.

COMAR 08.03.08.10 provides for the listing of Natural Heritage Areas by the Department of Natural Resources. A Natural Heritage Area must contain one or more threatened or endangered species or wildlife species; be a unique blend of geological, hydrological, climatalogical or biological features; and be among the best examples of its kind in the State. There are three such areas in Allegany County, and two in Garrett County.

The DNR designates Targeted Ecological Areas. These are lands and watersheds of high ecological value which have been identified as conservation priorities. They represent the most ecologically valuable areas in the State. These lands include large blocks of forests and wetlands, rare species habitats, aquatic biodiversity hotspots and areas important for protecting water quality. These ecologically important areas have been designated as conservation targets for the state Public Open Space acquisition program. The designation of land as a Targeted Ecological Area does not preclude development from taking place in this area. Similarly, Maryland's Rural Legacy Program "*provides funding to preserve large, contiguous tracts of land and to enhance natural resource, agricultural, forestry and environmental protection while supporting a sustainable land base for natural resource based industries.*" The program encourages local governments and land trusts to work together to protect natural resources and working landscapes. Again, the designation of land as a Rural Legacy program area would not preclude development from taking place in this area.

The DNR also facilitates setting up Conservation Easement areas. These are legal agreements between a landowner and a land trust, which place restrictions on the future uses of the landowner's property in order to protect natural habitats and other valuable natural resources. Depending on the terms of an individual Easement, this could potentially place a legal barrier in the way of shale gas development in a Conservation Easement.

The DNR oversees nearly 450,000 acres of land throughout the state, with the State Forest and Park Service managing 93 sites for natural, historical, cultural and recreational resources (Maryland DNR 2005 PR). The Wildlife and Heritage Service (WHS) within DNR manages the health and recreational enjoyment of the state's wildlife, including the conservation of rare plants and animals under the coordination of the Natural Heritage Program. There is one Wildlife Management Area in the area within which shale gas extraction could potentially take place: the Mount Nebo WMA in Garrett County. This WMA covers 1,863 acres of forest and bog habitat.

Some areas are designated as "Wildlands." State-designated Wildlands are managed for passive recreation only, such as hiking, hunting, fishing, bird watching, horseback riding and nature interpretation. In these areas, mineral extraction is specifically precluded. The following Wildlands are located in the shale gas extraction area shown in Figure 1:

- Bear Pen
- Middle Fork
- Big Savage Mountain
- Savage Ravines
- South Savage

A number of further Wildlands have been proposed in Garrett and Allegany Counties.

2.4.8 Noise impacts

Ambient noise standards are set in COMAR 26.02.03.02. These regulations set a limit of 65 dBA (daytime) and 55 dBA (nighttime) at residential locations. There is an exemption for noise generated by "Pile driving equipment during the daytime hours of 8 a.m. to 5 p.m." which might potentially be relevant in relation to shale gas operations.

2.4.9 Visual impact

As described above, conservation easements can be set up to protect areas of scenic beauty.

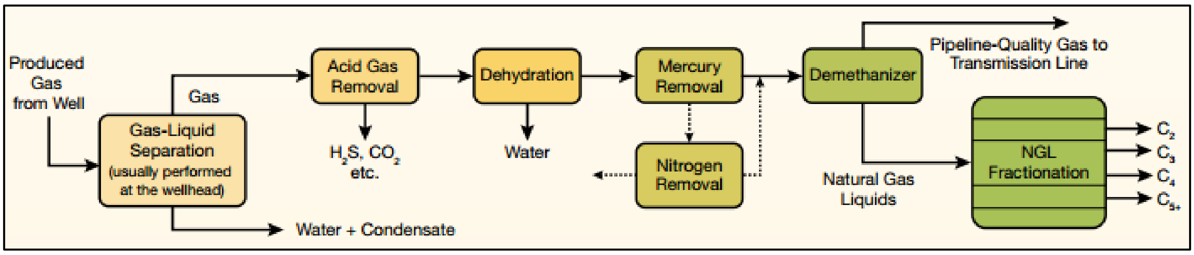
2.4.10 Traffic

Under the terms of COMAR 11.04.05.02, any individual who wishes to construct a commercial or industrial street entrance connecting with a State highway must apply to the State Highway Administration for a permit to do so.

2.5 Downstream infrastructure

Downstream infrastructure required following extraction of natural gas was summarized by Goellner (2012 PR) as shown in Figure below.

Figure 4: Processing steps involved in natural gas production



Following production, water and condensates (higher hydrocarbon liquids) are typically removed from raw gas at or near the wellhead. Gas is transmitted in gathering lines, typically to a gas processing facility. Other constituents are removed from the gas, resulting in processed gas which meets the pipeline specifications. The gas processing facility typically removes acid gases (carbon dioxide, hydrogen sulfide and organo-sulfur compounds), water, mercury, nitrogen and natural gas liquids (also known as condensates) from the gas stream. The condensates may be further separated into individual higher alkanes (ethane, propane, butane and C5+ alkanes) (Goellner 2012 PR).

Following processing, the methane (typically at a concentration of 80% or more) is compressed and added to the main gas transmission pipeline. Natural gas may be distributed for domestic/commercial uses or for combustion for generation of electricity and/or heat in the power and industrial sectors. Alternatively, natural gas may be liquefied for storage and further transportation, typically for export, or compressed to provide CNG for use as a transportation fuel.

2.5.1 Gas processing

As described above, natural gas produced from wells is a mixture of a large number of gases and vapors. Wellhead natural gas is often delivered to processing plants where the majority of higher molecular weight hydrocarbons, water, nitrogen, and other compounds are removed if they are present. Processing plants typically include one or more glycol dehydrators, process units that dry the natural gas. In addition to water, the glycol absorbent usually collects significant quantities of hydrocarbons, which can be emitted to the atmosphere when the glycol is regenerated with heat. The glycol dehydrators, pumps, and other machinery used in natural gas processing can release methane and hydrocarbons into the atmosphere, and emissions also originate from the numerous flanges, valves, and other fittings (Agbaji et al. 2009 NPR).

The process generally used for the water removal is glycol dehydration using a solution of diethylene glycol or triethylene glycol, with adsorption dehydration using silica gel. Amine treatment is typically used for removal of acid gases, resulting in the production of aminosulphides. The recovered sulphur can potentially be sold on for use as a chemical feedstock, and recovered carbon dioxide can be used for enhanced oil recovery.

Low temperature distillation is typically used to separate natural gas liquids from the purified gas.

2.5.2 Pipelines

Natural gas is transported from wells in mostly underground gathering lines that form networks that can eventually collect gas from hundreds of well locations. Gas is transported in pipeline networks from wells to processing plants, compressor stations, storage formations, and/or the interstate pipeline network for eventual delivery to customers. Gas gathering lines are typically 6 to 20 inch diameter pipelines, and gas mains are typically 20 to 48 inches in diameter. The Public Services Law defines major natural gas transmission facilities, which statutorily includes many gathering lines, as pipelines extending a distance of at least 1,000 feet and operated at a pressure of 125 psig or more" (New York State DEC 2011 PR p8-8). Regulatory authority for intrastate pipelines is divided between the state permitting authority, and the Public Services Commission.

Leakage from pipeline networks can occur from microscopic holes, corrosion, welds and other connections, as well as from blow and purge operations, pipeline pigging, and from the large number of pneumatic devices on the pipeline network. This can result in emissions of methane and hydrocarbons into the atmosphere and lost revenue for producers.

There are twenty interstate natural gas pipeline systems within the Northeast Region of the US, with one interstate pipeline running close to the border between Garrett and Allegany Counties and Pennsylvania to the north. These interstate pipelines deliver natural gas to several intrastate natural gas pipelines and at least 50 local distribution companies in the region. In addition, they also serve large industrial concerns and, increasingly, natural gas fired electric power generation facilities (EIA 2014 NPR).

2.5.3 Compressor plant

Compressors are extensively used to pressurize natural gas from wells to the pressure of gas gathering or main transmission pipelines. Compressor operation gives rise to operational noise, and can give rise to fugitive emissions from compressor intake and outlet seals, and compressor rod packing. Additionally, internal combustion engines typically provide the power to run compressors. The engines are often fired with raw or processed natural gas, and the combustion of the natural gas in these engines results in air emissions (New York State DEC 2011 PR p6-99).

2.5.4 Liquefaction and compression of natural gas

Belvalkar and Olewole (2010 PR) highlighted that compressed and liquefied natural gas is becoming increasingly popular as a transportation fuel. The authors suggest that transportation of LNG (e.g. by sea) has the advantage of posing no significant risk of pollution in the event of a spillage, as the gas would evaporate. Belvalkar and Olewole anticipated an expansion in LNG export facilities, as has taken place in Maryland with the proposed Cove Point LNG facility. The issues associated with this facility will be addressed in Appendix 1.

3 Environmental risk prioritisation

A shale gas development project is carried out in five main stages (Philippe and Partners, 2011 NPR p7-8) covering exploration (stages 1-4) and production (stage 5):

1. Identification of the gas resource.
2. Early evaluation drilling.
3. Pilot project drilling.
4. Pilot production testing.
5. Commercial development.

The exploration phase initially consists of drilling and fracturing a small number of vertical wells (typically only two or three wells) to determine if shale gas is present and can be extracted. A 'plug and perforate completion' technique tends to be used in the exploration phase. The well is lined and then perforated at certain points. Sections with the perforations are isolated with cement plugs before being fractured. The plugs are drilled through to allow the gas to flow to the surface where the potential for further development can be appraised.

If the initial indications are favourable, more wells (typically 10 to 15 wells) are drilled and fractured to characterise the shale, examine how fractures will tend to propagate and establish if the play could produce gas economically. Further wells (typically up to 30 wells) may be drilled to ascertain the long-term economic viability of the play (Royal Society and Royal Academy of Engineering (UK) 2012 PR).

The exploration phase is important in relation to the impacts of these pilot drilling and fracturing activities themselves, as well as in influencing the areas where full-scale shale gas extraction will take place.

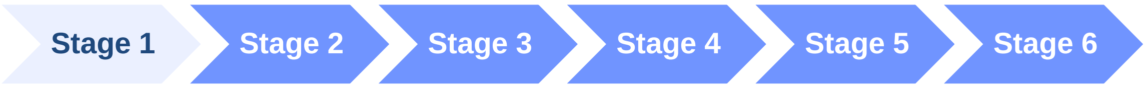
For an individual unconventional gas well, the process of well development is as follows:

1. Well pad site identification and preparation
2. Well Design, Drilling, Casing and Cementing
3. Technical Hydraulic Fracturing Stage
4. Well Completion (flowback)
5. Well Production
6. Well Abandonment

The remaining part of this chapter focus on the above six stages of well development and the key risks associated with each individual stage and for the total project. Additionally, this risk assessment considers a further aspect of shale gas field development:

7. Downstream infrastructure

3.1 Stage 1: Well pad site identification and preparation



3.1.1 Surface water contamination risks

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*minor*	*rare*	*low*
Cumulative effects of multiple installations	*Moderate*	*rare*	*moderate*

Peer reviewed research

Runoff and erosion during early site construction may lead to silt accumulation in surface waters (There is a greater potential risk with the use of hydraulic fracturing, because of larger well pads and storage impoundment construction). New York State DEC 2011 PR (page 6-14) highlights the particular risk of stormwater runoff leading to contaminants such as nutrient phosphorus and nitrogen, hydraulic oil, fuel and lubricating fluids entering water bodies, streams and groundwater. Common to industrial activity and construction sites generally, this impact relates to the extent of groundworks and the nature of surface construction (roads, concrete areas etc). The larger footprint of high volume multi-well pad installations (up to 7.4 acres/pad; New York State 2011 PR p5-6) compared with those for conventional gas (c.4.7 acres/pad) as well as larger storage impoundments mean that there are greater risk during the development phase of unconventional well pads when assessed on a “per site” basis.

Because of this larger footprint, shale gas installations have greater scope for habitat impacts directly associated with stormwater runoff, through the impact this has on the erosion of streams, sediment build-up, water quality degradation and potentially flooding. These stormwater impacts can be mitigated to an extent through managed drainage and controls on potential groundwater contaminants. The State of Texas sets a minimum distance between well pads and residential locations of 200 feet in order to protect against such impacts, although some individual municipalities have set local setback distances which range between 300 feet and 1500 feet (Fry, 2013 PR).

Access routes for heavy truck traffic requires a compacted gravel substrate. This can lead to increased storm-water runoff and erosion potential (Hazen and Sawyer, 2009 PR quoted in Eaton 2013 PR) from access routes to and from a wellpad, including during the construction phase.

Other research

Other research was not used in this evaluation.

Local context

A detailed program of baseline water quality monitoring is currently carried out by the Maryland Department of Natural Resources (Prochaska, 2013 NPR), as summarised in Section 3.3.2. If continued throughout the development of shale gas wellpads, this program would provide useful warning in the event of an acute impact on water quality. However, this would depend on the continuation of a comprehensive monitoring program, and would constitute at best a useful reactive measure for initiating action to mitigate impacts, rather than a preventive measure.

Judgment

As the risks posed by surface water runoff from individual well pad development are well understood for similar installations resulting in minimal impacts, the potential significance was considered to be “low”.

The potential cumulative effects on water quality due to development of multiple sites over an area of hundreds of square miles are a potential concern. Management of such impacts would require co-ordinated strategic controls, as well as effective controls on the development of individual well pads. As potential impacts could be additive, the potential significance of cumulative effects was considered to be "moderate".

3.1.2 Release to air

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*slight*	*short-term definite*	*low*
Cumulative effects of multiple installations	*slight*	*short-term definite*	*low*

Peer reviewed research

Heavy machinery/installations used for site preparation and construction give rise to exhaust emissions. At the site construction stage, these are not significantly different to emissions from any other similar construction activity, although the larger well pad site area in the case of HVHF means that emissions would be greater for HVHF than for conventional gas extraction. Adopting the findings of New York State (2011 PR p5-6) that the well pad may be approximately 60% larger for HVHF than for conventional gas, releases to air may be also expected to be approximately 60% higher. Attention is normally focused on diesel engine emissions during the drilling and fracturing stages (Howarth and Ingraffea, 2011 PR) rather than the site preparation phase, and are of less concern during site preparation. In this context, diesel engine emissions do not pose a significant environmental or health risk, and were assessed as a hazard of "slight" significance.

Similarly, there is a risk of fugitive emissions to air in the event of an equipment fuel or oil spillage, but this risk would be common to any similar activity and controlled via normal procedures for the oil and gas industry, and the wider construction industry.

The well pad construction phase may be expected to last up to 4 weeks per well pad (New York State 2011 PR p5-135).

Other research

Lechtenböhmer et al. (2011 NPR) concur that diesel engine emissions during the drilling and fracturing stages are an area of concern, and hence are not of significance at the site preparation stage.

Broderick et al (2011 NPR, p28) concur that the well pad construction phase may be expected to last up to 4 weeks per well pad.

Judgment

A consistent view was identified that emissions to air during site preparation are of less concern than emissions during later stages in the project. Exhaust emissions from off-road construction plant are controlled under federal legislation. In this context, diesel engine emissions would not pose a significant environmental or health risk, and were assessed as a hazard of "slight" significance.

Although no specific information was available with regard to the risks posed by fugitive emissions to air following a fuel or oil spillage, because these risks would be common to any similar activity, it was judged that this potential impact would be of "slight" significance.

Although no specific information was available in relation to cumulative impacts, in view of the limited significance of emissions to air during well pad site preparation, and with a typical well pad separation of approximately 1 mile, it is judged unlikely that the cumulative effect of emissions to air during this phase could pose a significant risk to air quality in the context of wider sources of emissions to air such as road traffic. This was therefore assessed as a hazard of "slight" significance.

3.1.3 Land take

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*minor*	*short-term definite*	*moderate*
Cumulative effects of multiple installations	*major*	*short-term definite*	*very high*

Peer-reviewed research

According to New York State DEC (2011 PR p5-6) land disturbance directly associated with high-volume hydraulic fracturing will consist primarily of constructed gravel access roads, well pads and utility corridors. This report explains how well numbers and pattern layouts contribute to the overall pad size. 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 pipelines would require land-take during the construction and operational phases. Pipelines may be buried which could enable this land to be returned to the previous use, or other beneficial use such as agriculture. road verges or sports/recreation areas.

Surface installations require an area of approximately 7.4 acres per pad for high volume hydraulic fracturing during the fracturing and completion phases, compared to 4.7 acres per pad for conventional drilling (New York State DEC 2011 PR Table 5.1) Meng (2014) identifies a well pad area of 4 to 5 acres, closer to the estimated well pad area for conventional drilling. The additional area for HVHF well pads is needed to accommodate the equipment and storage tanks/pits required for up to 7 million gallons of make-up water, together with chemical additives and waste water. Also, because of the lower yield of shale gas wells than conventional wells, more well pads are needed than is the case for conventional gas extraction. Hackbarth et al (2013 PR) identify that subsurface sweetspotting and accurate EUR prediction early in a project can assist in developing a highly concentrated pad, reducing overall land use.

Multi-well pads are now in widespread use for shale gas extraction. This enables a single pad to accommodate 6-10 wells (New York State 2011 PR p3-3), resulting in a lower land take impact compared to the use of single well pads. A single multi-stage horizontal well pad can be used to access approximately 640 acres of shale gas play, compared to approximately 40 acres for a vertical well pad (New York State 2011 PR p 5-23). Assuming 7.4 acres per multi-well pad (see below), 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.

Jenner and Lamadrid (2013) estimate that natural gas extraction requires 0.027 acres per GWh (7.9 acres per trillion BTU), or 0.032 acres per GWh (9.4 acres per trillion BTU) taking disturbance due to natural gas pipelines into account. Combining this with the estimated quantity of 1.5 to 12 trillion cubic feet extractable gas (University of Maryland 2013 NPR) suggests a total well pad land take of 12,000 to 98,000 acres. This corresponds to 2.4% to 19% of the land area shown in Figure 1, significantly higher than the estimates made by New York State DEC (2011 PR). However, experience elsewhere in the Marcellus Shale is that land take is closer to the figures quoted by New York State DEC, suggesting that the higher range extractable gas quantity estimate is excessive, or that the land take estimates produced by Jenner and Lamadrid are higher than would be normal for the Marcellus Shale.

Land used for shale gas wellpads can mostly be restored, but reforestation could take up to 300 years (Jenner and Lamadrid 2013 PR). It may not be possible to fully restore a site in a sensitive area following well completion or well abandonment. For example, sites in areas of high agricultural, natural or cultural value could potentially not be fully restorable following use.

As well as the well pads themselves, the associated infrastructure (access roads and pipelines) also results in land take and habitat fragmentation. For example, Sutherland et al. (2011 PR) highlight that over 30% of the 3,500 square miles of forest in the State of Pennsylvania have been made available for natural gas extraction, although only around 1.2% of this area (or less than 0.5% of the total forest area) would be taken for use in well pad development.

The use of land for gas development could be viewed as incurring an “opportunity cost” due to its unavailability for other, potentially more beneficial, uses. These opportunity costs have not been taken into account in this study.

Other research

The New York State DEC estimate of well pad area is consistent with a study carried out by the Nature Conservancy (2011 NPR p18) who estimate that 9 acres of forest land would be taken per well pad, including roads and other infrastructure. US DOE (2009 NPR) confirms the land requirements for conventional installations and installations using HVHF.

Lechtenböhmer et al. (2011 NPR page 21) highlight the potential significance of land take and habitat fragmentation due to associated infrastructure (access roads and pipelines).

Local context

Approximately 121,000 acres or 29% of Garrett County is regulated or protected by virtue of federal, state, or County ownership (primarily state forests and parks); utilities; wetlands; tax exempt status; or the presence of protective easements established through agricultural or other preservation programs (Garrett County Comprehensive Plan 2008). The plan states that the County’s intent is for Rural Resource areas “*to remain rural and to conserve these areas’ natural resources, primarily forest and timber resources, for future generations.*” The Comprehensive Plan sets out land use plans for the 12 watersheds within the County. The Comprehensive Plan sets a goal “*to protect Garrett County’s sensitive environmental resources and natural features. The objectives for achieving this goal are: 1. Limit development in and near sensitive environmental areas, including steep slopes, streams, wetlands, 100-year floodplains, and the habitats of threatened or endangered species…*” This will be implemented by ongoing use of the Sensitive Areas Ordinance and the Deep Creek Lake Watershed Zoning Ordinance.

The Allegany County Comprehensive Plan highlights the protection afforded to a wide range of sensitive areas in the County. The plan sets policies in relation to these designated sensitive areas, but does not preclude development in sensitive areas where this can be carried out consistent with the policy objectives for protection of the sensitive features. The policies include requirements for setbacks between buildings and streams, and an undertaking to refer applications in habitat areas for threatened or endangered species to the appropriate State agency. The Comprehensive Plan supports the exploitation of mineral resources in the County subject to proper development and oversight, particularly in sensitive areas.

Restrictions on well pad development in areas protected for their natural landscape and biodiversity value are discussed in Section 3.1.4 below.

Judgment

Land-take associated with an individual site is within the normal range of commercial and infrastructure developments, and it was judged that this can be considered as a minor impact. The cumulative land-take impact of 1.2% for full development of a gas reservoir compares to 10% of land in Garrett County and 16% of land in Allegany County described as “developed” (http://planning.maryland.gov/ourwork/landuse.shtml). This is judged to be of potentially major significance, and would be a short-term impact likely to be associated with the full development of any large shale gas concession and therefore classified as “short term definite" likelihood. Following the initial development of wellpads and drilling, hydraulic fracturing and completion, some of the land could potentially be returned to other uses. However, this land would potentially be required should re-fracturing be carried out in the future.

3.1.4 Biodiversity impacts

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*Minor*	*Occasional*	*Moderate*
Cumulative effects of multiple installations	*Moderate*	*Occasional*	*High*

The term "biodiversity" refers to the variability among living organisms from all sources; this includes diversity within species, between species and of ecosystems (adapted from the Convention on Biological Diversity). For the purposes of this project, "biodiversity" refers to the range of species supported by the ecosystem(s) surrounding a shale gas development or area of shale gas development, and the evaluation considers the risks to these species and ecosystems which could potentially result in a loss of biodiversity.

Peer-reviewed research

Gas extraction can affect biodiversity via a number of routes (New York State DEC 2011 Section 6.4; Entrekin et al. PR 2011). These include:

- Removal of habitat (addressed in Section 2.4.3 above). Jenner and Lamadrid (2013) note that gas exploration and extraction zones may affect lands of ecological value for rare species, riparian areas, streams, and wetlands. Sites in areas of high ecological value could potentially not be fully restorable following use.
- degradation of habitat (e.g. as a result of excessive water abstraction); or fragmentation (e.g. as a result of fencing, road construction)
- introduction of invasive species;
- noise and other disturbance
- water and land pollution

An invasive species is a species that is not native to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm or harm to human health. Invasive species can be plants, animals, and other organisms such as micro-organisms, and can impact both terrestrial and aquatic ecosystems (New York State DEC 2011 PR p 6.4.2). New York State DEC highlights the potential effects on biodiversity due to invasive species as a potential concern.

The main impacts at the site preparation stage would be associated with habitat loss or fragmentation, following land take as described in Section 3.1.3. 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 (Entrekin et al., 2011 PR p8). Entrekin et al. conclude that there are preliminary indications of detectable effects of sedimentation of watercourses due to shale gas development, and consider that scientific data are needed to ensure protection of water resources.

Other research

Lechtenböhmer et al.(2011 NPR page 19) found that there were no documented effects of shale gas extraction on biodiversity. The EPA (2012a NPR p9) highlighted a local issue linked to the introduction of algae into local water courses, resulting in major fish kills. Locally-gathered evidence indicates that gas extraction can affect biodiversity via the introduction of invasive species and via habitat loss (e.g. Heatley, 2011 NPR) but this evidence has not been published for external verification.

The Nature Conservancy (2011 NPR page 18) confirmed that development of well pads in forest areas in Pennsylvania affects a wider area than the site area itself. It was estimated that the area indirectly affected would be approximately an additional 2.4 acres for every acre of well pad area, or an additional 22 acres per well pad.

Local context

The Maryland DNR Natural Heritage Program is the state's leading program for wildlife diversity conservation. Rare and endangered species and natural communities throughout the state are identified, ranked, and conserved. The program currently monitors the status of over 1,100 native plants and animals, with more than 600 species and subspecies listed as endangered, threatened, in need of conservation, or endangered-extirpated in Maryland. The most endangered animal taxa in Maryland are among the invertebrates, with more than 40 species designated as threatened or endangered. Several of these species are highly specialized subterranean species found in springs, mines, and caves in the Maryland mountains (Maryland DNR 2005 PR). The Wildlife Conservation Plan highlights the risks to biodiversity posed by habitat loss and fragmentation, which are particularly relevant in relation to potential development of shale gas resources. Table 1.3 of the plan lists ten key statewide biodiversity risks, of which the following are particularly relevant:

- Pollution, including biological and chemical contaminants (risks due to pathogens and diseases are less relevant)
- Development, including road construction and salt application, impervious surfaces, impoundments, and conversion to other land uses, that results in erosion, sedimentation, nutrient enrichment, habitat loss and/or fragmentation, and isolation of local populations
- Invasive and/or non-native species that result in habitat loss or degradation
- Excessive human use and/or disturbance

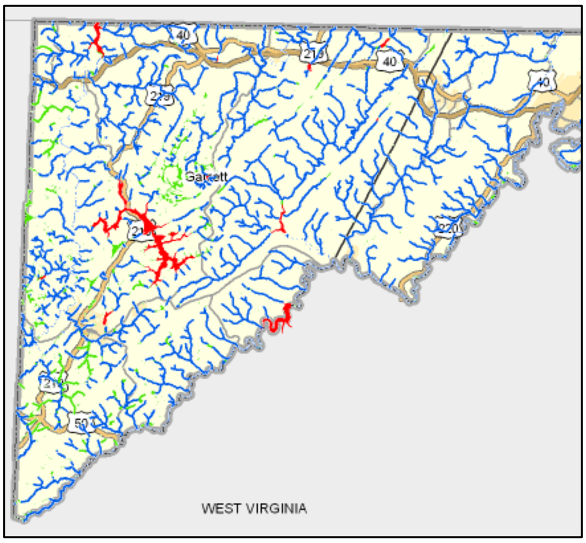
The Wildlife Conservation Plan lists actions for protecting sensitive habitats such as forests, which include the following:

- Conserve large blocks of contiguous forest where appropriate
- Protect all old growth forest habitat and adequate forested buffers
- Incorporate forest conservation actions into land use and land planning efforts by local, state, and federal agencies
- Minimize fragmentation of large, contiguous forest blocks

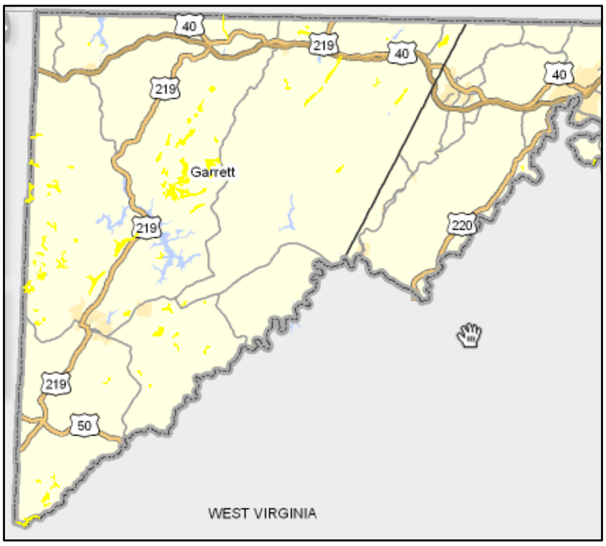
The only areas within which mineral extraction is specifically precluded are designated Wildlands. There are four such areas in Garrett County.

Protected areas in Garrett and Allegany Counties are shown in Figure 5 below.

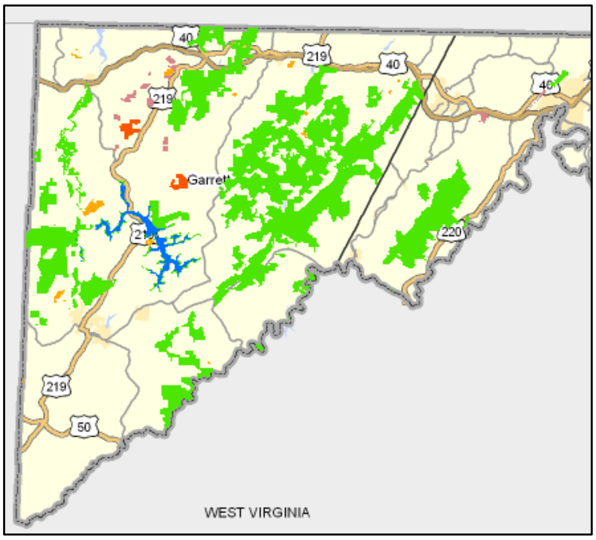
Figure 5: Protected areas in Garrett and Allegany Counties



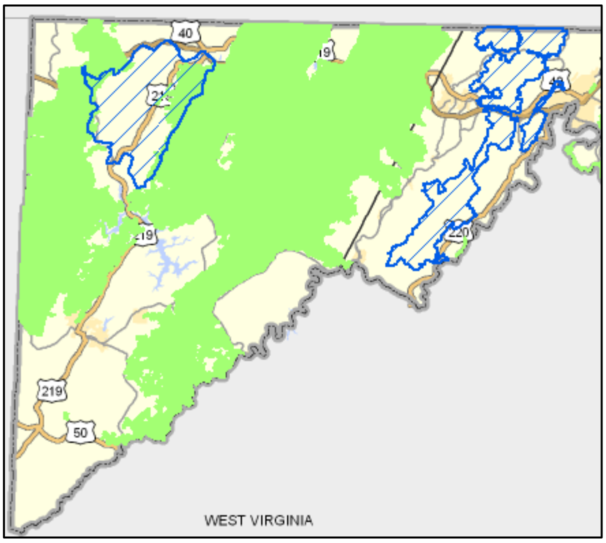
DNR Wetlands



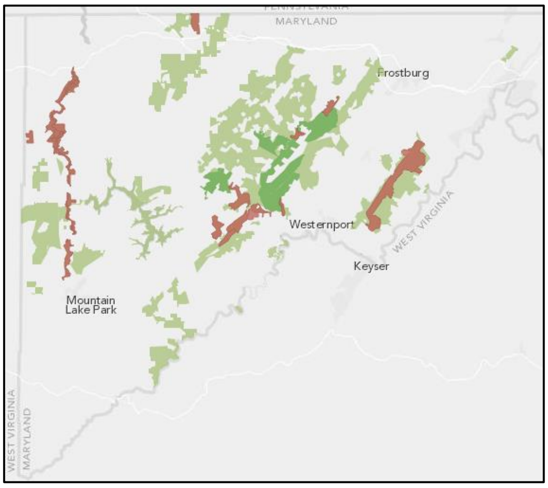
Wetlands of Special State Concern



Protected lands – DNR programs
Green: DNR Owned Properties
Orange: DNR Conservation Easements
Yellow: MD Environmental Trust Easements
Pink: Rural legacy



DNR Focal areas
Blue: Rural legacy areas
Green: Targeted Ecological Areas



Wildlands
Dark Green: Existing legislated Wildlands
Light Green: DNR owned lands
Brown: Candidate Wildlands (2013)

The DNR has developed the Biodiversity Conservation Network (BioNet), a digital mapping tool which prioritizes areas of the state for conservation of freshwater and terrestrial plants, animals, habitats, and landscapes (Eshleman and Elmore NPR 2013). This network provides decision support for species and land conservation programs, and enables compatible land uses and land management practices to be identified. The identified areas are prioritized into a five-tiered system, with the highest tier representing areas which are critically significant for biodiversity conservation. However, at present there would be no planning or statutory bar to development within an area identified at any tier within the BioNet classification.

Judgment

The risks to biodiversity arise due to accidental releases and habitat loss (up to 1.2% of habitat may be lost, with a further 2.9% of habitat indirectly affected). In view of the absence of published peer-reviewed research in this area, the risks to biodiversity posed by these impacts remains an area of plausible concern, but without a clear evidence base.

Garrett and Allegany Counties contain significant areas of high biodiversity, including areas which provide habitats for many rare and endangered species. Protection of forest habitats is a key focus of conservation activities, with prevention of habitat loss and fragmentation highlighted as an important action. Shale gas development would inevitably result in some loss and fragmentation of habitat (Slonecker et al. 2012 PR), and hence biodiversity impacts associated with wellpad development is identified as a potentially significant impact. At present, shale gas development would not be permitted in the relatively limited areas designated as Wildlands. Shale gas development could potentially be prevented in other protected areas, but this would be at the discretion of the competent authority/ies, and subject to the terms of individual site easements. Consequently, without further undertakings from the relevant authorities, it cannot be assumed that shale gas development in other protected areas would be prevented or restricted.

It was judged that the impacts on biodiversity associated with individual sites are likely to be limited to the vicinity of the site, supported by the conclusions of Entrekin et al. (2011 PR p8)and Nature Conservancy (2011 NPR). In view of the widespread presence of sensitive habitats in Garrett and Allegany Counties, biodiversity impacts associated with habitat loss and fragmentation were classified as “minor” for individual site development, and “moderate” for cumulative site development.

It was judged that impacts associated with disturbance and potential for introduction of invasive species would be less than at other stages in the process.

3.1.5 Noise

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*slight*	*periodic*	*low*
Cumulative effects of multiple installations	*minor*	*rare*	*low*

Peer-reviewed research

Noise from excavation, earth moving, other plant and vehicle transport could affect residential amenity and wildlife, particularly in sensitive areas during the period of site preparation – typically up to four weeks (see Section 3.1.2).

The levels of noise during site preparation were estimated by New York State DEC (2011 PR p6-289 to 6-300).

Fry (2013 PR) noted that noise, vibration and traffic are among the most noticeable impacts for local residents, but that minimum setback distances to residential properties are typically not linked to control of these impacts.

Other research

None referenced

Judgment

The levels of noise identified by New York State DEC (2011 PR) would not exceed the State daytime limit of 65 dBA at residential properties located 1,000 feet or more from access road construction, or 500 feet from well pad construction. Construction noise would take place for a relatively short period. Noise impacts could be controlled via appropriate site location and other mitigation measures to avoid significant impacts for members of the public. Site operatives and visitors may need additional controls to ensure that no adverse effects on health occur due to noise during this stage.

The issues associated with site preparation would be typical of the scale of impacts associated with any comparable construction activity and are therefore judged to be of “slight” significance for individual development. The separation of approximately 1 mile between multi-well pads would result in significant attenuation for receptors potentially affected by multiple developments, and there is judged to be a low risk of cumulative impacts due to noise during site development.

3.1.6 Visual impact

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*Minor*	*periodic*	*Moderate*
Cumulative effects of multiple installations	*Moderate*	*occasional*	*High*

Peer-reviewed research

Visual impacts are described by New York State DEC (2011 PR p6-263) as impacts that “*would typically result from the introduction of new landscape features into the existing settings surrounding well pad locations that are inconsistent with (i.e., different from) existing landscape features in material, form, and function.*" New York State DEC reviewed a number of field studies of visual impacts of shale gas production facilities, and concluded that, in the context of development in New York state, “*the visibility of new landscape features associated with well sites tends to be minimal from distances beyond 1 mile*” (p6-283). New York State DEC went on to summarise the range of features which may result in a visual impact over the lifetime of a shale gas development.

Meng (2013 PR) concluded that the construction of natural gas well pads with the use of hydraulic fracturing changes the environment and land surface characteristics. Meng states that intensive development has destroyed forested areas in the Marcellus shale region.

Other research

None referenced

Local context

The Garrett County Comprehensive Plan (2008) and Allegany County Comprehensive Plan (2002) refer to the State of Maryland “Visions for Future Development.” These include Vision 1: “*Development is concentrated in suitable areas.*” Distributed development of well pads and infrastructure following at subsequent stages is likely to take place typically in rural settings. This would not be in accordance with this “Vision for Future Development” in Maryland.

Vision 2 is that certain designated sensitive areas should be protected from development. This is defined for Allegany County as follows:

- *"Ensure compatibility between man-made development and the natural environment*
- *Protect Sensitive Areas and preserve air, water, vegetation, land, and historic resources*
- *Provide for the proper development and use of the County's mineral reserves…"*

Judgment

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. The new features introduced as a result of well pad construction would be temporary in nature, and in general familiar to local populations, even if they may represent a new feature in a particular landscape. However, changes in visual landscape appearance due to the clearance of natural features such as forested areas would be longer-term. Such development would not be in accordance with the State of Maryland "Visions for Future Development," and this would be particularly acute in the high-value natural landscapes of Garrett and Allegany Counties.

In view of the local context, the risks to the visual landscape from individual development are judged to represent a "minor" impact. These features are likely to proceed sequentially as a shale gas play is developed. The sequential development of well pads 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. Cumulative effects are therefore judged to represent a "moderate" hazard.

3.1.7 Traffic

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*slight*	*short term definite*	*low*
Cumulative effects of multiple installations	*slight*	*long term definite*	*moderate*

Peer-reviewed research

New York State DEC (2011 PR) summarises the potential effects of road traffic as follows: "*The introduction of high-volume hydraulic fracturing has the potential to generate significant truck traffic during the construction and development phases of the well. These impacts would be temporary, but the cumulative impact of this truck traffic has the potential to result in significant adverse impacts on local roads and, to a lesser extent, state roads where truck traffic from this activity is concentrated.*"

The New York State DEC (2011 PR Table 6.60) indicates that the total number of truck movements during drill pad construction is likely to be approximately 135 one-way trips per well, or about 7% of the total truck movements. This suggests approximately 500 – 800 truck movements for the development of a 10 well pad. This number of movements over a pad construction period of approximately 4 weeks (see Section 3.1.2) would not be environmentally significant in itself, although it would be noticeable in a rural or residential area (New York State DEC 2011 PR p6-308).

Other research

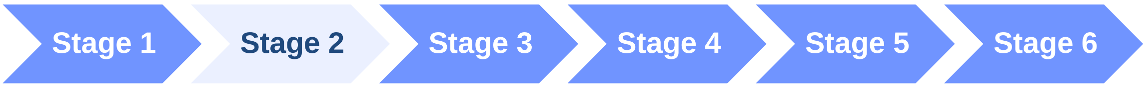
Broderick et al (2011 NPR) state that the data for New York combined with data in relation to exploratory drilling in the UK "*…suggests a total number of truck visits of 7,000-11,000 for* *the construction of a single ten well pad ... Local traffic impacts for construction of multiple pads in a locality are, clearly, likely to be significant, particularly in a densely populated nation…"*

Judgment

It is judged that the number of vehicle movements associated with site preparation would be a small proportion of the numbers of vehicles likely to give rise to significant environmental or health impacts. On this basis, it is judged to represent a "slight" impact. The impacts include air emissions, noise and visual impact, as well as transport system effects such as infrastructure damage, congestion and effects on road safety during the period of site preparation.

If a number of well pads are developed in a given area, the potential for adverse effects would be more significant, as there would potentially be a sustained increase in numbers of goods vehicle movements in a local area. Potentially all traffic requiring access to shale gas development in Garrett and Allegany Counties could use Highway 68, followed by state highways and minor roads to reach the site access roads. While site construction traffic would represent a noticeable increase in traffic flows, no significant current traffic congestion issues have been identified in the relevant areas of Garrett and Allegany Counties at present (see Section 3.3.9). Transportation impacts associated with cumulative well pad development is considered to be a "slight" potential impact in view of the relatively low vehicle numbers and low traffic flows in the area shown in Figure 1. Any impact could be more severe on unsuitable roads.

3.2 Stage 2: Well design, drilling, casing and cementing



In this section, the options of sequential well drilling and simultaneous well drilling have been considered. Each well is likely to take up to two weeks to drill, and one or two wells may be drilled at a time at an individual well pad (Broderick et al 2011 NPR p28). If wells are drilled sequentially, it may take three to five months to complete drilling at a single well pad with six to ten well bores. If two wells are drilled simultaneously, the drilling process would take six to ten weeks to complete, but activity would be more intense during this period.

3.2.1 Groundwater contamination and other risks

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*minor*	*rare*	*low*
Cumulative effects of multiple installations	*minor*	*rare*	*low*

Peer-reviewed research

During the well construction and development phase there is a risk of subsurface groundwater contamination due to drilling muds, additives and naturally-occurring chemicals in well cuttings. New York State DEC (2011 PR p6-40) identifies these risks as:

- Turbidity (suspension of solids within the water supply) arising from aquifer penetration, which it notes is short term in nature. The report (p2-24) highlights an incident in which an operator caused turbidity in drinking water supplies during well construction as a result of a "non-routine incident" in which a drill bit became stuck in a partially drilled well;

- Flow of fluids into or from rock formations – discussed below for hydraulic fracturing
- Natural gas migration. New York State DEC 2011 PR cites the preceding GEIS (New York State 1992 PR) which observes that natural gas migration to water supplies poses a hazard because it is combustible and an asphyxiant. It notes that whilst the impact may manifest itself during the production phase, the root cause lies in well construction integrity. Good construction practices can help to mitigate this risk.

Hackbarth et al (2013 PR) suggested that technology advancements in fiber optics surveillance can be used to improve well integrity.

Other research

The EPA (2012a NPR p8) noted a potentially higher risk of methane migration with air drilling compared to drilling using liquid muds, and recommended further research in this area.

SEAB (2011a NPR page 19) noted that where there is a large depth separation between drinking water sources and the producing zone the chances of contamination reaching drinking water is remote in a properly constructed well.

A surfactant additive used in well drilling was found to be emerging from a spring and contaminating a watercourse in Pennsylvania in 2010 (Pennsylvania Fish & Boat Commission 2011 NPR). The source was identified as a shale gas well site situated above the spring discharge, at a distance of approximately 2,000 feet. The surfactant was pumped into the well during the drilling process and was then flushed laterally through the underground rock strata by heavy rain runoff.

Local Context

In western Allegany County, it is possible that borehole completion may be closer to the surface due to the presence of the Marcellus Shale at shallower depths to the eastern boundary of the Appalachian Plateau Physiographic Province. This may result in cased zones being shorter or fewer in number. This may have a limited impact on the overall risk ranking but is unlikely to change the overall judgment for this development stage.

Judgment

Poor well construction can have important environmental consequences due to the effect that inadequate design or execution can have on the risks associated with hydraulic fracturing. These risks are described in more detail in section 3.3.1. The risk rating here is provided for risks occurring during the well construction and development phase.

The causes of groundwater contamination associated with the well design, drilling, casing and cementing stage generally relate to the quality of the well structure. The risk of contamination would increase in situations where casings are of inadequate depth. As discussed in section 3.3.1, wellbore casings provide the primary line of defence against contamination of groundwater, and any loss of integrity from catastrophic failure of well casing to poor cement seals can lead to a contamination event. Poor casing quality can thus lead to pollution of groundwater during subsequent well development stages, such as hydraulic fracturing, flowback or gas production activities. Furthermore, the risks due to surface spills, discussed in section 3.2.2 would also apply for drilling wastes.

The risks from these activities would increase linearly with the number of wells and the time period over which the risk exposure arises. Any significant increase in groundwater pollution during this phase could potentially affect health in the event that members of the public were exposed to pollution in drinking water.

The risks to groundwater posed by well construction for HVHF during the well construction stage are similar to those posed by well construction for conventional natural gas extraction. In view of the limited extent of potential effects and the established issues under consideration, impacts are considered to be of “minor” potential significance. In view of the limited number of incidents associated with the drilling and casing stage of the process in the peer reviewed and other literature, the frequency was considered to be "rare" for both individual facilities and cumulative impacts. It is also important to achieve a high standard of well integrity to ensure impacts are properly controlled during subsequent stages in the process, as discussed in Sections 3.3, 3.4 and 3.5 below.

3.2.2 Surface water contamination risks

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*moderate*	*rare*	*moderate*
Cumulative effects of multiple installations	*moderate*	*rare*	*moderate*

Peer-reviewed research

Natural gas well drilling operations use compressed air or muds during the drilling process as the drilling fluid. Compressed air may be used for vertical wells, and horizontal wells are normally drilled with muds (New York State DEC 2011 PR p5-32). The quantities of muds involved are likely to be greater for a horizontal shale gas well than for a conventional vertical well of similar depth, although the quantities would not be unusual in the context of wells encountered in the oil and gas extraction industry. USEPA (2011a PR) states that "*drilling muds are known to contain a wide variety of chemicals that might impact drinking water resources. This concern is not unique to hydraulic fracturing and may be important for oil and gas drilling in general.*"

Wells also produce cuttings which need to be properly handled. For example, a vertical well with surface, intermediate and production casing drilled to a total depth of 7,000 feet produces approximately 154 cubic yards of cuttings, while a horizontally drilled well with the same casing program to the same target depth with an example 4,000 foot lateral section produces a total volume of approximately 217 cubic yards of cuttings (i.e., about 40% more). Hence, the 4,000 foot horizontal section is estimated to give rise to approximately 63 cubic yards of mud and cuttings. A multi-well site would produce approximately that volume of cuttings from each well (adapted from New York DEC 2011 PR p5-34).

During the drilling stage, contamination can arise as a result of failure to maintain stormwater controls (potentially leading to site-contaminated runoff), ineffective site management, inadequate surface and subsurface containment, poor casing construction or more generally well blowout or component failure events (New York State 2011 PR page 6-15). The greater intensity and duration of well pad activities for multiple shale gas wells increases the potential for accidental release if engineering controls are not sufficient. As well as management and engineering practices, these risks can be reduced by avoiding locating drilling fluids in primary or principal aquifer areas. Bamberger and Oswald (2012 PR) reported an incident of exposure to drilling chemicals which occurred during a blowout when liquids ran into a pasture and pond. Cows grazing in this area were reported as giving birth to stillborn calves, some with congenital defects.

Measurement of radioactivity of cuttings from the Marcellus Shale and Barnett Shale found that levels were not significantly elevated above background (New York State 2011 PR p5-34).

Other research

The US EPA (2012a NPR p4) highlights that horizontal wells would overall result in a lower volume of cuttings than vertical wells for development of a given area.

The Paleontological Research Institute (2011 NPR p5) also found that levels of radioactivity in cuttings were not significantly elevated above background, although the US EPA (2012a NPR p4 and p5) reports other data sets from the Marcellus Shale with higher levels of Naturally-Occurring Radioactive Material (NORM).

Local context

The extensive stream monitoring program currently being carried out by Maryland Department of Natural Resources would provide an indication of any potential water quality issues arising from well pad drilling, if continued throughout the development of shale gas resources (see Section 3.3.2).

Judgment

Exposure to materials with elevated radiological activity could potentially be of concern with regards to health. This would only take place in the event of failure of established control systems and procedures which are in place to address radiological risks.

It is important to ensure proper storage and disposal of cuttings. Established procedures are in place for management of waste from hydrocarbon extraction activity, for example, under the Mining Waste Directive (see Chapter 3). The introduction of wide scale shale gas extraction would result in a significant increase in the quantities of potentially contaminated material (some of which may have elevated radiological activity) requiring storage, handling, treatment and disposal.

There is no centralised database of information on spillages of muds during shale gas drilling activities, although it may be expected that any potentially significant incidents would be reported. Limited evidence was found that drilling fluids could have adverse effects on the environment (Bamberger and Oswald 2012 PR). A spillage of muds was described by Lechtenböhmer et al.(2011 NPR p27) as a "possible" source of water contamination. On the basis of one reported incident, the frequency was classified as "rare". In view of the potential significance of impacts of spillages on sensitive water resources, the risks were considered to be of "moderate" significance.

3.2.3 Release to air

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*minor*	*occasional*	*moderate*
Cumulative effects of multiple installations	*Moderate*	*Occasional*	*high*

Peer-reviewed research

As described in New York State DEC 2011 PR (page 6-114), drilling operations can lead to air emission from 1) combustion from diesel-powered plant on site; and 2) truck activities near the well pad. The overall impact of these is affected by the period over which the activities take place.

New York State DEC 2011 PR (page 6-105) identifies the primary pollutants as particulate matter (PM), NO_x, CO, VOCs and SO_2, and estimates, based on industry data, emissions for drilling, completion and production under flaring and venting scenarios. While there is a complex picture of diverse impacts and stages, the overall assessment of hazardous air pollutants shows greatest impacts associated with flaring of wet gas, production of wet gas and drilling in all scenarios. Wet gases from some fields have relatively high levels of higher molecular weight VOCs. In dry gas scenarios, drilling is the largest single emitting activity when pollutants are aggregated. These figures are indicative and New York State DEC 2011 PR should be examined for further details and also regarding the extensive modelling performed to calculate expected air quality impacts from potential developments.

The main issue of potential concern with regard to emissions to air during well drilling is the risk of emissions of diesel exhaust fumes from well drilling equipment (Howarth and Ingraffea, 2011 PR). Emissions from numerous well developments in a local area or wider region could also potentially have a significant effect on air quality. Diesel emissions are likely to be a contributory factor to winter ozone events observed in Texas, Wyoming and Ohio, which are believed to be due to interaction of oxides of nitrogen and non-methane hydrocarbon emissions from unconventional gas activities (Rappenglück et al. 2013 PR)

Other research

The period of well drilling is typically four weeks per well (Broderick et al 2011 NPR). Lechtenböhmer et al. (2011 NPR) concur that the main issue of potential concern with regard to emissions to air during well drilling is the risk of emissions of diesel exhaust fumes from well drilling equipment.

Other research also concludes that diesel emissions could be a contributory factor to winter ozone episodes in rural Wyoming and Ohio (Argetsinger, 2011 NPR ; University of Wyoming, 2012 NPR).

Judgment

The potential effects of emissions from diesel-powered plant would in principle be greater for HVHF than for conventional gas extraction because of the larger well volumes, as described in Section 3.2.2. Emissions from diesel-engined plant are well understood and emission regulations for stationary diesel engines are published in Title 40 Chapter I, Part 60 of the Code of Federal Regulations (CFR). In view of this, the emissions from individual installations are judged to be of “minor” significance. No significant adverse effects on health would be expected to arise from a properly designed and operated individual installation.

There is evidence of the cumulative effects of emissions to air from hydrocarbon facilities on environmental levels of ozone in Texas, Wyoming and Ohio, although no evidence was found for a significant impact of shale gas development on levels of ozone in Pennsylvania. However, the most recent air quality report published by the Pennsylvania Department of Environmental Protection was in 2009, and more recent data may provide a clearer indication as to whether there are any significant effects on ozone levels. In view of the relatively small scale of shale gas development in Maryland, and good baseline air quality in Garrett and Allegany Counties (see Section 3.4.3), the potential significance of these impacts was described as “moderate.” Exposure to elevated levels of ozone can have an adverse effect on respiratory health, and this impact was also considered to be potentially “moderate”.

Additionally, there is a risk of fugitive emissions to air in the event of an equipment fuel or oil spillage, but this risk would be common to any similar activity. There is no centralised database of information on such spillages during shale gas drilling activities. No evidence was found that fuel spillages pose a significant risk to air quality. It was judged that the potential effects of any intermittent spillage would not be significant in the overall context of gas extraction processes.

3.2.4 Biodiversity impacts

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*minor*	*rare*	*low*
Cumulative effects of multiple installations	*minor*	*rare*	*low*

Peer-reviewed research

Gas well drilling could potentially affect biodiversity primarily via noise and disturbance caused by the drilling process itself, together with associated vehicle movements and site operations. However, the evidence in relation to biodiversity impacts is that any impacts are associated with other stages of the well development process – e.g. via land-take at well pad construction stage (New York State 2011 PR p6-67). Consequently, the impacts at this stage are considered to be of “minor” significance.

Adequate handling, treatment and disposal of well drilling fluids as described in Section 3.2.2 is needed to avoid potentially significant impacts on biodiversity, and more data is needed to fully understand these effects (Entrekin et al., 2011 PR).

Other research

As discussed above, drilling at a multi-well pad could take place for up to 5 months (Broderick et al 2011 NPR p28) assuming wells are drilled sequentially.

Judgment

As noted in Section 3.1.4, there is no evidence in the peer-reviewed literature for effects of shale gas extraction on biodiversity, although informal publications and presentations provide plausible indications that adverse effects on biodiversity could occur due to activities other than well drilling. Well drilling could potentially cause local disturbance as described in Section 3.2.5 below, but would not give rise to concerns related to wider scale effects associated with other aspects of shale gas extraction. On this basis, it is judged that there is a minor potential for cumulative impacts on biodiversity associated with well drilling at multiple well pad installations.

3.2.5 Noise

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*Minor*	*Occasional*	*Moderate*
Cumulative effects of multiple installations	*Minor*	*Short-term definite*	*Moderate*

Peer reviewed research

New York State DEC (2011 PR p6-289 to 6-297) indicates that well drilling is one of the more significant sources of noise, other than during the fracturing process itself. This would also need to be seen in the context of ongoing noise from sources including well pad construction, hydraulic fracturing and road traffic.

Fry (2013 PR) noted that noise, vibration and traffic are among the most noticeable impacts during this stage of development.

Other research

The process lasts up to 4 weeks per well (Broderick et al 2011 NPR table 2.5), but drilling is continuous for 24 hours per day over this time. Broderick et al consider that drilling is the stage of greatest continuous noise pollution. Furthermore, if a number of wells are developed on a single pad, this would extend the period that this impact takes place to up to five months.

Judgment

The levels of noise identified by New York State DEC (2011 PR) would not exceed the State daytime limit of 65 dBA at residential properties located 500 feet or more from well drilling. The night-time noise limit of 55 dBA could be exceeded at distances up to 1,000 feet from the well pad. If two wells are drilled simultaneously at a well pad, this could result in a doubling of the noise source, with a resultant increase in noise level experienced in the local area by up to 3 dB(A). Because of the sensitivity of the human ear to sound, an increase of 3 dB(A) would be detectable, but would not be perceived as a doubling of sound level. With this increase, the noise levels would continue to be less significant, although longer lived, than those associated with the hydraulic fracturing process.

Effective noise abatement controls are well established in the oil and gas industry (New York State DEC 2011 PR p6-289 to 6-297). Noise impacts could be controlled via appropriate site location and other mitigation measures to avoid significant impacts for members of the public.

Noise from well drilling could potentially affect residential amenity and wildlife, particularly in sensitive areas. Noise impacts over the shale gas pre-production stages are discussed in section 3.3.7 and highlight that whilst construction and drilling noise levels can be significant, they are lower than for the hydraulic fracturing stage itself.

The levels of noise during drilling forecast by New York State DEC (2011 PR p6-289 to 6-300) could be controlled to avoid risks to health for members of the public. Site operatives and visitors may need additional controls to ensure that no adverse effects on health occur due to noise during this stage.

If a number of well pads are developed in a given area close to sensitive residential areas or habitats, the potential for adverse effects would be more significant, as there would potentially be a sustained increase in noise levels for an extended period. A typical separation of 1 mile between well pads would provide significant attenuation of cumulative noise impacts. In view of the achievability of compliance with Maryland state noise standards and separation between wellpads, cumulative impacts were judged to be of “minor” significance, but to be of periodic (i.e. short term definite) probability.

3.2.6 Visual impact

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*Minor*	*Occasional*	*Moderate*
Cumulative effects of multiple installations	*Moderate*	*Short-term definite*	*High*

Peer-reviewed research

The use of well drilling rigs could potentially result in adverse visual intrusion over the approximately 4 week period of well drilling, particularly in sensitive areas of high landscape value, or in close proximity to residential areas (New York State DEC (2011) PR section 6.9.2.2).

Meng (2013 PR) describes mountain top sites as resembling small towns, with the mountain top being clear cut, paved with gravel and inhabited by dozens of trucks bulldozers and storage containers during the drilling and hydraulic fracturing stages.

Other research

An example drilling rig is shown as the highest vertical feature in Figure 4.

Figure 6: Drilling rig used in well excavation, Eagle Ford Shale, Texas

Local context

Garrett County and Allegany County Comprehensive plans highlight the importance of concentrating development in suitable areas, and ensuring sensitive areas are protected (see Section 3.1.6).

Judgment

The plant and equipment required for well drilling would typically be visible in the surrounding area, unfamiliar to local populations, and would represent a new industrial feature in a particular landscape. Individual wellpads would be separated by approximately 1 mile. Furthermore, the development of a number of wells on a single pad would extend the period that this impact takes place. Such development would not be in accordance with the State of Maryland “Visions for Future Development,” and this would be particularly acute in the high-value natural landscapes of Garrett and Allegany Counties. In view of the limited duration associated with drilling at individual well pads, this impact is judged to be of “minor” significance.

These features are likely to proceed sequentially as the Marcellus Shale gas field is developed in Maryland. The sequential development of well pads 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. Consequently, development of a shale gas play could affect a landscape over a longer period. Cumulative impacts were therefore judged to be potentially of “moderate” significance.

3.2.7 Traffic

Risk Characterization	Hazard classification	Probability classification	Risk ranking

Individual installation	*slight*	*short term definite*	*Low*
Cumulative effects of multiple installations	*Slight*	*long term definite*	*Moderate*

Peer-reviewed research

New York State DEC (2011 PR Table 6.60) indicates that the total number of truck movements during well drilling is likely to be approximately 515 one-way trips per well, or about 26% of the total truck movements. This suggests approximately 5,000 truck movements for the development of a 10 well pad. This number of movements over a pad construction period of approximately three to five months would not be environmentally significant in itself, although it would be noticeable in a rural or residential area (New York State DEC 2011 PR p6-308). Fry (2013 PR) noted that noise, vibration and traffic are among the most noticeable impacts during this stage of development.

Other research

Broderick et al (2011 NPR) state that the data for New York combined with data in relation to exploratory drilling in the UK "*…suggests a total number of truck visits of 7,000-11,000 for the construction of a single ten well pad ... Local traffic impacts for construction of multiple pads in a locality are, clearly, likely to be significant, particularly in a densely populated nation…*"

Judgment

The number of heavy vehicle movements may be approximately 60 movements per day (New York State DEC 2011 PR).

It is judged that this number of vehicle movements associated with drilling would be a small proportion of the numbers of vehicles likely to give rise to significant environmental or health impacts. On this basis, it is judged to represent a "slight" impact. The impacts include air emissions, noise and visual impact, as well as transport system effects such as infrastructure damage, congestion and effects on road safety during the period of site preparation.

If a number of well pads are developed in a given area, the potential for adverse effects would be more significant, as there would potentially be a sustained increase in numbers of goods vehicle movements in a local area. Following the approach adopted in Section 3.1.7, in the context of Garrett and Allegany Counties, it is judged that the cumulative traffic impacts may be considered a "slight" potential impact.

3.3 Stage 3: Technical Hydraulic Fracturing

<u>Constituents of fracturing fluid</u>

Peer reviewed research

Many chemicals have been used across the hydraulic fracturing industry. However, only a small number of chemicals are used in an individual fracturing operation – typically 6 – 12 chemicals, depending on the nature of the fluid used (King, 2012 PR).

Other research

The constituents of hydraulic fracturing fluids are examined in USEPA (2011a PR page 30), although it states this list to be incomplete given the lack of information regarding the frequency, quantity and concentration of chemicals used. It identifies a research activity to gather additional data on hydraulic fracturing fluid composition, although acknowledges that this information may be seen as commercially confidential by the companies using the fluids. USEPA (2011a PR page 31) sets out a program to examine the chemical, physical and toxicological properties of these chemicals, citing the US House of Representatives Committee on Energy and Commerce (2011 NPR) which identified 2,500 hydraulic fracturing products containing 750 chemicals in use between 2005 and 2009 in the US. These included 29 chemicals that were known human carcinogens, regulated under safe drinking water legislation or listed as hazardous air pollutants under clean air legislation.

SEAB (2011a NPR page 23) examines the issue of composition of fracturing liquids and notes that some US States have adopted disclosure regulations for chemicals added to fracturing liquids, as well as there being (as of August 2011) Federal interest in this issue.

3.3.1 Risks of groundwater contamination

Leakage via wellbore or induced fractures

Garrett County

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installations (more than 2,000 feet separation between fracturing zone and groundwater)	*moderate*	*Rare*	*moderate*
Individual installation (less than 2,000 feet separation between fracturing zone and groundwater)	*moderate*	*Rare*	*Moderate*
Cumulative effects of multiple installations	*moderate*	*Occasional*	*High*

Western Allegany County (especially close to eastern boundary of exploration zone shown in Figure 1)

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installations (more than 2,000 feet separation between fracturing zone and groundwater)	*moderate*	*Rare*	*moderate*
Individual installation (less than 2,000 feet separation between fracturing zone and groundwater)	*moderate*	*occasional*	*high*
Cumulative effects of multiple installations	*moderate*	*occasional*	*high*

Peer-reviewed research

Considerable measures are taken during hydraulic fracturing to prevent leakage of the fracturing liquid into the groundwater due to inadequacies in the well casing or due to the extension of induced fractures into zones which could potentially result in movement of contaminants to groundwater. Hydraulic fracturing can also affect the mobility of naturally occurring substances in the subsurface, particularly in the hydrocarbon-containing formation (EPA 2011a PR). The substances of potential concern include the chemical additives in hydraulic fracturing fluid, produced water, gases, trace-elements, naturally occurring radioactive material and organic material. Some of these substances may be liberated from the formation via complex biogeochemical reactions with chemical additives found in fracturing fluid (Falk et al., 2006 PR ; Long and Angino, 1982 PR quoted in EPA 2011a PR). If fractures extend beyond the target formation and reach aquifers, or if the casing around a wellbore is inadequate in extent or fails under the pressure exerted during hydraulic fracturing, contaminants could potentially migrate into drinking water supplies.

Recent evidence indicates that a separation of the order of 2,000 feet would result in a remote risk of properly injected fluid resulting in contamination of potable groundwater (Davies et al., 2012 PR). Similar data are reported by Fisher and Warpinski (2012 PR Figure 2), indicating a maximum vertical fracture extent of approximately 2,000 feet. Another recent study finds evidence however that in particular locations methane and fugitive gases from deep geological layers can migrate upwards into shallow strata through natural pathways (Warner et al. (2012) PR). This indicates a need for systematic processes to characterise the geology to enable any such migration risks to be understood and taken into account in the site selection and design process. This study followed on from a study of methane contamination in aquifers overlying the Marcellus and Utica shale formations of north-eastern Pennsylvania and upstate New York (Osborn et al. 2011 PR) which is discussed in Section 3.5.1. No evidence for contamination of drinking-water samples with deep saline brines or fracturing fluids was found by Osborn et al.

The analysis carried out by Fisher and Warpinski indicated that fracturing carried out close to the surface tended towards the formation of horizontal fracturing, which would reduce (although not eliminate) the risk of fractures interacting with water resources in shallower shale gas formations.

The lack of baseline monitoring carried out in the US prior to shale gas development may partly explain why the evidence of contamination associated with shale gas extraction is complex and uncertain.

Other research

SEAB (2011a NPR page 28) states, in the context of the potential effects of methane contamination, *"leakage to water reservoirs is widely believed to be due to poor well completion, especially poor casing and cementing….. there need to be multiple engineered barriers to prevent communication between hydrocarbons and potable aquifers. In addition, the casing program needs to be designed to optimize the potential success of cementing operations. Poorly cemented cased wells offer pathways for leakage; properly cemented and cased wells do not."* In this context, the term "reservoirs" refers to underground aquifers.

SEAB (2011a NPR , p19) highlights that regulators and geophysical experts agree that the likelihood of properly injected fracturing liquid or naturally occurring contaminants reaching underground sources of drinking water through fractures is remote where there is a large depth separation between drinking water sources and the producing zone. According to SEAB, this view is confirmed by the existence of few, if any, documented examples of such migration. The SEAB does not specify what a "large depth" would constitute.

In contrast, where there is no such large depth separation, nor cap rock between the aquifer and the gas play, the risks are greater. At one such site setting (Pavillion, Wyoming), hydraulic fracturing occurred in gas production wells at a depth as shallow as 1,220 feet below ground surface (EPA, 2011c NPR (draft)). Overlying the gas field, there is an aquifer in a formation where water wells are excavated to depths of 50 to 750 feet or more. These wells are the principal source of domestic, municipal and agricultural water in the area of Pavillion. Groundwater contamination has been found in this area. The US EPA (2011c NPR) draft report concluded that the data indicate likely impact to ground water which can be explained by hydraulic fracturing. The USEPA's draft report concluded that the observed contamination was linked to inadequate vertical well casing lengths and a lack of well integrity (USEPA 2011c NPR p37, p38). However, the initial sampling will need to be completed in a next phase of testing. (Wyoming State Governor; the Northern Arapaho and Eastern Shoshone Tribes, and US EPA Administrator, 3 March 2012 NPR).

The geological setting at Pavillion is unique in the US, and fracturing was carried out directly from vertical wells, whereas fracturing which is the focus of this study is carried out from the horizontal section of wells.

Broderick et al (2011 NPR page 81) notes that once installed, wellbore casings provide the primary line of defence against contamination of groundwater, and states that any loss of integrity from catastrophic failure of well casing to poor cement seals can lead to a contamination event. It notes, however, that loss of casing integrity events would require physical failure of both steel casing and cement. In this respect Broderick et al (2011 NPR pages 81 and 82) emphasise the role of high quality cementing as protection against contamination.

The US EPA (2011a PR p35) highlights the potential impacts on well integrity of multiple-stage fracturing processes and of repeated fracturing of a well over its lifetime. As discussed in Section 2.3, it is assumed that hydraulic fracturing may be repeated up to four times during the operational lifetime of a well to maintain the flow of hydrocarbons to the well. The EPA indicates that the potential effects of repeated hydraulic fracturing treatments on well construction components (e.g., casing and cement) are not well understood. This is an area where additional information is needed to draw firm conclusions with regard to potential impacts, and is highlighted as an issue of high potential significance.

Local Context

In western Allegany County, it is possible that borehole completion may be closer to the surface due to the presence of the Marcellus Shale at shallower depths to the eastern boundary of the Appalachian Plateaus Physiographic Province. This has the potential to impact the overall risk ranking where multiple installations are placed close to the eastern boundary of the exploration zone. This would change the overall judgement in a restricted area close to the boundary if development occurred as the separation between the fracturing zone and the groundwater could be significantly reduced.

Judgment

The issue of groundwater contamination as a result of the technical hydraulic fracturing stage will be highly site specific and can be to a degree mitigated through site selection processes as mentioned above. Measures may include limiting extraction to shale gas formations at significant depth and ensuring the presence of low permeable geological strata between the producing zone and aquifers in use as a source of drinking water. Furthermore, there is little information on the potential impacts on well integrity of repeated fracturing of a well over its lifetime.

In view of the currently available evidence that there have been few past incidents of contamination which were associated with practices which would not be carried out under HVHF and the controls which are now well established in the industry, it is judged that the frequency of incidents of groundwater contamination during hydraulic fracturing due to wellbore leakage is rare. The frequency would increase when considering drilling across the area shown in Figure 1, where the drilling of several hundred wells may be envisaged (see Section 1.2).

It is judged that the magnitude of a contamination event is no more than “moderate,” defined as “a localized environmental effect." Because of the low likelihood of contamination events taking place on adjacent wells, it is judged that the magnitude of cumulative impacts would be unchanged compared to the magnitude for individual events with more than 2,000 feet separation between the fracturing zone and groundwater. For individual sites with less than 2,000 feet separation between the fracturing zone and groundwater, the risk was judged "high".

For the zone close the eastern exploration boundary from Figure 1, it is judged that the likelihood of contamination events for cumulative installations should increase to "occasional". This is because boreholes in this area could be significantly less than 2,000 feet. The result is that the overall risk ranking would increase to "high".

Migration through faults and pre-existing manmade structures

Garrett County

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installations (more than 2,000 feet separation between fracturing zone and groundwater)	*moderate*	*rare*	*moderate*
Individual installation (less than 2,000 feet separation between fracturing zone and groundwater)	*moderate*	*occasional*	*high*
Cumulative effects of multiple installations	*moderate*	*occasional*	*high*

Western Allegany County (especially close to eastern boundary of exploration zone shown in Figure 1)

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installations (more than 2,000 feet separation between fracturing zone and groundwater)	*moderate*	*Rare*	*moderate*
Individual installation (less than 2,000 feet separation between fracturing zone and groundwater)	*moderate*	*occasional*	*high*
Cumulative effects of multiple installations	*moderate*	*occasional*	*high*

Peer-reviewed research

As discussed above, the potential exists in principle for the fugitive gases, chemical additives in the fracturing liquid or the liberated, naturally occurring substances to reach underground sources of drinking water raises concerns over the risks to human health. This could potentially occur, for example, if extended fractures are linked to aquifers via faults or pre-existing manmade structures.

Recent evidence discussed above indicates that in most cases a separation of the order of 2,000 feet would result in a remote risk of properly injected fluid resulting in contamination of potable groundwater, though site-specific geological circumstances would need to be considered. Besides leakage through artificial pathways, Warner et al (2012 PR) show that there is also a possibility of leakage of fluids or gases through natural geological structures, cracks, fissures or interconnected pore spaces.

Other research

Research indicated that predicted and actual fracture lengths often differ (Daneshy, 2003 NPR ; Warpinski et al. 1998 NPR , quoted in EPA 2011a PR ; Damjanac et al, 2010 NPR).

Due to this uncertainty in fracture location, fracturing may lead to fractures intersecting local geologic or man-made features, potentially creating subsurface pathways that allow fluids or gases to contaminate drinking water resources. These may include fault zones, underground voids or cave systems in limestone formations or abandoned mines or boreholes.

Broderick et al (2011 NPR page 81) identified common subsurface pathways as the outside of the wellbore itself, incomplete or plugged wellbores from abandoned wells, fractures and other natural cracks, fissures and interconnected pore spaces. As described above, Broderick et al (2011 NPR pages 81 and 82) emphasise the role of high quality cementing as protection against contamination.

Local Context

The Western Maryland Gas Field which produces gas from the Oriskany Sandstone that underlies the Marcellus Shale is located in Garrett County. This is within the zone of potential exploration and thus there will be a number of existing boreholes to significant depth that will have been completed through the Marcellus Shale. Closed or producing wells may provide pathways to surface if the seal between casing and the borehole wall fails.

In western Allegany County, it is possible that borehole completion may be closer to the surface due to the presence of the Marcellus Shale at shallower depths to the eastern boundary of the Appalachian Plateaus Physiographic Province. This has the potential to impact the overall risk ranking where multiple installations are placed close to the eastern boundary of the exploration zone. This would change the overall judgement in a restricted area close to the boundary if development occurred as the separation between the fracturing zone and the groundwater is significantly reduced.

Judgment

Control measures may include preliminary surveys to ensure the absence of natural pathways in the geological strata). The potential also exists for pre-existing manmade structures (e.g. abandoned oil and gas wells) in the vicinity of injection zones or wells to serve as conduits increasing the reach of contaminated groundwater. The existence of abandoned wells is a significant issue in the US, where oil and gas extraction has proceeded for decades. The existence and location of many of these wells is not recorded.

Based on the examined literature, there appears to be no identified records of incidents of contamination due to hydraulic fracturing linked to faults and pre-existing manmade structures. It is judged that the frequency of incidents of groundwater contamination during hydraulic fracturing via this pathway would be rare when there is more than 2,000 feet of separation between the fracturing zone and groundwater, and could be reduced further by the specification of appropriate minimum separation distances such as currently exist via COMAR 26.19.01.09. However, if development occurred close to the Western Maryland Gas Field the frequency of incidents could increase to “occasional” where existing wells provide pathways to the near-surface aquifers.

The evidence from other stages in the process and via other pathways is that contamination is likely to be limited to the immediate vicinity of the relevant wells. In view of this, it is judged that the magnitude of a contamination event is no more than “moderate,” defined as “a localized environmental effect.” Because of the low likelihood of contamination events taking place on adjacent wells, it is judged that the magnitude of cumulative impacts would be unchanged compared to the magnitude for individual events. For individual installations with less than 2,000 feet separation between the fracturing zone and groundwater, the risk was judged to be "high".

For the zone close the eastern exploration boundary from Figure 1, it is judged that the likelihood of contamination events should increase for cumulative installations to “occasional” as it cannot be less than that for individual installations. This is because all boreholes could be significantly less than 1969 feet. The result is that the overall risk ranking would increase to “high”.

A similar issue may occur if development occurred close to the existing Western Maryland Gas Field. Thus for cumulative effects for multiple installations in Garrett County the overall risk ranking has been increased to “high” to reflect the local conditions

Accidental surface spills

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*moderate*	*not classifiable*	*not classifiable*
Cumulative effects of multiple installations	*Moderate*	*not classifiable*	*not classifiable*

A further aspect of groundwater contamination during hydraulic fracturing is that related to accidental spills and leakages. Section 3.3.2 sets out the potential sources of spillages during hydraulic fracturing.

Peer-reviewed research

New York State DEC (2011 PR p6-15) highlights the risks to subsurface soils and aquifers via this pathway.

Other research

Broderick et al (2011 NPR page 81) highlight the key factors affecting the potential severity of groundwater contamination, citing the significance of the aquifer for abstraction; the extent and nature of contamination; the concentration of hazardous substances; and connection between groundwater and surface waters. US EPA (2011a PR p28) highlights the risk of contamination of soil and near-surface aquifer via this pathway, and has focused further research in this area. The Department of Energy SEAB (2011a NPR p19-20) also highlights the risks to subsurface soils and aquifers via this pathway.

Judgment

The potential significance of impacts posed by a single well pad is considered likely to be localized in nature but with potential for transport away from the site. Taking the issues outlined above into consideration, this impact is judged to be potentially of “moderate” significance.

Multiple development would pose risks of more widespread contamination if not properly managed. However, in view of the relatively small scale of potential operations in Maryland, and the low risk of multiple surface spills affecting a single area, the cumulative impact is also judged to be of “moderate” significance.

No information was identified on the frequency of liquid spillage, and it was therefore not possible to classify the frequency of risks to groundwater posed by spillages.

3.3.2 Risks of surface water contamination

The relevant issues are:

- Accidental spillage of fracturing fluid and other fluids at the surface;
- Wellbore leakage; and
- Accidental surface spills due to vehicle accidents (see Section 3.3.9)

Accidental spillage at the surface

Risk Characterization	Hazard classification	Probability classification	Risk ranking

Individual installation	*Minor*	*occasional*	*Moderate*
Cumulative effects of multiple installations	*major*	*Occasional*	*High*

Peer-reviewed research

New York State DEC 2011 PR (page 6-15) identifies that the amount of fracturing liquid used is considerably greater for horizontal drilling compared with more conventional vertical drilling. Typically, 300,000 to 600,000 gallons of fracturing fluid are used for a vertical well (New York State 2011 PR p3-6). Horizontal drilling involves the fracturing of multiple stages, each of which can be expected to use a similar volume of fluid. The New York State DEC adopts a definition of high-volume hydraulic fracturing as that involving the use of 300,000 gallons of fracturing fluid per well or more.

New York State 2011 PR p6-15 quotes an analysis carried out by the state which indicates that the proposed additives for high volume horizontal drilling are similar to those used for vertical drilling. It therefore concludes that the risks (from spillage) are proportionally higher for horizontal drilling, although notes previous work (New York State 1992 GEIS PR) that there are no qualitatively different exposure situations for horizontal drilling.

New York State DEC 2011 PR (page 6-15) highlights that other spillage events could arise from tank ruptures, piping failures, equipment or surface impoundment failures, overfills, vandalism, accidents, fires, drilling and production equipment defects or improper operations. It expands on the causes and management practices related to these:

- The causes and modes of release events are similar for hydraulic fracturing additives as for drilling fluids. Contamination can arise as a result of failure to maintain stormwater controls, ineffective site management, inadequate surface and subsurface containment, poor casing construction or more generally well blowout or component failure events. Risks can be reduced by siting hydraulic fracturing fluids away from primary or principal aquifer areas. The risk is increased under high-volume hydraulic fracturing because of the larger fluid volumes.
- Leaks and spills of flowback water could also pose environmental or human health risks. The potential causes of releases are similar to those for the primary injection fluid, with the added risks associated with flowback water containment and processing equipment, including hoses or pipes to convey flowback water to tanks and trucks or leakage from those vessels. Flowback water will include fracking liquid additives as well as constituents from the local environment and well equipment. Produced water from wet shales could include dissolved solids, metals, biocides, lubricants, organics and naturally occurring radioactive materials and degradation products.

The risks due to leakages and spills of chemicals used in the fracturing process were highlighted by Carter et al (2013 PR), suggesting that such incidents could contaminate the site, soil, shallow aquifers and surface waters near the site.. Bamberger and Oswald (2012 PR) identified two incidents in which livestock (cows and goats) was harmed as a result of accidental release of hydraulic fracturing chemicals. Eaton (2013 PR) refers to an analysis which indicated that, if chemical spillages were to occur at up to a dozen wells, this could threaten water in reservoirs in New York State. Eaton also highlighted the potential for impacts to arise due to numerous smaller-scale spillages. New York State DEC (2011 PR) also refers to the risks posed by truck accidents, although these risks are not quantified.

Centner (2013 PR) highlights the importance of disclosure of information on the chemicals used in fracturing fluids, to enable accurate and fast response to any leaks or spills. Operating companies are not currently required to disclose the chemical compounds used in the hydraulic fracturing process (Finkel and Hays 2013 PR). Chemical additives typically account for 1% – 2% of liquid volumes used (Eaton 2013), and typically include biocides and chemicals with potentially hazardous properties. These additives may potentially be harmful if discharged inappropriately resulting in exposure of humans or natural ecosystems.

Other research

DOE (2009 NPR p64) and BRGM (2011 NPR p59) confirm that typically 200,000 to 400,000 gallons of fracturing fluid may be used per well.

The frequency of spillage events is not well known. USEPA (2011a PR page 29) cites numerous media reports of spills but also points to a lack of robust data on the frequency or causes of such events. A key concern for accidental fluid release is the potential impact on surface waters as well as public water supplies. The risks of drinking water contamination from spills are affected by the processes for managing contaminated water and the actions taken to mitigate the effects of any spills or leakages. SEAB (2011a NPR page 20) states that additional measures are being taken by some operators and regulators to manage this risk, including the use of mats, catchments and groundwater monitors associated with the hydraulic fracturing installation, together with buffers around surface water resources. Whilst the specific measures may be considered site specific the principles and approaches to managing these risks may be treated as generic best practice.

Local context

Approximately 24% of residences in Garrett County receive drinking water from public systems (Garrett County Comprehensive Plan 2008). The Comprehensive Plan acknowledges the risks posed by the use of chemicals for hydraulic fracturing: "*In particular, the fluid by-products of the drilling process contain a number of contaminants. If not properly contained and disposed of, these fluids can pose threats to water quality and nearby habitat.*" The plan envisages that the County authorities will "*Work with MDE, SHA, other state agencies, and energy companies to monitor natural gas development activities to ensure the safety of the ground and surface water supplies, to protect sensitive environmental areas...*"

Communities in the Frostburg area are served by water from the Piney Reservoir, which is treated at a plant west of Frostburg. Outside this area, water supplies for residents of western Allegany County are taken from wells, springs and small surface reservoirs. Water supplies in the west of the county were considered to be adequate, with some improvements planned (Allegany County Comprehensive Plan 2002 and Water Resources Element Amendment 2010).

The Allegany County Water Resources Element 2010 Amendment indicates that water quality in Allegany County is not currently of concern with regard to the potential effects of contaminants on health (Table 12). However, some watercourses are of concern with regard to the potential effects of sediment, nutrients, phosphorus, or low pH on aquatic life and biodiversity.

The Maryland Department of Natural Resources is co-ordinating a comprehensive program of baseline water quality monitoring. This program includes a significant volunteer effort, with a co-ordinated training program to ensure high quality data on baseline water quality in Garrett and Allegany Counties (Prochaska, 2013 NPR). The program includes continuous monitoring of conductivity and temperature in streams at approximately 90 sites. The sites were selected on the basis of options taken out by minerals exploitation companies to be the locations most likely to be affected by shale gas development, if this should proceed. The baseline monitoring program has been able to establish stable baseline levels for conductivity at many locations: the key influences on conductivity at this stage appears to be: (a) flow rate; (b) the presence or otherwise of roads which are salted during the winter months; (c) recent rainfall which can either increase dilution or bring an additional flow of accumulated saline run-off.

In addition to the continuous monitoring program, measurements of a wider range of parameters are carried out on a periodic basis at 13 conductivity logger stations and 6 intensive monitoring sites. The parameters measured at these locations comprise:

Alkalinity	Magnesium	Strontium	Aluminum
Manganese	Sulfate	Barium	Nitrate
TDS	Bromide	Nitrite	Temperature
Calcium	Orthophosphate	TSS	Chloride
pH	Turbidity	Conductivity	Potassium
DO	Selenium	Iron	Sodium
Methane	Methane isotope	Surfactants	Gross alpha/beta
Golden algae	PAHs (48 individual species)		

This monitoring program has been carried out by DNR without specific additional funding. The DNR intends to continue this program during any development of shale gas resources in Maryland, following the Before/After/Control/Impact (BACI) Model. Implementation of this monitoring program would require the department to make resources available, not just to develop/adapt the monitoring network, but also to enable data to be logged and evaluated. While the baseline survey demonstrates that a cost-effective program of monitoring at approximately 100 sites is feasible, at present, there is no guarantee that support would be available for such a program to continue in an effective manner, should shale gas development proceed.

Judgment

A spillage at a single well pad or a vehicle accident could potentially affect surface water at some distance away from the site. There is significant evidence that spillages of chemicals have given rise to occasional issues for surface water quality. A proportion of properties in Garrett and Allegany Counties obtain drinking water from local wells and reservoirs, without the benefit of public water treatment systems. Taking the issues outlined above into consideration, this impact is judged to be potentially of “minor” significance – i.e. a risk of exceeding a water quality guideline in the near vicinity of an incident.

Multiple development of wellpads at approximately 1 mile separation would pose more significant risks due to the number of activities being undertaken, which is considered to be potentially of “major” significance.

The existence of reported spillages indicates that the frequency of occurrence should be considered “occasional” although improved data would be useful in this regard. The likelihood of cumulative impacts is judged to be “rare” because it is less likely that multiple events would affect one surface water body: reported incidents refer to single events only.

Wellbore leakage

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*moderate*	*rare*	*moderate*
Cumulative effects of multiple installations	*major*	*rare*	*moderate*

Peer-reviewed research

A common concern with hydraulic fracturing is leakage of the fracturing liquid through fractures into the groundwater (as discussed in Section 3.3.1 above) and ultimately into drinking water. The key issues are set out in Section 3.3.1.

Other research

None reviewed

Judgment

Wellbore leakage at a single well pad could potentially affect surface water at some distance away from the site. This impact is judged to be potentially of “moderate” significance.

Multiple development of wellpads at approximately 1 mile separation could pose a more significant and widespread risk to surface waters, which is considered to be potentially of “major” significance.

The absence of reports of surface water contamination due to wellbore leakage during technical hydraulic fracturing indicates that the frequency of occurrence should be considered “rare” although improved data would be useful in this regard. The likelihood of cumulative impacts is also judged to be “rare” because it is unlikely that multiple events would affect one surface water body.

3.3.3 Water resource depletion

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*Slight*	*occasional*	*Low*
Cumulative effects of multiple installations	*moderate*	*occasional*	*High*

Peer-reviewed research

The hydraulic fracturing process is water intensive and abstraction impacts can be significant. Water demand issues were highlighted by Eaton (2013) as one of the key issues for hydraulic fracturing of the Marcellus Shale in New York State. There is also a need at land surface for effective management and safe disposal of the millions of gallons of water and additives (sand and chemicals) needed per well for hydro-fracturing.

Jenner and Lamadrid (2013) indicate that total water use per Marcellus Shale well is 3,880,000 gallons. In the broader context, however, New York State DEC 2011 PR (page 6-9) notes that water abstraction from conventional oil and gas drilling is a very small percentage of overall water withdrawal, and the contribution of gas extraction 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; New York State DEC 2011 PR p6-12. Kharaka et al (2013 PR) estimated that the total water used for drilling and fracturing shale gas wells is 0.06% of available water for the Marcellus Shale.

However, New York State DEC also points out that there is potential for adverse effects when water withdrawals occur on low flow or drought conditions or in unsustainable locations New York State DEC 2011 PR (page 6-10).

Jenner and Lamadrid (2013) comment that it is more cost effective to re-use the flow back water used in the hydraulic fracturing process than to clean up to the levels necessary for surface discharge. 80% of the flow back water can be cleaned using reverse osmosis and advanced membranes: however, this process is very energy intensive, and therefore not widely used. Hackbarth et al (2013 PR) found that the use of shear stimulation can reduce water resource requirements compared to current practice.

A proportion (25% to 100%) of the water used in hydraulic fracturing is not recovered, and consequently this water is lost permanently to re-use, which differs from some other water uses in which water can be recovered and processed for re-use. The potential impacts described cover:

- 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 affects 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.
- An 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

New York State DEC 2011 PR (page 6-9) considers the potential volume of abstraction in New York and states this to be unknown due to uncertainty in the number of wells that could be operated. This highlights that the overall cumulative impact from hydraulic fracturing is as much determined by the local density of well sites as the characteristics of the fracking process itself. As an example of the figures involved, New York State DEC 2011 PR (page 6-10) reports that between July 2008 and February 2011, average water usage for high-volume hydraulic fracturing within the Susquehanna River Basin in Pennsylvania was 4.2 million gallons per well based on data for 553 wells.

The quantity of water withdrawn is influenced by the re-use of flowback water from previous fracturing operations, which New York State DEC 2011 PR (page 6-10) estimated to typically account for 10%-20% of the injected fracturing fluids. Recent estimates indicate recycling of approximately 77% of wastewater in the second half of 2011 in Pennsylvania, compared to 10% two years previously (Yoxtheimer, 2012 PR), although there is uncertainty over the typical rate of recycling in the US, which may be significantly lower.

Yoxtheimer (2012 PR) described how many of the challenges associated with processing the flowback for re-use have been overcome, in particular by the introduction of friction reducers which permit the re-use of high salinity water.

Other research

The evaluation of potential impacts is supported by Broderick et al (2011 NPR page 90). This study highlighted that local effects could be much more significant and areas already under the strain of water scarcity may be affected especially as longer term climate change impacts of water supply and demand are taken into account.

USEPA (2011a PR pages 25 and 27) cites similar impacts. In highlighting the potential of diversion of drinking water supplies, it references stakeholder concerns regarding high volume withdrawals from small streams in the headwaters of watersheds supplying drinking water in the Marcellus Shale area. This impact on the drinking water system can lead to the need for engineering solutions for reduced aquifer levels – for example lowering of pumps or deepening of wells as required in the area of the Haynesville Shale. Further consequences of reduced water levels mentioned include:

- 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.
- upwelling of lower quality water or other substances (e.g. methane – shallow deposits) from deeper and subsidence or destabilization of geology

Following recent low rainfall, water withdrawal permits for shale gas well development in the Susquehanna River Basin in Pennsylvania have been temporarily suspended (SRBC, 2012b NPR). This substantiates the concerns expressed by New York State DEC (2011 PR).

The water abstraction volumes identified by New York State DEC (2011 PR) are consistent with the range of 1 to 5 million gallons per well cited in SEAB (2011a NPR p19). USEPA (2011a PR pages 22 and 25) cites similar figures.

USEPA (2011a PR page 23) estimates that 25-75% of the original fluid injected in the first two weeks after a fracture is recovered. Processing and re-use of flowback has improved substantially in recent years. Because of the incomplete fluid recovery, re-used fluid is typically blended with a similar volume of fresh water.

Local context

Public water supplies in Allegany County are provided by a number of surface water impoundments and runs, supplemented by 20 wells to a maximum known depth of 1354 feet (Allegany County Water Resources Element, 2010). The water supply is considered to be adequate for existing and future uses.

The 2008 Garrett County Comprehensive Plan indicates that water resources are adequate for future demands in most parts of the county, but a deficit is forecast for the Mountain Lake Park/Loch Lynn Heights and Grantsville areas by 2030. This could potentially pose a constraint to the development of shale gas resources in these areas. The Comprehensive Plan states: "*Development of Garrett County's potential natural gas resources (see Chapter 11) could have impacts on water supply and water quality. Natural gas mining techniques can involve considerable water consumption, and can produce wastewater that must be treated before being discharged*." The Comprehensive Plan goes on to state that: "*MDE is responsible for monitoring and enforcing environmental regulations related to natural gas drilling. The County—particularly the Health Department and Department of Planning and Land Development—should work with MDE to closely monitor such activity to ensure that it does not adversely impact water resources and sensitive environmental areas.*"

Judgment

Published research consistently finds that water use for hydraulic fracturing is significant, but manageable in the context of overall water resource use. The potential impact of a single site on water resources is judged to be "slight." The potential exists for impacts on water resource management if development within a water catchment is not properly managed, or in a situation of a water resource deficit such as that forecast in parts of Garrett County by 2030. This would require careful management to ensure that development takes place at an appropriate pace. If this management is not in place, development of multiple sites could pose a "moderate" risk to water resources in some areas. Any such impacts on stream water flows could potentially be detected by the Maryland DNR stream monitoring program, if this is continued throughout the development of shale gas resources (see Section 3.3.2). The frequency of these potential effects are judged to be "occasional," defined as "could potentially occur … if management or regulatory controls fall below best practice standards."

3.3.4 Release to air

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*minor*	*occasional*	*moderate*
Cumulative effects of multiple installations	*moderate*	*occasional*	*High*

Peer-reviewed research

As discussed in section3.2.3, New York State DEC 2011 PR (page 6-114) identifies the main sources of air emissions from drilling, completion and production activities and examines their relative significance. Sources of emissions include diesel fumes and truck activities near the well pad. Emitted substances include PM, NO_x, CO, VOCs and SO_2. Emissions of diesel fumes from fracturing fluid pumps were highlighted by Howarth and Ingraffea (2011 NPR).

Finkel and Hays (2013) highlight emissions to air of hydrocarbons such as benzene, toluene, and xylene from active wells. Residents living near active wells have complained of noxious odours emanating from the well pad area. However, Litovitz et al (2013 PR) calculated that the impacts of emissions to air during the production stage outweighed the impacts associated with hydraulic fracturing and completion, even during intensive well development of the Marcellus Shale in Pennsylvania in 2011.

Other research

The issues of potential concern with regard to emissions to air during hydraulic fracturing comprise the following:

- Emissions of diesel fumes from fracturing fluid pumps (Lechtenböhmer et al. 2011 NPR)
- On-site handling (by conveyor and blender) of proppant (sand) which can emit significant quantities of dust. Kellam (2012 NPR) reported that 0.25% (by weight) of proppant sand was emitted to the air as fine dust during fracturing fluid make up operations.

Judgment

As discussed in Section 3.2.3, impacts during hydraulic fracturing from individual sites are considered to be of “minor” significance, but the cumulative impact from multiple sites could potentially be of greater significance. The production stage is the major contributor to air pollution emissions and any regional air quality issues (Litovitz et al 2013 PR), and the cumulative impact from the technical hydraulic fracturing stage was judged to be “moderate”.

Additionally, there is a risk of fugitive emissions to air in the event of an equipment fuel or oil spillage, but this risk would be common to any similar activity and not significant in the overall context of gas extraction processes. There is no centralised database of information on such spillages during shale gas drilling activities. No evidence was found that fuel spillages pose a significant risk to air quality in the context of other sources of emissions to air. On this basis, the risks of fugitive emissions following a spillage were judged to be of minor significance.

3.3.5 Land take

Land is required for storage of hydraulic fracturing fluids and waste water, together with vehicle access, pipelines and associated plant and equipment. This is addressed in Section 3.1.3.

3.3.6 Biodiversity impacts

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*minor*	*rare*	*low*
Cumulative effects of multiple installations	*Major*	*rare*	*moderate*

On-site storage and transportation of water can affect biodiversity due to land take, disturbance and/or by the introduction of non-native invasive species. Land take is discussed in Section 3.1.4.

Peer-reviewed research

New York State DEC (2011 PR p6-3) cites the effect of shale gas exploitation activities on ecosystems and wildlife. The impacts will be strongly location dependent but general effects can be defined. These include fragmentation of habitat, potential transfer of invasive species and impacts on endangered or threatened species. Entrekin et al (2011 PR p8) describe the risks to wildlife posed by sediment runoff into streams, reductions in streamflow, contamination of streams from accidental spills, and inadequate treatment practices for recovered wastewaters as “realistic threats”.

Other research

The EPA (2012a NPR p9) highlighted a local issue linked to the introduction of algae into local water courses, resulting in major fish kills.

Three examples of uncontrolled release of fluids with actual or potential effects on biodiversity and agriculture are quoted by Michaels et al. (2011 NPR).

Judgment

The impact will be related to the footprint of the development sites, including the effects of access roads and utility services. These are discussed in section 3.1.3. In addition, contamination of local water sources and the effects of water depletion could all potentially harm local ecosystems. These potential effects are described in sections 3.3.1 and 3.3.3. The stream monitoring program currently being carried out by the DNR (see Section 3.3.2) would provide data on water quality and early warning of any impacts on water quality with implications for biodiversity, if this program continues throughout the use of hydraulic fracturing for shale gas development. At present, this program is anticipated to continue (Prochaska 2013 NPR), but this is not guaranteed. Impacts could also be associated with short-term but intensive disturbance, and potential for introduction of invasive species. It was judged that the impacts on biodiversity associated with hydraulic fracturing operations are likely to be limited to the vicinity of the site, supported by the conclusions of Entrekin et al. (2011 PR p8) and Nature Conservancy (2011 NPR).

As discussed in Section 3.1.4, Garrett and Allegany Counties contain significant areas of high biodiversity, including areas which provide habitats for many rare and endangered species. At present, shale gas development would not be permitted in the relatively limited areas designated as Wildlands, but could potentially take place in other protected areas.

In view of the existence of limited evidence of effects of hydraulic fracturing on biodiversity, the frequency is considered to be “rare.” The biodiversity impacts of potential concern (e.g. Michaels et al. 2011 NPR ; New York State DEC 2011 PR p6-3) are associated with cumulative development over a wider area, and in view of the risk of development taking place in areas of high biodiversity value are judged to be potentially of “major” significance.

3.3.7 Noise

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*Moderate*	*Occasional*	*High*
Cumulative effects of multiple installations	*Moderate*	*short-term definite*	*High*

Peer-reviewed research

Noise emissions associated with operation of well and associated equipment could affect residential amenity and wildlife, particularly in sensitive areas. New York State DEC 2011 PR (pages 6-289 to 6-300) describes the noise impacts from hydraulic fracturing. The noise level differs with the stages in the preparation and production cycle. At 250 feet, for example, the maximum calculated composite noise level for construction equipment is 70dBA. For horizontal drilling the corresponding maximum noise level is 64dBA. The hydraulic fracturing process, however, can produce noise levels of 90dBA at that distance. This is calculated on the basis that up to 20 diesel pumper trucks are required to operate simultaneously to inject the required water volume to achieve the necessary pressure. The operation takes place over a period of several days for each well and would be repeated at a site for multiple wells and pads. This noise has the potential to temporarily disrupt and disturb local residents and wildlife. The level of noise quoted by New York State DEC is above the Maryland standards for both daytime and night-time noise at distances of 2,000 feet from the source (this is the maximum distance quoted). Extrapolating from data in New York State DEC 2011 PR Table 6.58 indicates that noise levels could potentially achieve the daytime standard at a distance of 2,500 to 4,400 feet from the source.

Fry (2013 PR) noted that noise, vibration and traffic are among the most noticeable impacts during this stage of development.

Other research

Broderick et al (2011 NPR , p92) examined noise pollution, with a focus on the extent of activities rather than their noise levels, focusing on Cuadrilla Resources' Preese Hall exploratory site in the UK. It states that each well pad (assuming 10 wells per pad) would require 800 to 2,500 days of noisy activity during pre-production. This covers ground works and road construction as well as the hydraulic fracturing process. Drilling, which it states as the stage of greatest continuous noise pollution, is required for 24 hours per day for four to five weeks at each well.

Local context

The Garrett County Comprehensive plan (2008) acknowledges that gas drilling activity can generate noise. The plan envisages that the County authorities will "*Work with MDE, SHA, other state agencies, and energy companies to … address the socioeconomic impacts of natural gas drilling...*"

Judgment

The levels of noise during fracturing forecast by New York State DEC (2011 PR p6-289 to 6-300) would need to be carefully controlled to avoid risks to health for members of the public. Site operatives and visitors may need additional controls to ensure that no adverse effects on health occur due to noise during this stage. Controls on noise can be applied in the oil and gas industry, but the forecast levels of noise would exceed the Maryland standard over a distance of 2,500 to 4,400 feet from the site over short periods of 2 to 5 days per well. It is judged that the potential significance of noise issues is "moderate," defined as a "localized environmental effect."

3.3.8 Visual impact

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*slight*	*short-term definite*	*low*
Cumulative effects of multiple installations	*slight*	*long-term definite*	*moderate*

Peer-reviewed research

New York State DEC 2011 PR (page 6-275) reviewed visual impacts associated with hydraulic fracturing activities at well sites. It identifies landscape features as access roads, pipelines, water impoundment areas, storage vessels and other hydraulic fracturing equipment, vehicles and buildings. It notes that these impacts would be short-term, but could repeat periodically over the life of a multi-well location. The visual impact is of more consequence in developments at more rural locations. A more comprehensive summary of visual impacts is presented in New York State DEC 2011 PR (page 6-285) for Horizontal

Drilling and Hydraulic Fracturing in the Marcellus and Utica Shale Area of New York, although many of the impacts have more general applicability.

As noted in section 3.2.6 above, Meng (2013 PR) describes mountain top sites as resembling small towns during the drilling and hydraulic fracturing stages.

Other research

Broderick et al (2011 NPR page 92) also identifies visual impacts, citing the UK Cuadrilla development at Blackpool as involving a footprint of 1ha per well pad for up to 80 pads. Broderick et al. concur that the visual impact is of more consequence in rural locations.

Local context

Garrett County and Allegany County Comprehensive plans highlight the importance of concentrating development in suitable areas, and ensuring sensitive areas are protected (see Section 3.1.6).

Judgment

The plant and equipment required for hydraulic fracturing would typically be visible in the surrounding area, unfamiliar to local populations, and would represent a new industrial feature in a particular landscape. Hydraulic fracturing takes place over a short period of a few days for each well, although plant and equipment may be present on site for a longer period.

The development of a number of wells on a single pad would extend the period that this impact takes place. Such development would not be in accordance with the State of Maryland “Visions for Future Development,” and this would be more acute in the high-value natural landscapes of Garrett and Allegany Counties. Impacts can be expected to occur with an individual site over a short period, and for multiple development over an extended period. On this basis, the likelihood of impacts was judged to be “short-term definite” for individual sites and “long-term definite” for multiple sites. As the duration and vertical scale of equipment is less for hydraulic fracturing than for drilling, the significance of the impact was classified as “slight.”

These features are likely to proceed sequentially as the Marcellus Shale gas field is developed in Maryland. The sequential development of well pads 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. Consequently, development of a shale gas play could affect a landscape over a longer period. Cumulative impacts were therefore judged to be potentially of “moderate” significance.

3.3.9 Seismicity

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*slight*	*rare*	*low*
Cumulative effects of multiple installations	*minor*	*rare*	*low*

Peer-reviewed research

New York State DEC 2011 PR (page 6-319) describes two types of induced seismic events associated with hydraulic fracturing. One is micro-seismic events resulting from the physical fracturing process. These are sufficiently small to require very sensitive monitoring equipment to be detected. This is an inherent part of the fracturing process and data on these events is used to guide the fracturing process. Indeed SEAB (2011a NPR page 21) recommends micro seismic surveys as a means to understand fracture growth and limit methane leakage (as opposed to the management of seismic risks). For hydraulic fracturing, New York State DEC 2011 PR (page 6-321) notes that seismic activity is only detectable at the surface by very sensitive equipment, and that the magnitude can be minimised by avoiding pre-existing faults. It also describes the potential for sheer slip, in which slippage occurs on bedding planes, which it states to be several orders of magnitude less than that which would be felt by humans. It reviews operating experience and reports on consultations with experts to conclude that the possibility of fluids injected during hydraulic fracturing the Marcellus or Utica Shales reaching a nearby fault and triggering a seismic event is remote. A recent peer reviewed European report nevertheless provides recommendations on the need to introduce traffic light monitoring systems to mitigate induced seismicity (Royal Society and Royal Academy of Engineering PR 2012, p.6).

The second type of event results from injection fluids reaching existing geological faults, leading to more significant ground accelerations, potentially felt by humans at the ground surface. These types of events can arise in any process involving the injection of pressurised liquids underground. For example, New York State DEC 2011 PR (page 6-321) notes that carbon sequestration can cause such events, with magnitudes typically less than 3, and the events connected to circumstances that could be avoided through site selection and injection design.

The National Research Council (2013 PR) published preliminary findings of an examination of scale, scope and consequences of induced seismicity during fluid injection and withdrawal activities related to amongst other shale gas extraction. The process of hydraulic fracturing was found not to pose a high risk for induced seismicity.

Well integrity could potentially be affected by seismic activity – either activity induced by the hydraulic fracturing process, or other seismic events. This could potentially result in the migration of fracturing fluids or formation brines through natural or artificial fissures or legacy wells connected to groundwater supplies. This is managed by the normal processes for monitoring and maintaining well integrity.

Other research

Broderick et al (2011 NPR page 93) reviewed the discussion in the previous draft New York State DEC study (2009 PR) but went on to describe experiences at the Cuadrilla Resources' Preese Hall exploratory site in the UK. At that location hydraulic fracturing was halted in May 2011 following instrumental detection of seismic events of magnitude 1.5 and 2.3 in the vicinity. Subsequent studies suggested a link between the fracturing activities and the seismic events (de Pater and Baisch 2011 NPR). As reported by Broderick et al (2011 NPR), one study indicated a maximum induced magnitude of around 3, for that location, which was considered insufficient to cause surface structural damage but to potentially damage the wellbore itself. The UK Government has published research which sets out a proposed monitoring and control approach (UK DECC 2012 NPR) and anticipates lifting the temporary embargo on hydraulic fracturing operations in the UK with this system in place. Seismic activity was also recorded in Oklahoma in January 2011 (Holland 2011 NPR). It was concluded that the recorded earth tremors could possibly be linked to hydraulic fracturing activity in a nearby water disposal well. The study reported two previous events in Oklahoma, in which a link to hydraulic fracturing had been suggested over the period 1977 to 2011.

Local context

The Maryland Geological Survey advised that there are no records of earth tremors/earthquakes of magnitude 1.0 or greater in the Western Maryland area since 1900 (MGS 2013 NPR). MGS operates one seismic station at Reiserstown in central Maryland. This station is part of a national network of sites, with the closest other sites providing triangulation for Western Maryland located at Mount Chateau, WV and Standing Stone, PA.

Judgment

Maryland is in a stable geological setting, with minimal natural seismic activity. The national monitoring network enables earthquakes to be detected, but would not be adequate to manage any seismic impacts associated with individual hydraulic fracturing jobs.

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.

3.3.10 Traffic

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*minor*	*occasional*	*moderate*
Cumulative effects of multiple installations	*moderate*	*occasional*	*high*

Peer-reviewed research

The traffic impacts of shale gas pre-production are examined in New York State DEC 2011 PR (pages 6-300 to 6-316). It estimates the number of loaded truck trips per horizontal well during construction. Two scenarios are considered, one in which all water (fracking fluid and backflow) are transported by truck, and one in which pipelines are used in part of that activity. In the former, a total of heavy 1,148 truck trips are envisaged, with the largest single activities associated with hydraulic fracturing (175 for the transportation of equipment and 500 for transport of water to site). This figure reduces to 625 where pipelines are assumed to be available for water and waste transport. Furthermore, the temporal distribution of these activities is uneven, so the total number of trips during the heaviest period could be as high as 250 per day (including lighter trucks).

Fry (2013 PR) noted that noise, vibration and traffic are among the most noticeable impacts during this stage of development.

New York State DEC 2011 PR goes on to examine some of the potential impacts of this level of transport. These include:

- Increased traffic on public roadways. This could affect traffic flows and congestion.
- Road safety impacts.
- Damage to roads, bridges and other infrastructure. This could lead to decreased road quality and increased costs associated with maintenance for roads not designed to sustain the level of traffic experienced.
- Risks of spillages and accidents involving hazardous materials.

In addition to the above, the road vehicles would cause air emissions with the potential for localized air quality impacts, as well as increasing the potential for community severance (reduction in community interaction due to roads with high traffic volumes) and potentially affecting residents’ quality of life. The noise impacts are described above.

Other research

For more widespread development, EPA (2012a NPR p14) suggests that there may be a sustained impact at this level.

Local context

The State Highways Administration Mobility report for 2013 (page II-9 to II-13) indicates that there were no significant congestion issues on state highways in Allegany or Garrett

Counties in 2012. None of the 30 “statewide most congested locations” are in Allegany or Garrett Counties. The Comprehensive Plans for the two counties indicate some limited areas where traffic congestion can be an issue.

The Garrett County Comprehensive plan (2008) acknowledges that gas drilling activity can generate heavy truck traffic. The plan envisages that the County authorities will “*Work with MDE, SHA, other state agencies, and energy companies to … ensure the safety and adequacy of roads to accommodate natural gas drilling activities.*”

The Allegany County Comprehensive Plan (2002) highlights the need for additional maintenance, and in some cases reconstruction, of roads in the Georges Creek area, where there has been extensive heavy truck traffic. If shale gas development proceeds, it is conceivable that this road maintenance requirement will need to be extended to the relatively low density of roads in the west of the county.

Judgment

Even at the levels described above, the impact in traffic terms associated with an individual site would be no more than “minor” in view of the short duration, although it would potentially be noticeable by local residents. The impacts include air emissions, noise and visual impact, as well as transport system effects such as infrastructure damage, congestion and effects on road safety during the period of hydraulic fracturing.

An increase in road transportation of potentially hazardous chemicals and waste materials would result in an increased risk of environmental pollution due to accidents, although these risks cannot be quantified at present. The established controls on transportation of dangerous goods would reduce the risks posed by vehicle accidents.

If a number of well pads are developed in a given area, the potential for adverse effects would be more significant, as there would potentially be a sustained increase in numbers of goods vehicle movements in a local area. The EPA (2012a NPR p14) indicates that, if extensive refracturing is required, truck traffic associated with shale gas development in New York state could become fairly continuous. In the context of Garrett and Allegany Counties (see Section 3.1.7), the impact of traffic associated with more widespread development, including the risks posed by traffic accidents, could be considered of “moderate” significance.

3.4 Stage 4: Well Completion

3.4.1 Groundwater contamination and other risks

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*moderate*	*occasional*	*high*
Cumulative effects of multiple installations	*moderate*	*occasional*	*high*

During the well completion phase, operators need to handle flowback and produced water to ensure that accidents, runoff and surface spillages do not occur, which would pose risks of groundwater contamination. If flowback water is used to make up fracturing fluid, this would increase the risk of introducing naturally occurring chemical contaminants and radioactive materials to groundwater. Relevant naturally occurring substances could include:

- Salt

- Trace elements (mercury, lead, arsenic)
- NORM (radium, thorium and uranium)
- Organic material (organic acids, polycyclic aromatic hydrocarbons)

Peer-reviewed research

New York State DEC (2011 PR Table 6.1) lists a large number of chemicals recorded in flowback water, or present in fracturing fluid which may be present in flowback waters, and concludes that "… *high-volume hydraulic fracturing operations, although temporary in nature, may pose risks to Primary and Principal Aquifers*…"

Other research

As noted in Section 3.3.6, three examples of uncontrolled release of fluids with actual or potential effects on biodiversity and agriculture are quoted by Michaels et al. (2011 NPR).

Judgment

These risks are similar to those discussed during the hydraulic fracturing phase in Section 3.3.1.

In view of the risks posed by metals and NORM in flowback fluid and the findings of New York State DEC quoted above, the potential impacts are judged to be of "moderate" significance for individual installations, and "major" significance in relation to cumulative impacts. On the basis of reported instances of uncontrolled releases in non-peer reviewed research, it is judged that the likelihood of impacts from individual sites and for cumulative impacts should be considered as "occasional" – defined as "could potentially occur … if management or regulatory controls fall below best practice standards."

3.4.2 Surface water contamination risks

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*moderate*	*occasional*	*high*
Cumulative effects of multiple installations	*moderate*	*occasional*	*high*

Peer-reviewed research

Waste water disposal was highlighted by Eaton (2013 PR) as one of the key issues for hydraulic fracturing of the Marcellus Shale in New York State. Flow back fluids typically have increased levels of salinity, as well as some metals (arsenic, barium, strontium, selenium), low level radionuclides, and volatiles organic compounds including benzene (Jenner and Lamadrid, 2013 PR; Finkel and Hays, 2013 PR; Balaba and Smart, 2012 PR). Finkel and Hays (2013 PR) estimate that 30% to 70% of fracturing fluids resurface with the flowback water.

Madden and Vossoughi (2013 PR) highlight that unlawful disposal of flowback waters poses the greatest environmental risk. Treatment in municipal sewage treatment plant is generally not appropriate, as flowback water can affect the plant due to the salt content of the water. If not properly handled, this can reduce the overall effectiveness of the sewage works. New York State (2011 PR p6-62) highlights the scale of water treatment resources that would be needed to maintain adequate treatment capacity. Also, some parameters which are likely to be present in flowback water may not be properly treated in a standard sewage treatment facility. New York State DEC highlights the potential for accumulation of NORM in sewage sludges.

Bamberger and Oswald (2012 PR) investigated incidents of exposure to contaminants in wastewater due to leakage or improper fencing of impoundments, alleged compromise of a liner in an impoundment to drain fluid, direct application of the wastewater to roads, and dumping of the wastewater on creeks and land. The most common route of livestock exposure was via affected water wells and/or springs, and the next most common exposure was to affected ponds or creeks.

There have been reports of directly dumping untreated wastewater into rivers and streams and of wastewater being sprayed on rural roads and forests (Finkel and Hays 2013). In some parts of the United States (e.g. West Virginia), Finkel and Hays report that it is legal to spray wastewater on the land, and cite newspaper evidence of radioactive wastewater being discharged to rivers used to supply drinking water in Pennsylvania and Maryland.

Howarth and Ingraffea (2011 NPR) cite examples of water contamination of tributaries of the Ohio River with barium, strontium and bromides from municipal wastewater treatment plants receiving wastewater from hydraulic fracturing processes.

Other research

Flowback waters are collected and recycled in the hydraulic fracturing process, or sent for treatment and disposal. The options for recycling are limited to some extent because of a build-up of salts and contaminants in flowback fluid which ultimately makes the fluid unsuitable for use without dilution. Arthur (2008 NPR p19-20) highlights the development of research and pilot-scale projects for flowback water recycling. This work has accelerated in recent years, with 77% of wastewater estimated to have been recycled in Pennsylvania in the second half of 2011 (Yoxtheimer, 2012 NPR), and 90% of Marcellus Shale flowback estimated by Jenner and Lamadrid (2013) to be recycled. However, there is uncertainty over the typical rate of recycling in the US, which may be significantly lower.

A number of options are available for disposal of flowback water:

- Direct discharge to surface rivers and streams can affect water quality, particularly in the light of the high salt content. This practice is banned in the U.S.
- Waste water may be injected into disposal wells if such facilities are available and if it is not prohibited by law
- Waste water may be treated in on-site facilities or in separate sewage works including commercial facilities designed for treatment of produced water from wet shale formations. Extensive desalination treatment, such as evaporation/distillation, allows discharge of the treated water to surface waters. Less extensive chemical precipitation treatment is used to remove suspended solids and divalent cations (magnesium, calcium, strontium, barium and radium) to facilitate wastewater reuse (Yoxtheimer, 2012 NPR).

Arthur (2008 NPR p19) refers to the need for development of new waste water treatment technologies.

Lechtenböhmer et al. (2011 NPR section 5.4.2) refers to the treatment of waste water as an issue that “may also complicate projects” and cites an example in which the rate of disposal of gas drilling wastewaters had to be reduced by 95% as a result of non-compliance with water quality standards. Lechtenböhmer et al. highlighted in particular the risks potentially posed by metals and NORM in waste waters.

Examples of spillages and accidental discharges are cited by Michaels et al. (2011 NPR) – for example, 109 spillages were reported in Colorado during a three year period.

Local context

A detailed program of baseline water quality monitoring is currently carried out by the Maryland Department of Natural Resources (Prochaska, 2013 NPR), as summarised in Section 3.3.2. If continued throughout the development of shale gas wellpads, this program would provide useful warning in the event of an impact on water quality. However, this would depend on the continuation of a comprehensive monitoring program, and would constitute at best a useful reactive measure for initiating action to mitigate impacts, rather than a preventive measure.

Judgment

In view of the risks posed by metals and NORM in waste waters, and evidence for spillages having occurred, resulting in localized environmental effects, the potential impacts are judged to be of "moderate" significance. Multiple development would pose risks of more widespread contamination if not properly managed. However, in view of the relatively small scale of potential operations in Maryland, and the low risk of multiple surface spills affecting a single watercourse, the cumulative impact is also judged to be of "moderate" significance.

In view of the reported incidents of discharges to water in peer reviewed and non-peer reviewed research, it is judged that the likelihood of impacts from individual sites and for cumulative impacts should be considered as "occasional" – defined as "could potentially occur … if management or regulatory controls fall below best practice standards."

3.4.3 Release to air

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*minor*	*occasional*	*moderate*
Cumulative effects of multiple installations	*moderate*	*occasional*	*high*

Peer-reviewed research

As discussed in section 3.2.3, New York State DEC 2011 PR (page 6-114) identifies the main sources of air emissions from drilling, completion and production activities and examines their relative significance. Sources of emissions include combustion from engines and flares; venting; and truck activities near the well pad. Emitted substances include PM, NO_x, CO, VOCs and SO_2. Flowback gas would normally be dry although wet gas, requiring removal of condensable hydrocarbons, could be encountered.

Flaring is typically carried out during the first 24 hours of flowback operations while a well produces a high ratio of flowback water to gas (New York State DEC 2011 PR p5-134). Flaring may result in emission to air of combustion gases, and of some unburnt hydrocarbons, depending on the efficiency of the flaring process.

Bunch et al. (2013 PR) reviewed air monitoring data from six locations representative of intensive gas field development in the Texas Barnett Shale. For the range of VOCs measured, shale gas production activities have not resulted in community-wide exposures to those VOCs at levels that would pose a health concern. Annual average benzene concentrations were found to have decreased over the period 2000-2011, despite an increase in gas extraction activity during this time. Only n-hexane showed a statistically significant linear increase in urban areas. These results indicate that shale gas operations in the Barnett Shale do not have a significant impact on ambient air concentrations of VOCs, consistent with the findings of other research (Barnett Shale Energy Education Council, NPR 2010 cited in Bunch et al. 2013 PR; Eastern Research Group 2011 NPR).

For the Marcellus Shale, Litovitz et al (2013 PR) calculated that the impacts of emissions to air during the production stage outweighed the impacts associated with hydraulic fracturing and completion, even during intensive development in Pennsylvania in 2011. Litovitz et al. (2013 PR) note that the US EPA will prohibit venting or flaring by 2015, requiring the use of Reduced Emissions Completions to capture completion emissions rather than venting or flaring them. Many natural gas producers have already begun following this practice.

Rappenglück et al. (2013 PR) investigated ozone events observed in Texas, Wyoming and Ohio, and concluded that these were due to the interaction of oxides of nitrogen and non-methane hydrocarbons, emitted from unconventional gas activities. As noted in Section 3.3.4 above, the production stage is the major contributor to air pollution emissions and any regional air quality issues (Litovitz et al 2013 PR).

Other research

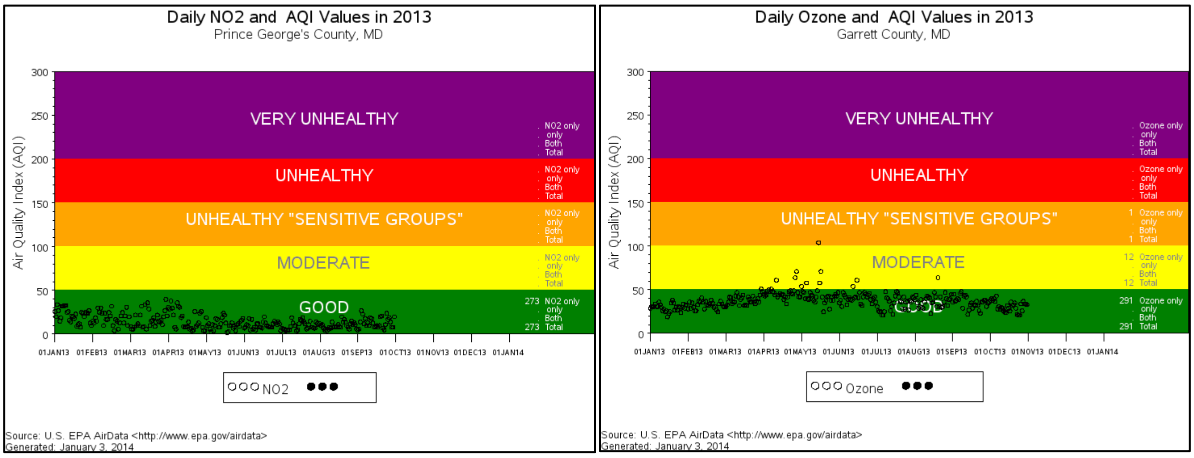
The issues of potential concern with regard to emissions to air during hydraulic fracturing comprise the following:

- Emissions of hazardous air pollutants, ozone precursors and/or odours due to gas leakage during completion (Lechtenböhmer et al., 2011 section 2.3.1; Michaels et al. 2011 NPR p19). Leakage may take place from pumps, valves, pressure relief valves, flanges, agitators, and compressors (EPA 2011b NPR Sections 4.2 and 8.1).
- Emissions of hazardous air pollutants, ozone precursors and/or odours from gases dissolved in flowback water during well completion or recompletion (EPA 2011b NPR Section 4). The short-term storage of flowback water on site can lead to considerable emissions of VOCs. The amount of VOCs and methane released varies over the flow back period. Reduced Emissions Completions can use open tank storage, which may result in flashing and evaporative emissions.
- Fugitive emissions of methane and other trace gases may take place from routeing gas generated during completion via small diameter pipeline to the main pipeline or gas treatment plant. This is likely to be more severe from wells developed during the pilot stages than from production stage wells, by which stage robust pipeline infrastructure should be in place (EPA 2011b NPR Section 4.4.2.1). Emissions to air could also occur from flaring of methane during exploratory phases prior to the construction of gas collection infrastructure (British Columbia OGC 2011 NPR).

Local context

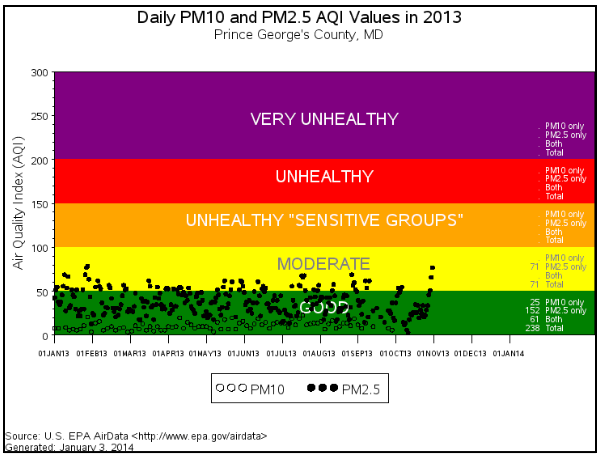
Air monitoring is carried out at Piney Run reservoir in Garrett County for sulfur dioxide and ozone. Levels of nitrogen dioxide, PM_{10} and $PM_{2.5}$ are not measured in Garrett County or Allegany County, but levels are measured at a suburban and a rural location in Prince George's County (Maryland DOE 2013b PR). The levels measured during 2013 are summarised in Figure 5 below.

Figure 7: Measured levels of airborne pollutants in Maryland

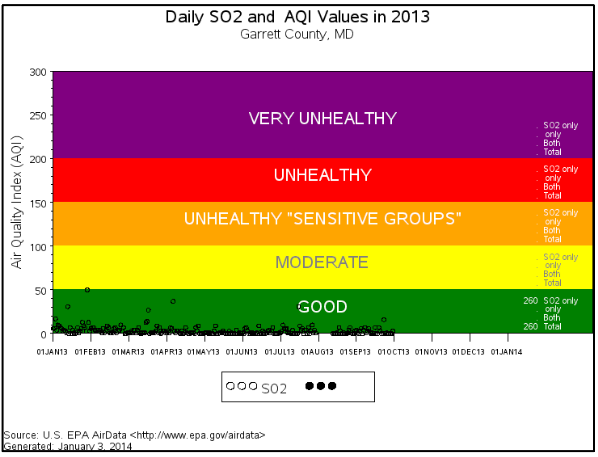

Daily NO2 and AQI Values in 2013
Prince George's County, MD

Daily Ozone and AQI Values in 2013
Garrett County, MD

Source: U.S. EPA AirData <http://www.epa.gov/airdata>
Generated: January 3, 2014


Daily PM10 and PM2.5 AQI Values in 2013
Prince George's County, MD

Source: U.S. EPA AirData <http://www.epa.gov/airdata>
Generated: January 3, 2014


Daily SO2 and AQI Values in 2013
Garrett County, MD

Source: U.S. EPA AirData <http://www.epa.gov/airdata>
Generated: January 3, 2014

The measured levels shown in Figure 4 indicate that measured levels of air pollutants at rural locations are generally good, with levels of ozone and $PM_{2.5}$ periodically classified as “moderate.” On one occasion in 2013, levels of ozone reached a level described as “unhealthy for sensitive groups.” Hence, in rural areas of Garrett and Allegany Counties, baseline air quality is likely to be generally good, although there may potentially be some locations close to sources of pollution such as congested roads where levels of airborne pollution may be higher. Maryland DOE confirmed that both Garrett and Allegany Counties are in attainment for all criteria pollutants (Maryland DOE 2013 NPR).

Judgment

Relevant naturally occurring substances could include:

- Gases (natural gas (methane, ethane), carbon dioxide, hydrogen sulphide, nitrogen and helium)
- Organic material (volatile and semi-volatile organic compounds)
- Naturally-occurring radioactive material (NORM)

The potential effects of emissions during well completion can be expected to be greater for HVHF than for conventional gas extraction because of the wider range of potential sources of process and fugitive emissions. As discussed in Section 2.4.6, shale gas infrastructure normally falls outside the scope of the Clean Air Act (see also Madden and Vossoughi 2013 PR). Consequently, there is not normally a requirement for emissions from shale gas installations to comply with National Emissions Standards for Hazardous Air Pollutants via the application of Maximum Achievable Control Technology. However, the US EPA will prohibit venting or flaring by 2015, requiring the use of Reduced Emissions Completions to capture completion emissions (Litovitz et al. 2013 PR).

In view of good baseline air quality in Garrett and Allegany Counties, the low significance of completion emissions in the context of production phase emissions and future requirement for Reduced Emissions Completions, impacts from individual sites are therefore considered to be of “minor” significance. As the production stage is the major contributor to air pollution emissions, the cumulative impact on emissions from the Completion stage, and hence on air quality and any associated health impacts, was judged to be “moderate”.

3.4.4 Land take

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 resulting in habitat loss (New York State DEC (2011) p6-68), resulting in a long-term impact as described in previous sections and in Section 3.5.5.

3.4.5 Biodiversity impacts

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*minor*	*rare*	*low*
Cumulative effects of multiple installations	*Major*	*rare*	*moderate*

Contamination of local water sources due to spillages or inadequate treatment of waste waters can potentially harm local ecosystems, similarly to the impacts described in Section 3.3.6. These effects in the context of Garrett and Allegany Counties are described in sections 3.3.1, 3.3.2 and 3.4.2.

3.4.6 Noise

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*not classifiable*	*short-term definite*	*not classifiable*
Cumulative effects of multiple installations	*not classifiable*	*short-term definite*	*not classifiable*

Peer-reviewed research

Noise from the well completion process could arise from on-site plant and machinery, but is likely to be lower than at other stages in the gas extraction process, and of limited duration (New York State DEC 2011 PR p 6-289 to 6-300).

Judgment

No peer-reviewed evidence was found in relation to noise from gas flaring. Noise from flares can be minimised using appropriate flare design. Residual noise from flares could not be controlled using engineering measures in the same way that plant and equipment noise can be controlled because of the nature of the source.

No adverse effects on public health would be expected to arise due to noise from plant and equipment provided established controls used in the oil and gas industry are applied. However, because of the uncertainty associated with flaring noise, it is judged that noise impacts are not classifiable.

3.4.7 Seismicity

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*minor*	*rare*	*low*
Cumulative effects of multiple installations	*minor*	*rare*	*low*

Peer-reviewed research

Injection of waste water derived from energy technologies such as hydraulic fracturing poses some risks for induced seismicity, but the National Research Council found that "*very few events have been documented over the past several decades relative to the large number of disposal wells in operation*" (National Research Council, 2013 PR)

Other research

Recent evidence indicates that injection of waste water into disposal wells may have been associated with minor earth tremors of magnitude 2.7 to 4.0 on the Richter scale (Madden and Vossoughi 2013 PR; Ohio Department of Natural Resources, 2012 NPR ; Arkansas Sun Times, 2011 NPR).

Judgment

If injection of waste water from hydraulic fracturing into disposal wells were permitted to occur in Maryland or elsewhere, earth tremors of the magnitude recorded in Ohio would not normally have significant consequences at the surface, and are judged to be of minor significance. On the basis of some reported occurrences of minor earth tremors, the frequency of seismic impacts is judged to be rare.

3.4.8 Traffic

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*slight*	*short-term definite*	*low*
Cumulative effects of multiple installations	*minor*	*short-term definite*	*moderate*

Peer-reviewed research

The traffic impacts of shale gas pre-production are examined in New York State DEC 2011 PR (pages 6-300 to 6-316). It estimates the number of loaded truck trips per horizontal well during completion. 100 truck movements per well are estimated to be needed for waste water disposal. This figure reduces to 17 movements where pipelines are assumed to be available for water and waste transport. This represents a small proportion of overall truck movements, but would contribute to the net impacts of traffic associated with a well development.

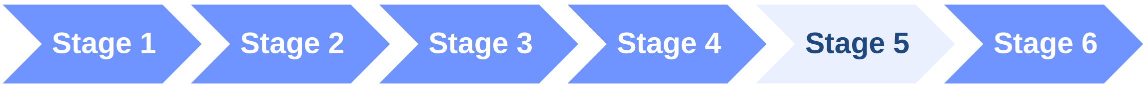
Other research

None reviewed

Judgment

In view of the low number of traffic movements associated with well completion phase and the absence of significant traffic congestion in Garrett and Allegany Counties (Maryland State Highways Administration 2013 NPR), the impacts associated with an individual well pad are judged to be slight, and those associated with wider area development are judged to be minor.

3.5 Stage 5: Well Production



3.5.1 Groundwater contamination and other risks

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installations (more than 2,000 feet separation between fracturing zone and groundwater)	*moderate*	*rare*	*moderate*

Individual installation (less than 2,000 feet separation between fracturing zone and groundwater)	*moderate*	*occasional*	*high*
Cumulative effects of multiple installations	*moderate*	*occasional*	*high*

Risks to groundwater are principally those posed by failure or inadequate design of well casing leading to potential aquifer contamination. The substances of potential concern comprise naturally occurring substances such as heavy metals, together with natural gas, naturally occurring radioactive material (NORM), and technologically enhanced NORM (TENORM) from drilling operations.

Peer-reviewed research

Osborn et al (2011 PR) investigated methane in shallow groundwater used as a drinking water resource in aquifers overlaying the Marcellus and Utica shales of NE Pennsylvania. Samples taken close to active gas extraction sites were compared with samples distant from any active gas extraction. Higher levels of methane were identified in samples taken near active wells than at more distant sites. The isotopic signature of the methane samples taken near active wells was found to be characteristic of deeper deposits. Whilst this suggests a link between the elevated methane levels and the gas extraction process, there was no evidence of mixing of aquifer water with either fracturing fluids or shale formation waters and thus it was concluded that the water chemistry was consistent with historical baseline data.

Osborn et al. considered the possible mechanisms for elevated concentrations of thermogenic gas to be found in the aquifers. The three mechanisms they propose are: first, physical movement of gas rich fluids from the shale, but this would have to be rapid, and they therefore rule this out based on their negative results from chemical analysis to identify evidence of mixing of aquifer water with deep formation water. Second, the fracturing process could create new fracture pathways from the shale to the aquifer and methane gas being released to solution due to pressure reduction during extraction. This could then allow gas phase methane to migrate through the fissure network. Indeed there is evidence that rapid vertical gas migration is possible, particularly where there are old unused gas wells that are uncased and abandoned in the neighbourhood, and where the overlying formations are naturally highly fractured, and faulted. Third, the authors conclude that a more likely explanation would be that the methane may have leaked from leaky gas casings at depths of up to hundreds of feet below ground, followed by migration of the methane both laterally and vertically towards the water wells. This finding has been challenged by Molofsky et al. (2011 PR), who found that the isotopic signatures of thermogenic methane identified by Osborn et al. (2011 PR) were more consistent with shallow deposits overlying the Marcellus shale. Molofsky et al interpreted these results to mean that the methane detected in the Duke study could have originated entirely from shallower sources above the Marcellus which are entirely unrelated to hydraulic fracturing. Osborn et al. reported methane present at lower levels at locations distant from active gas extraction wells, and concluded that this was likely to have resulted from natural release of methane from source rocks in view of its more biogenic signature. The Duke University team is continuing its research, sampling approximately 150 water wells in Northeast Pennsylvania (see Warner et al. (2012 PR) discussed in Section 3.3.1).

Additional research published in 2013 (Jackson et al. 2013 PR) provided further evidence from statistical analysis of data, isotopic signatures and hydrocarbon ratios (methane to ethane and propane), and the ratio of the noble gas helium-4 to methane. The statistical analysis indicated that distance to gas wells was the most significant association, with no significant association with distances to valley bottoms and the Appalachian Structural front (proxy for tectonic deformation). Isotopic signatures and hydrocarbon ratios were characteristic of a thermogenic Marcellus-like source in some cases. The overall conclusion was that some homeowners living within 1 km (0.6 miles) of gas wells have drinking water contaminated by stray gases.

Considine et al. (2012 PR) reviewed all the Notices issued by the Pennsylvania Department for Environmental Protection between 2008 and 2011 in relation to incidents at shale gas extraction sites. The 2,988 notices issued related to 845 environmental events, of which 25 were considered to be major events. Six events were not fully mitigated, of which two related to contamination of groundwater. The causes of these events were linked to inadequate well casing.

Other research

A number of studies have highlighted potential links between shale gas extraction and groundwater contamination. However, reliable examples of contamination are limited, partly because of the difficulty of distinguishing between naturally or previously occurring contamination, and contamination associated with shale gas extraction operations. The US EPA (2011c NPR, in draft) found that hydraulic fracturing of tight and conventional gas fields may have resulted in contamination of a drinking water aquifer at Pavillion in Wyoming. This incident was linked in the EPA draft report to inadequate vertical well casing lengths and a lack of well integrity (USEPA 2011c NPR p37, p38). However, the findings of this study are preliminary and will be followed by further ongoing research (see Section 3.3.1).

It is well established that methane can be present in shallow aquifers independent of shale gas extraction activity (e.g. Breen et al., 2007). SEAB (2011a NPR) found that the research carried out by Osborn et al. (2011 PR) provided credible evidence of elevated levels of methane originating in shale gas deposits in wells surrounding a shale production site and recommended further investigation of this issue.

Re-fracturing may be needed during the production phase. It is estimated that re-fracturing may take place up to four times from an individual well, as described in Section 2.2.5. The USEPA (2011a PR p82) highlights concerns that the potential effects of repeated pressure treatments on well construction components (e.g., casing and cement) are not well understood.

Judgment

It is anticipated that any potential failure of the well would be monitored during the re-fracturing process, and remedial measures implemented to address any issues identified using established industry processes (e.g. API 2009 NPR is used as a reference standard for shale gas production operations in the US). Nevertheless, in view of the possible evidence for methane migration into potable groundwater (Osborn et al. 2011) and uncertainty around the risks associated with re-fracturing, the potential for increased risk due to re-fracturing remains an area of uncertainty, and hence has been assigned a risk ranking of “high” for installations with less than 2,000 feet distance between fracturing zone and groundwater and "moderate" for installations with more than 2,000 feet distance. In other respects, the risks and impacts associated with re-fracturing would be similar to those described in Section 3.3.

Because potential emissions to groundwater would only occur in the event of a failure of control systems, it is judged highly unlikely that multiple incidents would affect the same location. On this basis, cumulative impacts are not judged likely to be significantly different to the impacts associated with individual installations.

3.5.2 Surface water contamination risks

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*minor*	*rare*	*low*
Cumulative effects of multiple installations	*minor*	*occasional*	*moderate*

Peer-reviewed research

Production water is the fluid returning from the borehole during the production phase (US EPA 2011a PR page 1; New York State DEC 2011 PR p6-17). This brine requires interim storage, transport, processing and disposal or re-use. Accidental releases can arise as a result of tank ruptures, equipment or surface impoundment failures, overfills, vandalism, fires and improper operations. The production brine can have elevated levels of naturally occurring radioactive materials (higher than for flowback liquid) such as radium, thorium and uranium.

Olawoyin et al (2013 PR) found that 0.5 % to 1% of wells drilled in Pennsylvania result in a blowout, and recorded a total of 2601 violations between 2008-2010 by 65 operators in the Marcellus Shale. However, not all of these incidents have significant environmental consequences. Well blowout has been reported as giving rise to four major environmental incidents in Pennsylvania between 2008 and 2012 (Considine et al. 2012 PR). When blowout or uncontrolled venting occurs, fluids and gases may be released from the wells. The quantities of fluid cannot be quantified, but discharges from the four incidents identified by Considine et al were sufficient to result in significant pollution of surface waters, requiring remedial action.

Re-fracturing may be needed during the production phase on up to four occasions, as described in Section 2.3. This could potentially pose additional risks to surface waters in the event that repeated pressure treatment affects the integrity of the well (US EPA 2011a PR). In this case, the integrity and capacity of the well would need to be assessed, to enable a site-specific assessment of risks and impacts to be carried out (King 2012 PR, p2).

Other research

None reviewed

Judgment

The risks posed by the handling and treatment of production water are similar to those described in Section 3.4.2 above. The stream monitoring program carried out by Maryland DNR would provide a useful indication of an increase in contaminants in stream waters resulting from shale gas production, if this program is continued through the production phase. While this would not be a preventive measure, it may enable early action to be taken to deal with any incidents which may occur.

On the basis of the peer-reviewed research, the impact associated with surface water contamination during the production phase is judged to be “minor” – that is, potentially giving rise to an exceedance of an environmental quality guideline. The probability of events was judged to be “rare” for an individual installation, and “occasional” on a cumulative basis.

3.5.3 Water resource depletion

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*Slight*	*occasional*	*Low*
Cumulative effects of multiple installations	*moderate*	*occasional*	*high*

Re-fracturing may be needed during the production phase on up to four occasions, as described in Section 2.2.5. In this case, the impacts would be similar to those described in Section 3.3.

3.5.4 Release to air

Risk Characterization	Hazard	Probability	Risk ranking

	classification	classification	
Individual installation	*minor*	*periodic*	*moderate*
Cumulative effects of multiple installations	*major*	*occasional*	*high*

Peer-reviewed research

Litovitz et al (2013 PR) carried out a first-order estimate of air pollutant emissions, and the monetary value of the associated environmental and health damages from the extraction of unconventional shale gas in Pennsylvania. The damage cost estimates ranged from $7.2 to $32 million dollars for 2011. The majority of emissions and associated costs are related to on-going activities (gas production and compression), which persist beyond initial development and which are largely unrelated to the unconventional nature of the gas resource. The principal activities which lead to emissions are:

1. Diesel and road dust emissions from trucks transporting water and equipment to the site, and wastewater away.
2. Emissions from well drilling and hydraulic fracturing, including diesel combustion.
3. Emissions from the production of natural gas, including on-site diesel combustion and fugitive emissions.
4. Combustion emissions from natural gas powered compressor stations.

Bamberger and Oswald (2012 PR) identified incidents in which livestock was exposed to emissions of airborne pollutants associated with compressor station malfunction, pipeline leaks, and well flaring. Litovitz et al (2013 PR) note that there is considerable uncertainty in emissions associated with shale gas development. This is due to a scarcity of emissions data and to actual differences in emissions caused by regional and site-specific variations in technology and processes, such as length of well bore, number of fracturing stages geographic location and characteristics of the natural gas.

The majority of annual attributable emissions continue for the life of the well and associated compressor facilities. This was found to be the case, despite the relatively high level of development activity in 2011 and the relatively low number of actively producing shale gas wells, compared to what is expected in coming years. More than half of estimated damage costs were estimated as being due to compressor stations, which may serve dozens of individual wells.

Well blowout has been reported as giving rise to four major environmental incidents in Pennsylvania between 2008 and 2012 resulting in the release of fluids and gases (Considine et al. 2012 PR). The quantities of fluid cannot be quantified, but discharges identified by Considine et al were sufficient to result in significant pollution of surface waters, requiring remedial action.

McKenzie et al. (2012 PR) calculated a small increase in cancer risk due to increased benzene exposure within half a mile of gas wells in a tight gas resources in Colorado. An increase was only detected when considering peak (95th percentile) exposures: there was a slight decrease in exposure when considering median exposures.

Emissions from numerous well developments in a local area or wider region could potentially have a significant effect on air quality. For example, emissions from regional shale gas development are considered likely to be a contributory factor to ozone episodes in Texas, Wyoming and Ohio (Rappenglück et al. 2013).

Other research

Flaring or venting of gas may also be required during the pilot testing phases, before a gathering line is in place (British Columbia OGC 2011 NPR).

Ongoing fugitive losses of methane and other trace hydrocarbons are likely to occur during production phase via leakages from valves, flanges, compressors etc (US EPA 2011b NPR ; Lechtenböhmer et al. 2011 NPR). These fugitive losses may contribute to local and regional air pollution, with potential for adverse effects on health, as described in the above sections.

The role of emissions from regional shale gas development on ozone episodes in Texas, Wyoming and Ohio was also identified by Michaels et al. 2011 NPR ; Argetsinger, 2011 NPR; and University of Wyoming, 2011 NPR.

Judgment

As discussed in Section 3.2.3, impacts from individual sites are considered to be of “minor” significance, but the cumulative impact from multiple sites could potentially be of “major” significance. The potential effect of elevated levels of ozone on respiratory health was also considered to be potentially “major”. The production phase is the major source of emissions to air from shale gas development (Litovitz et al. 2013 PR).

Emissions to air during blow-outs would contribute to fugitive emissions from shale gas extraction more widely. The risk of direct environmental or health effects due to emissions under blowout conditions cannot be ruled out, although there are no specific reports associated with these incidents.

Re-fracturing may be needed during the production phase on up to four occasions, as described in Section 2.2.5. In this case, the impacts would be similar to those described in Section 3.3. The potential climate impacts of fugitive methane emissions are not addressed in this study.

3.5.5 Land take

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*slight*	*long-term definite*	*moderate*
Cumulative effects of multiple installations	*minor*	*long-term definite*	*high*

Peer-reviewed research

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 resulting in habitat loss (New York State DEC (2011) p6-68), resulting in a long-term impact as described in previous sections.

Slonecker et al. (2012 PR) found that natural gas extraction in Pennsylvania is affecting the landscape configuration. Agricultural and forested areas are being converted to land characterised by disturbance due to natural gas development. In two example case study counties, Slonecker et al. found that forest area declined slightly between 2001 and 2011. Perhaps more significantly than the area loss is the increase in forest fragmentation. In both counties, forests became more fragmented due to natural gas resource development between 2001 and 2010. Bradford County lost 0.12% percent forest, with a 0.32% loss of interior forest and a gain of 0.11% in edge forest. Washington County lost 0.42% forest, with a 0.96% loss of interior forest and a gain of 0.38% percent in edge forest. Slonecker et al. found that the combined effects of Marcellus and non-Marcellus development can be substantial.

Other research

None reviewed

Judgment

It is judged that land take during the production phase would be ongoing, but at a lower level than during earlier phases. This is judged to be of potentially minor significance, and would be a long-term impact likely to be associated with the full development of any large shale gas formation.

Re-fracturing may be needed during the production phase on up to four occasions, as described in Section 2.2.5. In this case, the impacts would be similar to those described in Section 3.3.

3.5.6 Biodiversity impacts

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*minor*	*occasional*	*moderate*
Cumulative effects of multiple installations	*major*	*occasional*	*high*

Peer-reviewed research

There would be a slight potential for disturbance to natural ecosystems during production phase due to human activity, traffic, land-take, habitat degradation and fragmentation, and introduction of invasive species (New York State 2011 PR Section 6.4).

Pipelines constructed for use during the production phase would constitute new linear features, which could adversely affect biodiversity, particularly in sensitive ecosystems.

Other research

None reviewed

Judgment

The discussion in New York State 2011 PR Section 6.4 was used to assess the risks to biodiversity during the production stage. As discussed in Section 3.1.4, Garrett and Allegany Counties contain significant areas of high biodiversity, including areas which provide habitats for many rare and endangered species. At present, shale gas development would not be permitted in the relatively limited areas designated as Wildlands, but could potentially take place in other protected areas. During production, there would be relatively little human activity, but the shale gas infrastructure (well pads and pipelines) would remain. The loss of habitat, and in particular forest habitat, described in Section 3.5.5 above would go against policies to conserve forest lands in Garrett County in particular (Garrett County Comprehensive Plan 2008; see Section 3.1.3). Hence, the cumulative impact of shale gas production in Maryland on biodiversity was judged to be potentially “major.”

Re-fracturing may be needed during the production phase on up to four occasions, as described in Section 2.2.5. In this case, the impacts would be similar to those described in Section 3.3.

3.5.7 Noise

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*slight*	*occasional*	*low*
Cumulative effects of multiple installations	*slight*	*occasional*	*low*

Peer-reviewed research

Once completed, there is expected to be minimal ongoing noise from wellhead installations (New York State 2011 PR p6-300) although no specific information is available on noise levels.

Other research

Noise may be associated with new gas compressor stations and treatment facilities which may be needed to handle gas extracted from new well infrastructure (Lechtenböhmer et al. 2011 NPR).

Judgment

Noise from pipeline construction could affect residential amenity and wildlife, particularly in sensitive areas. However, this is likely to be lower intensity than other phases in shale gas development, and not to be correlated with other sources of noise associated with shale gas extraction.

Re-fracturing may be needed during the production phase on up to four occasions, as described in Section 2.2.5. In this case, the impacts would be similar to those described in Section 3.3.

3.5.8 Seismicity

Re-fracturing may be needed during the production phase, as described in Chapter 1. In this case, the impacts would be similar to those described in Section 3.3, although improved knowledge gained during the initial fracturing may enable these risks to be reduced.

3.5.9 Visual impact

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*minor*	*rare*	*low*
Cumulative effects of multiple installations	*minor*	*Occasional*	*Moderate*

Peer-reviewed research

None reviewed

Other research

None reviewed

Judgment

Well head plant and equipment could have a visual impact, particularly in residential areas or high landscape value areas, but this would be minimal compared to the impacts during the drilling and fracturing stages.

Pipelines could have a visual impact, particularly in residential areas or high landscape value areas such as those found in Garrett and Allegany Counties. County policy is to concentrate the development of new industrial infrastructure in appropriate areas, which would typically not conform to the requirements of shale gas infrastructure development. However, these are typically low-lying structures, and the likelihood of significant impacts on visual amenity is low.

Re-fracturing may be needed during the production phase on up to four occasions, as described in Section 2.2.5. In this case, the impacts would be similar to those described in Section 3.3

3.5.10 Traffic

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*slight*	*periodic*	*low*
Cumulative effects of multiple installations	*slight*	*periodic*	*low*

Peer-reviewed research

None reviewed

Other research

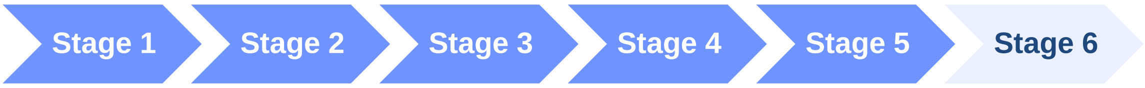
None reviewed

Judgment

Transportation of materials and equipment for maintenance could have minor adverse effects due to noise, community severance etc during the operational phase. These impacts are judged to be minimal compared to impacts during the drilling, fracturing and completion stages.

Re-fracturing may be needed during the production phase on up to four occasions, as described in Section 2.2.5. In this case, the impacts would be similar to those described in Section 3.3.

3.6 Stage 6: Well / Site Abandonment



The assessment of post-abandonment impacts considers potential impacts over short-medium timescales and long timescales. Over short-medium timescales of decades, it is assumed that management and maintenance regimes will be in place. Over long timescales of hundreds of years, potentially management and maintenance regimes will no longer be in place.

There is generally little difference between conventional and unconventional wells in the post-abandonment phase, with the exception of the presence of unrecovered hydraulic fracturing fluids in the shale formations in the case of hydraulically fractured wells. The presence of high salinity fluids in shale gas formations indicates that there is normally no pathway for release of fluids to other formations (New York State 2011 PR p11). Hence, the issue of potential concern would be the risk of movement of fracturing fluids to aquifers or surface waters via the well and/or via fractures introduced during the operational phase.

3.6.1 Groundwater contamination and other risks

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*not classifiable*	*not classifiable*	*not classifiable*
Cumulative effects of multiple installations	*not classifiable*	*not classifiable*	*not classifiable*

At present, there is little information to enable a judgment to be made regarding the risks posed by movement of hydraulic fracturing fluid to the surface in the long term. Uwiera-Gartner (2013 PR) suggested that the greatest risk factor for freshwater contamination and intermediate groundwater flow systems is the migration of stray gas along the wellbore and behind casing which can occur for a long period after the well is plugged and abandoned.

The presence of high salinity fluids in shale gas formations indicates that there is normally no pathway for release of fluids to other formations (New York State 2011 PR p11). Furthermore, some of the chemicals used in fracturing fluids will be adsorbed to the rocks (e.g. surfactants and friction reducers) and some will be biodegraded in situ (e.g. guar gums used for gels).

Other research

None reviewed

Judgment

Inadequate sealing of a well could potentially result in subsurface pathways for contaminant migration leading to groundwater pollution, and potentially surface water pollution. 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. However, this experience does not yet extend into the long term (considered to represent periods of hundreds of years following abandonment).

The chemical constituents of hydraulic fracturing fluids remain an area of uncertainty pending the development of a more extensive database of behaviour of fluids in shale formations over time.

3.6.2 Release to air

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*minor*	*rare*	*low*
Cumulative effects of multiple installations	*moderate*	*rare*	*moderate*

Peer-reviewed research

None reviewed

Other research

None reviewed

Judgment

Inadequate sealing of wells could result in fugitive emissions to air. 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. However, this experience does not yet extend into the long term (considered to represent periods of hundreds of years following abandonment).

At present, there is little information to enable a judgment to be made regarding the risks posed by movement of airborne pollutants to the surface in the long term. It is judged that any risks are likely to be similar to those posed by conventional wells.

3.6.3 Land take

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*minor*	*not classifiable*	*not classifiable*
Cumulative effects of multiple installations	*moderate*	*not classifiable*	*not classifiable*

Peer-reviewed research

It may not be possible to return the entire site to beneficial use following abandonment e.g. due to concerns regarding public safety (New York State DEC 2011, PR Section 6.4).

Other research

None reviewed

Judgment

It is judged that the consequences for land take at an individual site in the post-abandonment phase would be comparable with many other industrial and commercial land-uses, and are of no more than minor significance. It may not be possible to return the entire site to beneficial use following abandonment, e.g. due to concerns regarding public safety. 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. There is no evidence available to enable the likelihood of permanent effects on land-use to be evaluated.

3.6.4 Biodiversity impacts

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*minor*	*not classifiable*	*not classifiable*
Cumulative effects of multiple installations	*moderate*	*not classifiable*	*not classifiable*

Peer-reviewed research

It may not be possible to return the entire site to its previous state following abandonment, which could be particularly significant for sites located in sensitive areas. Over a wider area, this could potentially result in a significant loss or fragmentation of a sensitive natural habitat (New York State DEC 2011 PR Section 6.4).

Other research

None reviewed

Judgment

It is judged that the consequences for biodiversity at an individual site in the post-abandonment phase would be comparable with many other industrial and commercial land-uses, and are of no more than minor significance. Over a wider area, this could potentially result in a significant loss of natural habitat. This could potentially be significant for the high value habitats present in Garrett and Allegany Counties, although the impacts would be expected to be less than during the operational phases of development.

There is no evidence available to enable the likelihood of effects on biodiversity during the post-abandonment phase to be evaluated.

3.6.5 Visual impact

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*slight*	*not classifiable*	*moderate or low*
Cumulative effects of multiple installations	*slight*	*not classifiable*	*moderate or low*

Peer-reviewed research

None reviewed

Other research

None reviewed

Judgment

It may not be possible to remove all wellhead equipment from site. This is not considered likely to pose a significant impact in view of the small scale of equipment potentially remaining on site.

3.7 Downstream infrastructure

3.7.1 Groundwater contamination risks

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*Slight*	*Rare*	*Low*
Cumulative effects of multiple installations	*Minor*	*Rare*	*Low*

Research

No evidence was found in relation to the presence or absence of groundwater contamination risks associated with downstream shale gas activities.

Judgment

It is judged that minor risks to groundwater would exist at gas clean-up facilities due to the handling and storage of chemicals such as amines and reduced sulfur compounds. Minor risks may also exist as a result of the storage and handling of condensates, if these are found to be present in gas in Maryland.

It is judged that minor risks to groundwater would exist at gas liquefaction plants, due to the handling and storage of refrigerants, fuels water, catalysts and waste materials.

3.7.2 Surface water contamination risks

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*Minor*	*Rare*	*Low*
Cumulative effects of multiple installations	*Minor*	*Periodic*	*Moderate*

Research

No evidence was found in relation to direct contamination of surface waters as a result of downstream shale gas activities.

The key issue for surface water contamination is the intersection of gas transmission pipelines with water courses and watersheds (New York State DEC 2011 PR p6-50). Pipelines are often constructed in straight lines and across the landform, and consequently can accelerate and channelize water flows during precipitation events. This may result in increased levels of suspended particulates and turbidity in potentially sensitive watercourses.

Judgment

It is judged that minor risks to surface waters would exist at gas clean-up facilities due to the handling and storage of chemicals such as amines and reduced sulfur compounds. Minor risks may also exist as a result of the storage and handling of condensates, if these are found to be present in gas in Maryland.

It is judged that minor risks to surface waters would exist at gas liquefaction plants, due to the handling and storage of refrigerants, fuels water, catalysts and waste materials.

The extensive stream monitoring program being carried out in Garrett and Allegany Counties would provide a useful early warning in the event of a surface water issue occurring, if this program is continued throughout the shale gas production phase.

3.7.3 Release to air

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*Slight*	*Long-term definite*	*Moderate*
	Moderate	*Occasional*	*High*
Cumulative effects of multiple installations	*Major*	*Occasional*	*High*

Research

New York State DEC (2011 PR p7-113) states that "*Equipment required to process produced natural gas, specifically the glycol dehydrators (i.e., vents & pumps) and pneumatic devices, generate CH4 emissions during normal production operations.*" NYS DEC goes on to set out the control, monitoring and recordkeeping requirements in relation to dehydration units. Sources with a throughput of 3 MMscf/day or greater and benzene emissions of 1.0 tons per year or greater are subject to emission reduction requirements."

Gas compression makes a significant contribution to methane and VOC emissions, and is estimated to account for about 7.9% of methane emissions from the natural gas industry (New York State DEC 2011 PR p6-200). Methane emissions can be particularly significant from compressor rod packing systems, and when taking compressors off-line (New York State DEC 2011 PR p7-113 to 7-114). Examples of fugitive emission sources include leaks from flanges, tube fittings, valve stem packing, open-ended lines, compressor seals, and pressure relief valve seats." (New York State DEC 2011 PR p6-188-9).

Emissions of NOx from a gas compressor station were estimated to be 2.0 g/Hp-hr (New York State DEC 2011 PR p6-101). For a continuously operating site with an engine rated at 2,500 Hp, this would correspond to an emission of approximately 48 tonnes NOx per year. It is anticipated that most operators would select a large 4-stroke lean-burn engine for gathering line compression because of its fuel efficiency. New York State DEC (2011 PR p6-107) highlights that reciprocating internal combustion engines also give rise to formaldehyde emissions. A dispersion modelling study was carried out which highlighted emissions of formaldehyde as a key issue for design of gas compressor stations (New York State DEC 2011 PR p6-158). The use of an oxidation catalyst to reduce emissions of carbon monoxide, VOCs and formaldehyde from engines at compressor plant, and a minimum stack height of 25 feet was recommended. Monitoring of BTEX and formaldehyde close to compressor stations was recommended (New York State DEC 2011 PR p6-182 and p7-102). At this stage, there are no guarantees regarding compressor plant emission control which would be applied in Maryland.

New York State DEC (2011 PR p6-105) highlights that there may be a need to store condensate in tanks either at the well pad or at the compressor station in situations where wet gas is encountered. Under these circumstances, there is a risk of emissions of VOCs and hazardous air pollutants such as benzene, and emissions "*should be minimized to the maximum extent practicable and controlled where necessary.*"

Armendariz et al (2009 PR) estimated that emissions to air from operations in the Barnett Shale were as follows:

Table 2: Emissions to air from the Barnett Shale

Source	**2007 Pollutants, Tons per day**		**2009 Pollutants, Tons per day**	
	NOx	**VOC**	**NOx**	**VOC**
Compressor Engine Exhausts	51	15	46	19
Condensate And Oil Tanks	0	19	0	30
Production Fugitives	0	17	0	26
Well Drilling and Completion	5.5	21	5.5	21
Gas Processing	0	10	0	15
Transmission Fugitives	0	18	0	28

Judgment

The information in Table 2 indicates that compressor plant accounts for the majority of NOx emissions associated with downstream operations. Fugitive emissions of VOCs arise from a wide range of sources associated with downstream operations, which were estimated to outweigh emissions from well drilling and completion. This is consistent with the findings of Litovitz et al (2013 PR), that the majority of emissions to air are associated with the production phase. These will be dominated by downstream infrastructure emission sources. In view of the analysis of compressor station emissions and requirement for mitigation measures identified by New York State DEC (2011 PR), it was concluded that there would be an occasional risk of a moderate (i.e. localized) impact on air quality.

Emissions to air can also be expected to occur from liquefaction plant. These would typically be fugitive emissions of methane and VOCs, together with combustion emissions.

While there is little evidence of a significant impact on air quality due to emissions of hazardous air pollutants, there is evidence that emissions to air from unconventional gas operations can have a significant impact on ozone levels in some circumstances (see Section 3.5.4).

3.7.4 Land take

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*Slight*	*Occasional*	*Low*
Cumulative effects of multiple installations	*Slight*	*Occasional*	*Low*

Research

In overall terms, approximately 1.66 acres of land is needed per well pad for gas gathering lines, and approximately 0.67 acre per well pad for compression plant (New York State DEC 2011 PR p5-14). The contribution from downstream infrastructure is in general taken into account in the assessment of land take set out in Section 3.1.3. However, this assessment does not take into account land take requirements for any LNG/CNG plant. The land take requirements for any such plant would be additional (see Appendix 1 for discussion of the Cove Point LNG facility).

New York State DEC (2011 PR p6-68) went on to state that “Habitat loss, conversion, and fragmentation (both short-term and long-term) would result from land grading and clearing, and the construction of well pads, roads, pipelines, and other infrastructure associated with gas drilling.”

Judgment

The land take requirements of downstream infrastructure are a component of those described in Section 3.1.3. Consequently, a small additional risk of land take has been highlighted in this section, due to the potential for development of any LNG/CNG or chemical processing plant.

3.7.5 Biodiversity impacts

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*Not classifiable*	*Long-term definite*	*Not classifiable*
Cumulative effects of multiple installations	*Moderate*	*Occasional*	*High*

Research

As noted above, New York State DEC (2011 PR p6-68) state that “*Habitat loss, conversion, and fragmentation (both short-term and long-term) would result from land grading and clearing, and the construction of well pads, roads, pipelines, and other infrastructure associated with gas drilling*.”

New York State DEC went on to highlight the risk of adverse impacts on the state‘s ability to maintain the existing large contiguous patches of forest.” (New York State DEC 2011 PR p6-91).

Existing regulation of wellhead and compressor station noise levels is designed to protect human noise receptors. Little definitive work has been done on the effects of noise on wildlife. (New York State DEC 2011 PR p6-68)

Judgment

Individual compressor plant could give rise to an impact on biodiversity due to noise, but this effect is not classifiable at present.

At present, development of downstream infrastructure would not be permitted in the relatively limited areas designated as Wildlands, but could potentially take place in other protected areas.

The cumulative effect of development of downstream infrastructure, and in particular pipelines, would contribute to habitat fragmentation as described in Section 3.1.4 above. Hence, cumulative impacts were assigned the same ranking as identified in Section 3.1.4.

3.7.6 Noise

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*Slight*	*Long-term definite*	*Moderate*
Cumulative effects of multiple installations	*Slight*	*Long-term definite*	*Moderate*

Research

Gas compressor stations are well established as sources of environmental noise (e.g. INGAA Foundation 1992 NPR p3-1; New York State DEC 2011 PR p6-251)

Judgment

Anecdotal evidence is that compressor stations give rise to detectable noise levels in the immediate vicinity of the site.

Ambient noise standards for Maryland are set in COMAR 26.02.03.02 (see Section 2.4.8). These regulations set a limit of 65 dBA (daytime) and 55 dBA (nighttime) at residential locations. Assuming that these limits are complied with, significant impacts on residential amenity should be maintained.

It is considered unlikely that there would be a significant cumulative effect, as any effects would be localised to an individual facility.

3.7.7 Visual impact

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*minor*	*rare*	*low*
Cumulative effects of multiple installations	*Moderate*	*Occasional*	*High*

Research

New York State DEC 2011 (PR p6-251) highlight the potential impact of pipeline construction on the landscape. Cleared rights-of-way would need to be maintained once the pipeline is in place. The report goes on to highlight the potential visual impacts of "*construction-related impacts associated with the preparation of drill sites, including the construction of access roads, connecting pipelines, and other ancillary facilities*" (p6-272)

A tourism study carried out on behalf of the New York State Southern Tier Central Regional Planning and Development Boards suggested that potential impacts from the creation of new pipeline-rights-of-way might result in changes in vegetation patterns, primarily through the creation of new and visible corridors, particularly where forest would be removed. The Marcellus Tourism Study found that multiple well sites and the associated off-site facilities could result in the creation of an industrial landscape which is not compatible with a scenic area (Rumbach 2011 quoted in New York State DEC 2011 PR p6-282-283).

Judgment

As discussed in Section 3.5.9, pipelines could have a visual impact, particularly in residential areas or high landscape value areas such as those found in Garrett and Allegany Counties. County policy is to concentrate the development of new industrial infrastructure in appropriate areas, which would typically not conform to the requirements of shale gas infrastructure development. However, these are typically low-lying structures, and the likelihood of significant impacts on visual amenity is low.

Other downstream infrastructure could potentially be more visually intrusive, but would be less widespread than wellpads and pipelines. However, it is judged that new compression and gas clean-up plant in sensitive natural areas could have a more significant visual impact, which was judged to be potentially of "moderate" significance.

3.7.8 Traffic

Risk Characterization	Hazard classification	Probability classification	Risk ranking
Individual installation	*Slight*	*Rare*	*Low*
Cumulative effects of multiple	*Minor*	*Rare*	*Low*

installations			

Research

No evidence was found in relation to the presence or absence of road traffic impacts associated with downstream shale gas activities.

Judgment

It is judged that downstream activities would not be likely to give rise to significant impacts due to traffic. Traffic movements associated with processing facilities would be limited in number, and the number of facilities would be a fraction of the number of well sites.

3.8 Summary of key issues

The preliminary risk assessment is summarised in Table 3. This table also sets out an overall risk rating across all project phases. This is identified as the highest rating of any individual phase as a minimum. A higher risk rating was considered in any cases where the ongoing nature of shale gas development could potentially warrant a higher risk rating than was applied to individual phases.

Table 3: Summary of preliminary risk assessment

Environmental aspect		Project phase							
		Site identification and preparation	Well design drilling, casing, cementing	Fracturing	Well completion	Production	Well abandonment and post-abandonment	Downstream infrastructure	Overall rating across all phases
Individual site									
Groundwater contamination[1]	More than 2,000 feet separation	Not applicable	Low	Moderate	**High**	Moderate	Not classifiable	Low	**High**
	Less than 2,000 feet separation			**High**		**High**			
Surface water contamination		Low	Moderate	Moderate	**High**	Low	Not applicable	Low	**High**
Water resources		Not applicable	Not applicable	Low	Not applicable	Low	Not applicable	Not applicable	Low
Release to air		Low	Moderate	Moderate	Moderate	Moderate	Low	Moderate-**High**	Moderate
Land take		Moderate	Not applicable	Not applicable	Not applicable	Moderate	Not classifiable	Low	Moderate
Risk to biodiversity		Moderate	Low	Low	Low	Moderate	Not classifiable	Not classifiable	Moderate
Noise impacts		Low	Moderate	**High**	Not classifiable	Low	Not applicable	Moderate	**High**
Visual impact		Moderate	Moderate	Low	Not applicable	Low	Low-moderate	Low	Moderate
Seismicity		Not applicable	Not applicable	Low	Low	Not applicable	Not applicable	Not applicable	Low
Traffic		Low	Low	Moderate	Low	Low	Not applicable	Low	Moderate

Environmental aspect	**Project phase**							
	Site identification and preparation	**Well design drilling, casing, cementing**	**Fracturing**	**Well completion**	**Production**	**Well abandonment and post-abandonment**	**Downstream infrastructure**	**Overall rating across all phases**
Cumulative								
Groundwater contamination	Not applicable	Low	**High**	**High**	**High**	Not classifiable	Low	**High**
Surface water contamination	Moderate	Moderate	Moderate-**High**	**High**	Moderate	Not applicable	Moderate	**High**
Water resources	Not applicable	Not applicable	**High**	Not applicable	**High**	Not applicable	Not applicable	**High**
Release to air	Low	**High**	**High**	**High**	**High**	Moderate	**High**	**High**
Land take	**Very high**	Not applicable	Not applicable	Not applicable	**High**	Not classifiable	Low	**Very High**
Risk to biodiversity	**High**	Low	Moderate	Moderate	**High**	Not classifiable	**High**	**High**
Noise impacts	Low	Moderate	**High**	Not classifiable	Low	Not applicable	Moderate	**High**
Visual impact	**High**	**High**	Moderate	Not applicable	Moderate	Low-moderate	**High**	**High**
Seismicity	Not applicable	Not applicable	Low	Low	Not applicable	Not applicable	Not applicable	Low
Traffic	Moderate	Moderate	**High**	Moderate	Low	Not applicable	Low	**High**

Note 1: Risks vary depending on whether fracturing zone is separated from near-surface aquifers by more or less than 2,000 feet of impermeable material
Not applicable: Impact not relevant to this stage of development
Not classifiable: Insufficient information available for the significance of this impact to be assessed

Table 3 highlights that the majority of issues under consideration continue throughout the lifetime of shale gas development, and continue into the post-abandonment phase. Table 3 also highlights the uncertainties associated with the post-abandonment phase. Further research in this area is recommended in Chapter 5.

One issue was identified as “very high” using this approach:

- Land-take during site preparation (cumulative)

This analysis has identified the following “high” significance issues:

- Biodiversity during site preparation (cumulative)
- Visual impact during site preparation (cumulative)
- Traffic during site preparation (cumulative)
- Releases to air during drilling (cumulative)
- Visual impact during drilling (cumulative)
- Groundwater contamination during fracturing with less than 2,000 feet separation between fracturing zone and near-surface groundwater (individual installation and cumulative)
- Groundwater contamination during fracturing with more than 2,000 feet separation between fracturing zone and near-surface groundwater (cumulative)
- Surface water contamination during fracturing (individual installation and cumulative)
- Water resource depletion during fracturing (cumulative)
- Noise during fracturing (individual installation and cumulative)
- Traffic during fracturing (cumulative)
- Groundwater contamination during completion (individual installation and cumulative)
- Surface water contamination during completion (individual installation and cumulative)
- Releases to air during completion (cumulative)
- Groundwater contamination during production with less than 2,000 feet separation between fracturing zone and near-surface groundwater (individual installation and cumulative)
- Groundwater contamination during production with more than 2,000 feet separation between fracturing zone and near-surface groundwater (cumulative)
- Water resource depletion during production (cumulative)
- Releases to air during production (cumulative)
- Land take during production (cumulative)
- Biodiversity impacts during production (cumulative)
- Releases to air from downstream infrastructure (individual installation and cumulative)
- Risk to biodiversity from downstream infrastructure (cumulative)
- Visual impact from downstream infrastructure (cumulative)

The following issues were identified as being “not classifiable” due to a lack of relevant data:

- Frequency of surface spillages during hydraulic fracturing
- Potential frequency and significance of road accidents involving trucks carrying hazardous substances in support of HVHF operations

- Noise impacts due to flaring, and associated controls
- Risks of groundwater contamination following abandonment
- Land take following abandonment
- Risks to biodiversity following abandonment
- Risks to biodiversity from downstream infrastructure

The issues identified during the preparation, drilling, fracturing and completion phases are more significant for high volume hydraulic fracturing than for conventional installations, or are unique to HVHF. The main causes of impacts and risks were as follows:

- The use of more significant volumes of water and chemicals compared to conventional gas extraction
- Lower gas yields per well, combined with increased economic cost of extracting shale gas resulting in a commercial requirement to carry out an intensive and widespread program of shale gas development.
- The challenge of ensuring the integrity of wells and other equipment throughout the development, operational and post-abandonment lifetime of the plant (well pad) so as to avoid the risk of surface and/or groundwater contamination
- The challenge of ensuring that spillages of chemicals and waste waters with potential environmental consequences are avoided during the development and operational lifetime of the plant
- The challenge of ensuring a correct identification and selection of geological sites, based on a risk assessment of specific geological features and any fracturing fluid that remains underground after hydraulic fracturing operations are completed. Residual fluid may pose a delayed risk of contamination of groundwater in systems where the net pore volume is low and the amount of fracturing fluid used constituents a high percentage of the total porosity.
- The potential toxicity of chemical additives and the challenge to develop greener alternatives
- The unavoidable requirement for transportation of equipment, materials and wastes to and from the site, resulting in traffic impacts that can be mitigated but not entirely avoided.
- The potential for development over a wider area than is typical of conventional gas fields
- The unavoidable requirements for use of plant and equipment during well construction, hydraulic fracturing, and for downstream handling and processing of gas. This equipment necessarily requires space to be sited and operated, and results in unavoidable emissions to air and noise impacts.

4 Environmental risk prioritisation taking account of BPMs

To be completed following finalisation of Best Practice Measures

5 Conclusions and recommendations

A high-level environmental risk assessment has been carried out for the development of Marcellus shale gas resources in Maryland. This risk assessment does not take account of site-specific mitigation and control measures, and should therefore be used to highlight attention towards aspects which require specific focus during the development of state policy with regard to shale gas development.

It is concluded that a wide range of aspects of shale gas development could pose significant environmental risks. The risks associated with visual impacts and potential impacts on biodiversity are particularly relevant to the development of shale gas in Maryland, in view of the biodiversity and natural resources of Garrett and Allegany Counties.

It is recommended that attention should be focused on the key risk areas highlighted as “high” or “very high” in the risk evaluation set out in Table 2 above. Risks identified as “moderate” also require attention during the planning, permitting, regulation and monitoring of shale gas installations, if it is decided to proceed with the development of shale gas resources in Maryland.

Control measures available to mitigate the impacts identified in Table 2 above are set out in guidance produced by the oil and gas industry (American Petroleum Institute 2009, 2010 and 2011), and more generally in our report to the European Commission (European Commission DG Environment 2012 PR). It is recommended that inclusion of shale gas installations on an aggregated basis within the scope of the Clean Air Act would enable the potential impacts of emissions to air to be more fully assessed and mitigated.

Further research is needed to fully understand, assess and (where necessary) mitigate risks in the following areas:

- Frequency of surface spillages during hydraulic fracturing
- Potential frequency and significance of road accidents involving trucks carrying hazardous substances
- Noise impacts due to flaring, and associated controls
- Risks of groundwater contamination following abandonment
- Land take following abandonment
- Risks to biodiversity following abandonment

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Appendices

Appendix 1: Cove Point LNG Facility

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To be completed

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