Roinn Cumarsáide, Gníomhaithe ar son na hAeráide & Comhshaoil
Department of Communications, Climate Action & Environment

Northern Ireland Environment Agency
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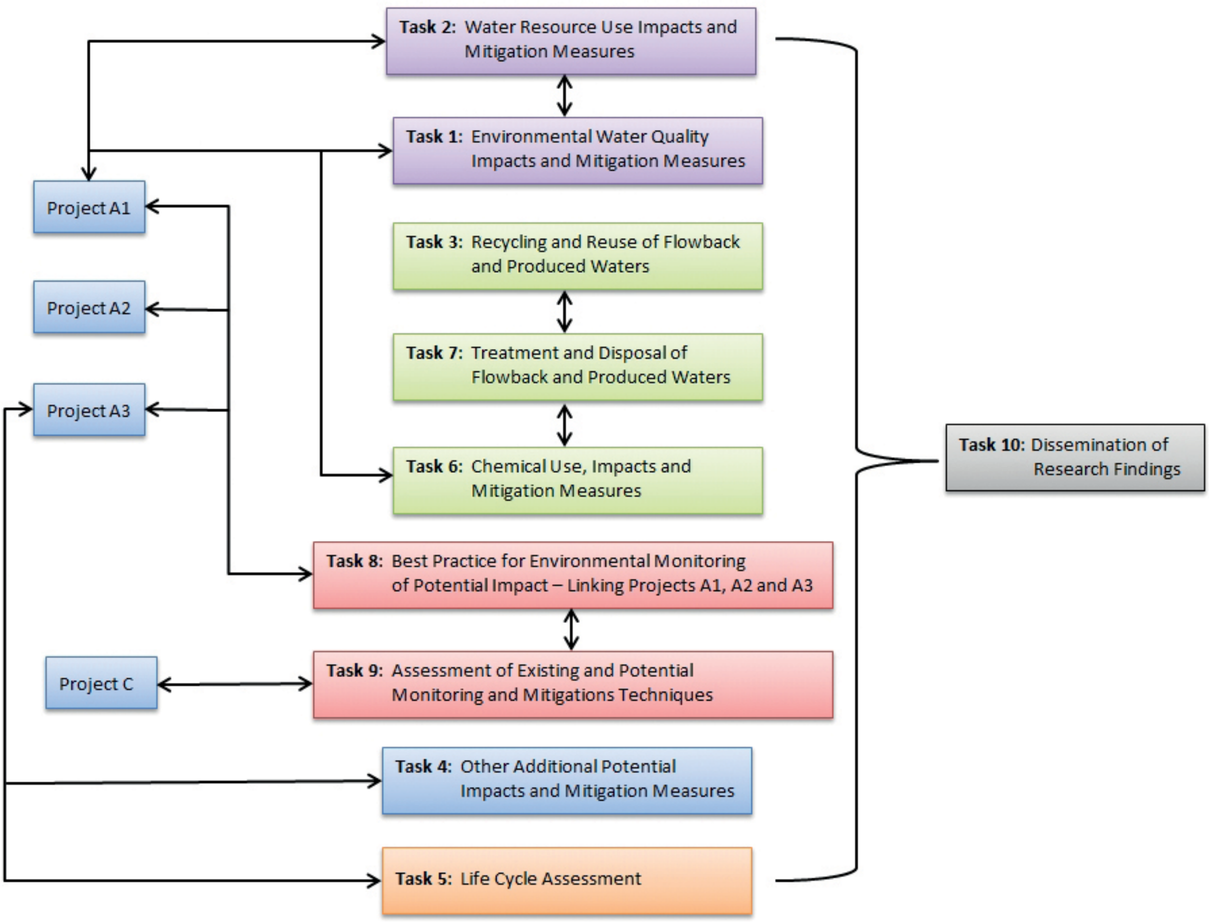
Unconventional Gas Exploration and Extraction (UGEE) Joint Research Programme

Summary Report 4: Impacts and Mitigation Measures

Authors: Roger Olsen, Dawn Keating, Carlos Claros, Henning Moe and Lorraine Gaston



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The Environmental Protection Agency (EPA) is an independent statutory body, established under the Environmental Protection Agency Act with a wide range of responsibilities including regulation of large scale industrial and waste facilities, monitoring and reporting on the state of the environment, overseeing local authorities' environmental responsibilities, coordinating environmental research in Ireland, promoting resource efficiency and regulating Ireland's greenhouse gas emissions. Through the Department of Communications, Climate Action and Environment (DCCAE) (and formerly through the Department of Environment, Community and Local Government - DECLG), the EPA has provided funding for environmental research since 1994. The current EPA Research Programme 2014-2020 is designed to identify pressures, inform policy and develop solutions to environmental challenges through the provision of strong evidence-based scientific knowledge.

On the 23rd of July 2016, the Department of Communications, Energy and Natural Resources (DCENR) became the DCCAE. Along with a name change, the new Department incorporates functions that were formerly held within the Environment Division of the DECLG. The Department retains responsibility for the Telecommunications, Broadcasting and Energy sectors. It regulates, protects, develops and advises on the Natural Resources of Ireland. Of particular relevance is the role of the Petroleum Affairs Division (PAD) to maximise the benefits to the State from exploration for and production of indigenous oil and gas resources, while ensuring that activities are conducted safely and with due regard to their impact on the environment and other land/sea users. The Geological Survey of Ireland (GSI) is also within DCCAE and provides advice and guidance in all areas of geology including geohazards and groundwater and maintains strong connections to geoscience expertise in Ireland.

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This Research Programme is being administered by the EPA and steered by a committee with representatives from DCCAE (formerly DCENR and the Environment Division of the DECLG), the Commission for Energy Regulation (CER), An Bord Pleanála (ABP), the GSI, NIEA, the Geological Survey of Northern Ireland (GSNI), as well as a Health representative nominated by the Health Service Executive (HSE).

UGEE Joint Research Programme

Environmental Impacts of Unconventional Gas Exploration and Extraction (UGEE)

(2014-W-UGEE-1)

Summary Report 4:

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by

CDM Smith Ireland Ltd

Authors:

Roger Olsen, Dawn Keating, Carlos Claros, Henning Moe and Lorraine Gaston

ENVIRONMENTAL PROTECTION AGENCY
An Ghníomhaireacht um Chaomhnú Comhshaoil
PO Box 3000, Johnstown Castle, Co. Wexford, Ireland

Telephone: +353 53 916 0600 Fax: +353 53 916 0699
Email: info@epa.ie Website: www.epa.ie

ACKNOWLEDGEMENTS

This report is published as part of the Joint Research Programme on the Environmental Impacts of Unconventional Gas Exploration and Extraction. This Research Programme is being administered by the EPA and steered by a committee with representatives from the Department of Communications, Climate Action and Environment [DCCAE, formerly the Department of Communications, Energy and Natural Resources (DCENR) and the Environment Division of the Department of the Environment, Community and Local Government (DECLG)], the Commission for Energy Regulation (CER), An Bord Pleanála (ABP), the Geological Survey of Ireland (GSI), the Northern Ireland Environment Agency (NIEA), the Geological Survey of Northern Ireland (GSNI) and the Health Service Executive (HSE) of Ireland.

References to government departments (DCENR and DCELG) throughout the report use the names of these departments prior to July 2016. References to the Department for the Economy (DfE) throughout the report use the name of its predecessor, the Department of Enterprise Trade and Investment (DETI), the department responsible for petroleum licensing in Northern Ireland until May 2016.

UGEE Joint Research Programme

Published by the Environmental Protection Agency, Ireland

PRINTED ON RECYCLED PAPER

ISBN: 978-1-84095-661-0

Price: Free 11/16/50

Project Authors

Dr Roger Olsen
CDM Smith
555 17th St #1100
Denver
CO 80202
United States
Tel.: +1 303 383 2300
Email: OlsenRL@cdmsmith.com

Henning Moe
CDM Smith
15 Wentworth
Eblana Villas
Dublin 2
D02 WK10
Tel.: +353 1 232 1044
Email: MoeH@cdmsmith.com

Dr Dawn Keating
CDM Smith
15 Wentworth
Eblana Villas
Dublin 2
D02 WK10
Tel: +353 1 232 1044
Email: keatingd@cdmsmith.com

Lorraine Gaston
CDM Smith
15 Wentworth
Eblana Villas
Dublin 2
D02 WK10
Tel.: +353 1 232 1044
Email: Dublin@cdmsmith.com

Carlos Claros
CDM Smith
11490 Westheimer Rd #700
Houston
TX 77077
United States
Tel.: +1 713 423 7300
Email: claroscd@cdmsmith.com

Project B Partners

CDM Smith Ireland
Alan Hooper
15 Wentworth
Eblana Villas
Dublin 2
D02 WK10
Tel: +353 1 232 1044

Project B Internal Review Panel[1]

CDM Smith Inc., Independent reviewer (German University), AMEC Foster Wheeler

1 More details available at: http://www.epa.ie/pubs/reports/research/ugeejointresearchprogramme/ugeejrptasksorganisations.html

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Executive Summary

Unconventional gas exploration and extraction (UGEE) involves hydraulic fracturing ("fracking") of low-permeability rock to permit the extraction of natural gas on a commercial scale from unconventional sources such as shale gas deposits, coal seams and tight sandstone. The Environmental Protection Agency (EPA), the Department of Communications, Energy and Natural Resources (DCENR) and the Northern Ireland Environment Agency (NIEA) awarded a contract in August 2014 to a consortium led by CDM Smith Ireland Limited to carry out a 24-month research programme looking at the potential impacts on the environment and human health of UGEE projects and operations (including construction, operation and aftercare).

The UGEE Joint Research Programme (JRP)[1] is composed of five interlinked projects and involves field studies (baseline monitoring of water and seismicity), as well as an extensive desk-based literature review of UGEE practices and regulations worldwide. The UGEE JRP was designed to provide the scientific basis to assist regulators – in both Northern Ireland and Ireland – in making an informed decision about whether or not it is environmentally safe to allow fracking. As well as research in Ireland, the UGEE JRP looked at and collated evidence from other countries.

Project B comprised the identification and a detailed examination of the potential impacts on the environment and human health, as well as the examination of mitigation measures to counteract these impacts associated with UGEE projects/operations that have come to the fore worldwide using published reports and other sources. The assessment took into account probable commercial scenarios. Where appropriate, findings were accompanied by references to experiences in other countries. Project B contained the tasks outlined below. These tasks are summarised in Chapter 3 of this report, and the key conclusions and recommendations are described in Chapter 4.

1 www.ugeeresearch.ie

Task 1: Water Impacts and Mitigation Measures

This task examined the potential environmental impacts of UGEE projects/operations on groundwater and surface water bodies, including the potential migration of methane, chemicals and other contaminants, both from surface and subsurface sources. Findings were informed by an objective assessment of the risks and hazards posed by UGEE projects/operations, supported by a literature review and experience from other jurisdictions. Mitigation measures to address water impacts (including, but not limited to, effluent management/treatment and well construction) were critically reviewed and presented. Innovative developments within the industry to reduce water impacts were also reviewed.

Task 2: Water Resource Use Impacts and Mitigation Measures

This task comprised an assessment of the direct (e.g. abstraction) and indirect impacts (e.g. drinking water, other receptors) on the use of local water sources for UGEE projects/operations and, specifically, for fracking. A review of innovative approaches within the industry to source water from existing industrial processes, such as cooling water, wastewater treatment work effluents and innovation related to water-free fracking was also carried out.

Task 3: Recycling and Reuse of Flowback and Produced Waters

This task comprised a comprehensive assessment of experience with the level of use of recycled flowback water in UGEE projects/operations and the potential for increasing these levels. The scope for, and implications of, recycling the flowback water for reuse in further fracturing operations in the case study areas were also considered.

Task 4: Other Potential Impacts and Mitigation Measures

This task employed similar approaches to those in Task 1 to examine the impacts from UGEE projects/operations on other areas, including, but not limited to, human beings, flora and fauna (including farm and domestic animals), air, landscape, material assets and cultural heritage, as well as examining the interactions between these areas. Mitigation measures to address these potential impacts are presented.

Task 5: Life Cycle Assessment

This task comprised a discussion of the cumulative environmental impact of UGEE projects/operations, supported by a literature review and experience from other jurisdictions, which was compared with similar published assessments of other energy sources.

Task 6: Chemicals

This task examined techniques in UGEE projects/ operations, including evidence of chemical-free UGEE projects/operations and the purposes of individual additives, to ascertain current and emerging practices in the context of avoidance of the use of additives that have the potential to harm the environment.

Task 7: Treatment and Disposal of Flowback and Produced Waters

This task comprised the identification and assessment of treatment and disposal methods for flowback fluid, identifying specific case studies. Linking with Task 6, it identified the treatment technologies available that can adequately treat the typical chemicals used in the process and the likely constituents of produced water. Disposal options linked to the available treatment options are reviewed and assessed.

Task 8: Best Practice for Environmental Monitoring of Potential Impact

Linking with projects A1, A2 and A3, this task comprised research into identifying best practice approaches for environmental monitoring of the potential impacts arising from individual UGEE project/operation sites (including the monitoring of emissions, mitigation measure effectiveness and impacts on the receiving environment).

Task 9: Assessment of Existing and Potential Monitoring and Mitigation Techniques

This task comprised the examination of the validity and range of existing and potential monitoring and mitigation techniques, including, but not limited to, geophysical techniques (down-hole and surface) for use in monitoring, control, horizon selection and injection management.

1 Introduction

1.1 Overall Project

Unconventional gas exploration and extraction (UGEE) involves hydraulic fracturing ("fracking") of low-permeability rock to permit the extraction of natural gas on a commercial scale from unconventional sources such as shale gas deposits, coal seams and tight sandstone. The Environmental Protection Agency (EPA), the Department of Communications, Energy and Natural Resources (DCENR) and the Northern Ireland Environment Agency (NIEA) awarded a contract in August 2014 to a consortium led by CDM Smith Ireland Limited to carry out a 24-month research programme looking at the potential impacts on the environment and human health of UGEE projects and operations (including construction, operation and aftercare).

The UGEE Joint Research Programme (JRP)[2] was composed of five interlinked projects and involves field studies (baseline monitoring of water and seismicity), as well as an extensive desk-based literature review of UGEE practices and regulations worldwide:

- Project A1 (Groundwater, Surface Water and Associated Ecosystems) dealt with the baseline characterisation of groundwater, surface water and associated ecosystems, which is required to enable potential impacts to be assessed.
- Project A2 (Seismicity) dealt with the baseline characterisation of seismicity, which is required to enable potential impacts to be assessed.
- Project A3 (Air Quality) dealt with the requirements and needs for additional air baseline monitoring (frequency, location and types of pollutants to be covered) in the context of Environmental Impact Statements (EIS).
- Project B (UGEE Projects/Operations: Impacts and Mitigation Measures) covered the identification and a detailed examination of the potential impacts on the environment and human health, as well as examining successful mitigation measures to counteract these impacts associated with UGEE projects/operations that have come to the fore worldwide using published reports and other sources.
- Project C (Regulatory Framework for Environmental Protection) was aimed at identifying all regulatory requirements, including gaps in existing regulations and best operational practices associated with the establishment and operation of UGEE projects/operations in an island of Ireland context.

The UGEE JRP was designed to provide the scientific basis to assist regulators – in both Northern Ireland and Ireland – in making an informed decision about whether or not it is environmentally safe to allow fracking. As well as research in Ireland, the UGEE JRP looked at and collated evidence from other countries.

1.2 Objective and Aim of Project B

The key questions to be addressed by the UGEE JRP are as follows:

1. Can UGEE projects/operations be carried out in the island of Ireland while also protecting the environment and human health?
2. What is "best environmental practice" in relation to UGEE projects/operations?

As part of addressing these questions, Project B involves the assessment of the impacts and mitigation measures for UGEE projects and operations.

The specific objectives of Project B include the following:

- identification and detailed evaluation of the potential impacts on the environment and human health associated with UGEE projects and operations;
- identification and evaluation of successful mitigation measures for the potential impacts.

The Environmental Impact Assessment (EIA) Directive (2011/92/EU) would apply to any UGEE projects/operations where hydraulic fracturing is proposed, as would all existing planning requirements. The outputs from Project B will assist regulators, who may be required to assess EIAs for UGEE projects in the future, to understand the potential impacts that should be considered by the applicants, including impacts on health and the environment, and will also provide the information required to evaluate the proposed mitigation measures.

2 www.ugeeresearch.ie

There are nine tasks as part of Project B that deal with specific elements of the impacts and mitigation measures of UGEE projects, as shown in Figure 1.1 (which also shows the linkages between the tasks and other projects). The tasks include the following, which are described in the corresponding chapters of *Final Report 4 – Impacts and Mitigation Measures*:

- Chapter 4: Environmental water quality impacts and mitigation measures (Task 1);
- Chapter 5: Water resource use impacts and mitigation measures (Task 2);
- Chapter 6: Recycling and reuse of flowback and produced waters (Task 3);
- Chapter 7: Other additional potential impacts and mitigation measures (Task 4);
- Chapter 8: Life cycle assessment (Task 5);
- Chapter 9: Chemical use, impacts and mitigation measures (Task 6);
- Chapter 10: Treatment and disposal of flowback and produced waters (Task 7);
- Chapter 11: Best practice for environmental monitoring of potential impact – linking projects A1, A2 and A3 (Task 8);
- Chapter 12: Assessment of existing and potential monitoring and mitigations techniques (Task 9).

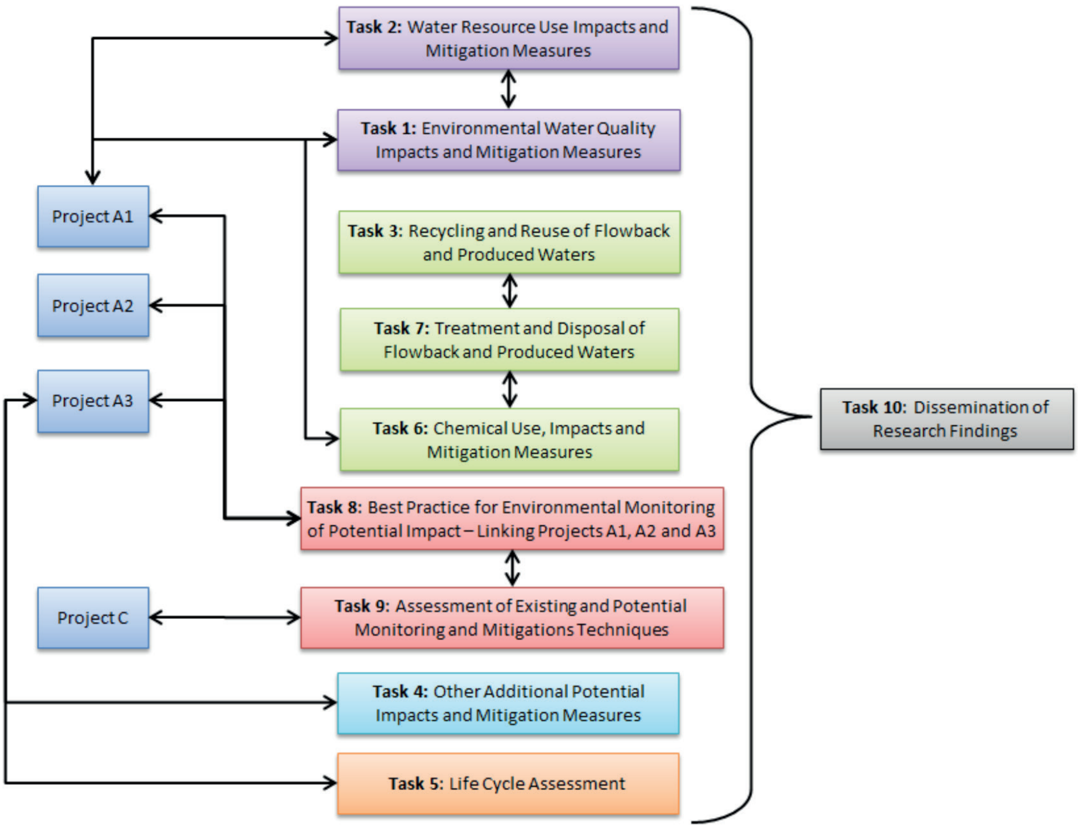

Figure 1.1. Tasks of Project B of the UGEE Joint Research Programme.

2 Background

2.1 Unconventional Gas Exploration and Extraction Projects and Operations

In general terms, UGEE projects follow these stages:

- Predevelopment: exploration, well pad identification and initial site access. This stage includes site identification and selection; site characterisation (baseline monitoring and establishment of baseline conditions for air, water, land, geology/deep-ground conditions); initial evaluation of potential environmental impacts; initial development of the geological conceptual model and geological risk assessment; exploratory boreholes for the evaluation of geology and the reserve; seismic surveys; and securing of necessary development and operation permits. Exploratory drilling is performed to determine if gas can be produced profitably. This stage also includes pad construction and site preparation, including construction of roads and any necessary water containment structures.
- Well design and construction, hydraulic fracturing and well completion. This stage includes pilot well drilling; initial horizontal wells drilled to determine reservoir properties and required well-completion techniques; further development of the geological conceptual model following test fractures; well-head and well design and construction (drilling, casing, cementing, integrity testing); multi-stage hydraulic fracturing (injection of fracture fluid and management of flowback, and produced water and emissions); well completion; and the establishment of the production monitoring network.
- Production (gas extraction). The production stage involves the commercial production of shale gas. The well pad is expanded and the necessary facilities constructed, including storage tanks, impoundments and secondary containment structures. The necessary equipment, water and chemical additives are transported to the site. Horizontal drilling is followed by hydraulic fracturing, and gas production and production monitoring is carried out.
- Project cessation, well closure and decommissioning. The well is decommissioned once it reaches the end of its productive life. Sections of the well are filled with cement to prevent gas flowing into water-bearing zones or up to the surface. A cap is welded into place and then buried, and work is carried out on-site to return it to a satisfactory state. Post-closure monitoring is conducted.

The “probable commercial scenario” approach was used to assess the potential impacts on the environment and human health and the relevant mitigation measures. This approach is a way of standardising assumptions made about future UGEE activities given the uncertainty over whether developments will proceed or not, and if so, how they would develop in Ireland. Details of the probable commercial scenarios used to assess potential impacts are described in section 2.3 of *Final Report 4: Impacts and Mitigation Measures*.

In terms of assessing potential impacts, particular reference is made to two study areas (See Figure 2.1).

- The Northwest Carboniferous Basin (NCB) study area is located in the north-west of Ireland. It includes parts of Counties Leitrim, Sligo, Cavan and Roscommon in Ireland, and part of County Fermanagh in Northern Ireland.
- The Clare Basin (CB) study area covers 495 km^2 of County Clare, along the Irish west coast.

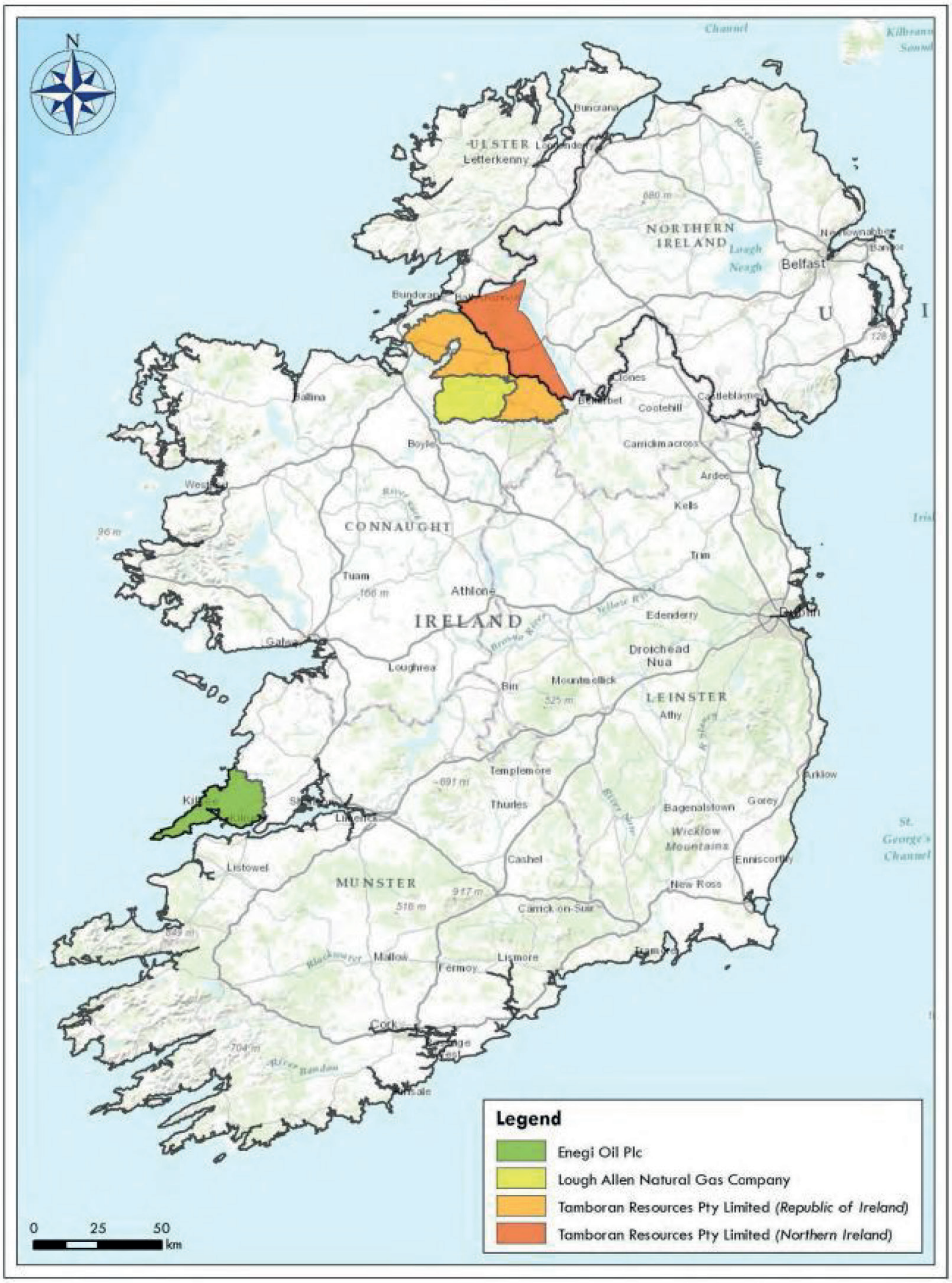

Figure 2.1. Overview of the case study areas of the UGEE Research Programme.

3 Impacts and Mitigation Measures

3.1 Environmental Water Quality Impacts and Mitigation Measures (Task 1)

The objective of Task 1 was to evaluate potential impacts on water resources and to identify relevant mitigation measures associated with UGEE development and production. Specifically, Task 1 addressed potential impacts on the quality of water resources in the case study areas and therefore supplemented Task 2 which assessed the available supply and quantitative aspects of water resource impact.

In Task 1 of Project B, the potential impacts on water quality were evaluated in the context of the following activities:

- storm water runoff and runon from utility corridors, road and pads;
- surface chemical spills and leaks during transportation, storage at well pads, drilling and hydraulic fracturing;
- improper well construction, well completion and operation, including failures during drilling, hydraulic fracturing and production;
- pit, impoundment or tank leaks of on-site stored flowback water, produced water, drilling muds and cuttings; and
- leaks, spills or improper disposal of flowback water, produced water, drilling muds and cuttings during off-site treatment, transportation and disposal.

The assessment methodology followed these basic steps:

- description of specific activities associated with UGEE and their potential impact on water quality (surface and groundwater);
- description of potential impact sources and associated potential contamination (e.g. storm water runoff, additives, drilling muds, flowback water, produced water, etc.) on water resources (i.e. the source element in the source-pathway-receptor model of risk assessment);
- description of potential release scenarios that could impact the quality of water resources (i.e. the pathway element of the source-pathway-receptor model of risk assessment);
- evaluation of risks of potential impacts for each activity and release scenario, with respect to both potential human and environmental receptors (i.e. the receptor element of the source-pathway-receptor model of risk assessment);
- description of relevant management strategies and mitigation measures to minimise or eliminate risks of potential releases and impact; and
- evaluation of cumulative impacts and associated risks.

General conclusions concerning the impacts and mitigation measures identified in Project B are as follows:

- Impacts from storm water runoff from road and pads. Storm water runoff from well pads in the NCB and CB may vary from as low as 400 m^3/month to as high as 5800 m^3/month depending upon the time of year (high or low rainfall months) and stage of activity (during construction, fracturing or production). Likewise, the amount of runoff from new roads may vary from 400 m^3/month per km to as high as 1300 m^3/month per km. Storm water runoff is not unique to UGEE operations. Given the potential volumes of runoff estimated in Ireland and Northern Ireland from each pad and road, the storm water runoff mitigation measures typically available would significantly limit the potential impacts of storm water during UGEE projects/operations if implemented and maintained properly. However, even with state-of-the-art storm water controls, risks still exist with regard to accidental spills, unanticipated events (e.g. rainfalls exceeding design capacities), inadequate designs and implementation and lack of proper maintenance. Therefore, a need still exists for appropriate regulations and approvals, and for oversight and inspections by regulatory bodies. The regulatory framework and potential gaps are addressed in the following reports: *Final Report 5: Regulatory Framework for Environmental Protection* and *UGEE Joint Research Programme Integrated Synthesis Report*.

- Impacts from surface chemical spills and leaks. The quantity of chemical additives used during hydraulic fracturing varies from 5 to 75 m^3 per well. Reported "spill rates" of chemical additives vary between 1.3 and 12.2 spills per 100 wells. The volume of the spills reported ranged from 19 to 72,000 L with a median volume of 1600 L. Despite the large ranges of reported spills and volumes, and the associated uncertainties, the fact remains that spills would occur and operators must be prepared with appropriate responses and mitigation measures. Even with the presence of laws, regulations, approvals and best practices/techniques, spills and leaks happen and therefore regulatory oversight and inspections are needed.
- Impacts associated with well construction, completion and operation. Fluids associated with drilling and hydraulic fracturing operations represent potential sources of contamination to the groundwater environment. Natural gas constituents that are naturally present or are released as a result of hydraulic fracturing operations are also potential sources of contamination, if these migrate to the near-surface environment via natural pathways (such as pre-existing faults), induced pathways (such as fractures created during the fracturing process) or artificial pathways (such as flaws and cracks in the cement grouting in the borehole). Induced subsurface pathways result from the produced fractures associated with the hydraulic fracturing process conducted to release gas from the target formation. The propagation length of fractures must be controlled and minimum vertical separation distances between target formations and aquifers specified. In addition, hydraulic fractures associated with one well may propagate and intersect hydraulic fractures associated with a nearby well. Therefore, the distance between hydraulic fracturing operations and wells must be controlled and minimum distances specified (anticipated to be 150 m to 750 m). Overall, deep hydraulic fracturing is not likely to result in a direct flow pathway into shallow aquifers if adequate separation distances are maintained. Overall, the primary risk of groundwater quality impact is stray gas migration from the gas production zone due to improper, faulty or failed production casing and/or poor or improper cement grouting of casing.
- Impacts from impoundment and tank leaks during storage and treatment of on-site produced wastes. The records document that spills of flowback and produced water can be expected from UGEE-related activities and risks of impacts would reflect the care and adequacy of operations and case- and site-specific risks. These spills are typically relatively small: half are less than 3800 L, and few exceed 38,000 L.
- Impacts from spills during off-site transport of produced wastes. The overall risk of impact from transportation-related spills of flowback and produced water is considered to be low. Using published statistics from the USA (USEPA, 2015) and the largest estimated distance of lorry travel per year in the NCB (384,000 km), this equates to an estimated rate of 0.021 to 0.024 spills per year from lorry accidents involving transport of flowback and produced waters. This does not preclude the fact that a spill could result in an environmental impact.

Project B identified that the planning and prior authorisation stage of UGEE-related activity is, arguably, the most important stage of UGEE development. Whereas implementation of prevention and mitigation measures safeguard against spills and leaks (and therefore potential impact), planning establishes rules, expectations and common understanding.

3.2 Water Resource Use Impacts and Mitigation Measures (Task 2)

Task 2 of Project B addressed the potential water resource impacts and associated mitigation measures. UGEE projects require water for several purposes, including drilling operations, well construction, hydraulic fracturing, sanitation and equipment washing. Concrete plans or details of any potential future UGEE projects/operations in both Ireland and Northern Ireland are as yet not known; accordingly, the actual volumes of water that would be needed for these operations are uncertain. Case-specific circumstances would determine actual water demands at any given well pad. For guidance purposes, ranges of water use requirements for UGEE projects/operations were researched from published international literature and applied to the specific characteristics of the study areas (e.g. depth of source formations and spatial distribution of well pads).

To assess the potential water resource impacts, the activities undertaken as part of Task 2 were as follows:

- The potential water use requirements for UGEE project/operations were defined, with regard to the probable commercial scenarios as set out in Chapter 2 of *Final Report 4: Impacts and Mitigation Measures* of the UGEE JRP. Required volumes of water depend on various factors, including general water demands (e.g. sanitation, equipment washing), drilling methods and progress, numbers of well pads in an area, numbers of wells per pad, details of the fracturing programme and timing of the build-out scenarios. Three scenarios were considered (low, moderate and high) corresponding to a maximum projected water (base fluid) demand of, for example, 186 m^3/day, 1032 m^3/day, and 4110 m^3/day for a representative lease area in the NCB.
- The available water resources in the two case study areas were described, based on the analysis of hydrometric data obtained from relevant information sources and the conceptual hydrogeological models developed. The available water resources of the two study areas are represented by rainwater, lakes and reservoirs, streams and rivers, and groundwater (including springs). Further information on the physiographical, geological and hydrogeological characteristics of the study areas are described in detail in *Final Report 1: Baseline Characterisation of Groundwater, Surface Water and Aquatic Ecosystems* of the UGEE JRP.
- Water use requirements and available water resources were compared, as a means of identifying potential impact. The comparison is contextualised with respect to existing legislation and regulations that currently govern the technical assessment of any potential future UGEE-related abstractions, as well as the metrics that are used by regulatory bodies in describing and reporting on the ecological status objectives of the European Union Water Framework Directive (2000/60/EC).

Short-term demand for water during individual hydraulic fracturing events would define maximum water use requirements. From the probable commercial scenarios, a total demand of 15,000 m^3 is assigned per well per hydraulic fracturing programme at one well pad. Assuming that the hydraulic fracturing programme is carried out over a 3-day period (which is conservatively short), an indicative water demand for that programme would be 5000 m^3/day, although actual demands would be case-specific. More significantly, if identical programmes are carried out at multiple wells concurrently, the total daily demand becomes significantly greater. For the peak build-out scenario defined by the probable commercial scenarios in Project B of the UGEE JRP, there would theoretically be approximately 105 wells for the moderate build-out scenario drilled and hydraulically fractured per year in the NCB study area. Assuming a 3-day duration for each hydraulic fracturing programme, this equates to 315 days of hydraulic fracturing, each requiring 5000 m^3/d in the example given. Therefore, the total demand is driven by how many wells are hydraulically fractured in the same time period and the potential risk of impact on supply (i.e. from the abstraction of available water resources) is determined by how and where the water is sourced.

Potential water resource impacts may be mitigated by:

- reducing demands on water resources (e.g. by the recycling of flowback waters);
- spreading abstractions to multiple sources;
- directing abstractions towards lower sections of catchments (higher-order streams);
- avoiding abstractions from ecologically sensitive catchments and streams; and
- timing operations to avoid overlap between maximum demand periods and low-flow conditions.

When sourcing alternative water supplies or deciding on a water alternative, the options need to be evaluated in a holistic manner and the impacts of the full life cycle of the technology considered (NYSDEC, 2011). For example, the use of some alternative water sources may be associated with a large carbon footprint, which may outweigh the positive environmental impacts associated with their use.

More information on the following general conclusions is available in Chapter 5 of *Final Report 4: Impacts and Mitigation Measures* of the UGEE JRP:

- Lakes: future risks of impact from UGEE-related lake abstractions under the various anticipated water demand scenarios are considered to be small, but this depends on how the water demands develop spatially and temporally. Volumetrically, the risks would be greater in small lakes compared with large lakes. Site-specific, case-by-case studies must be conducted to determine potential impacts and mitigation measures adequately. This includes knowledge concerning ecosystems and related environmental sensitivities, as well as water balance studies that define inflow, outflow and throughflow.

- Streams: the quick flashy nature of the streams' hydrographs, as well as the flat slopes of the low-flow section of available flow duration curves, imply that the majority of streams in the two study areas are sensitive to stream abstractions. Therefore, prior authorisations of any future UGEE-related abstractions should be reviewed in the context of catchment hydrological conditions on a case-by-case basis. In reality, it appears unlikely that the total water demand for UGEE-related activities can or would be sourced from a single catchment or stream. Abstractions which are concentrated in small areas within the same catchment can give rise to environmental concerns, especially during low-flow conditions.
- Groundwater: the hydrogeological characteristics of the bedrock aquifers in the two case study areas are complex. The complexity and the frequent unpredictability of bedrock aquifers means that well yields and the influences of abstractions cannot be predicted with certainty without detailed studies. However, overall, groundwater abstraction pressures in the two study areas are low and in the context of the anticipated UGEE water demand scenarios, groundwater is a viable source of water to meet demands, at least in part. The ability to develop a sufficient supply to meet demands locally for UGEE activities would be subject to exploration and testing and may require multiple wells at multiple locations.

3.3 Recycling and Reuse of Flowback and Produced Waters (Task 3)

The recycling and reuse of flowback and produced water is an important development measure in terms of reducing the impact of water resource requirements for UGEE projects. The rates of water recycling and reuse typically increase as UGEE production expands in the areas and flowback water becomes available for nearby additional well developments.

The ability to recycle and reuse flowback waters is a common and accepted practice in the USA (typically 90% to 95% of the flowback water is recycled and 55% to 60% of produced water is recycled), but this practice may be limited by current regulations in Ireland and Northern Ireland (see project C of the UGEE JRP for additional details). Planned reuse in the Bowland Shale at Roseacre Wood, Lancashire, UK, (Cuadrilla, 2014) was also considered in Project B and water use data from Poland and Germany examined.

Task 3 investigated the current practices and technical aspects of the recycling and reuse of flowback and produced water. While the developing nature of the UGEE practices, as well as the commercial sensitivity around proprietary techniques and water reuse criteria, make it difficult to establish generalised water quality guidelines for reuse, water reuse criteria for hydraulic fracturing found in the literature were examined, compiled and summarised in section 6.3 of *Final Report 4: Impacts and Mitigation Measures* of the UGEE JRP.

Environmental regulations applicable to the reuse and recycling, storage and transfer of flowback and produced water in the Marcellus Shale region (USA), as well as pertinent regulations in the EU, were reviewed. The Ireland and Northern Ireland regulations do not currently have provisions in the regulations for recycling and reuse of flowback and produced water from UGEE operations. Recycling and reuse of flowback water would likely be covered under existing regulations relating to the Waste Framework Directive (EC, 2008) and existing licensing regimes, which are discussed further in Project C of the UGEE JRP, Regulatory Framework for Environmental Protection.

Technical advancements concerning the properties of hydraulic fracturing fluids have resulted in less stringent requirements for reuse (e.g. waters with high dissolved solids content can be used). These advancements require less treatment of produced waters before use as hydraulic fracturing fluids. However, the ability to recycle and reuse flowback or produced waters may be limited by current regulations in Ireland and Northern Ireland (e.g. not all chemical additives would be removed from the flowback water).

Potential problems associated with reuse of flowback and produced water include:

- fluid instability (change in fluid properties);
- well plugging (restriction of flow);
- well bacteria growth (buildup of bacteria on casing);
- well scaling (accumulation of precipitated solids); and
- formation damage (restriction of flow in the reservoir).

3.4 Other Additional Potential Impacts and Mitigation Measures (Task 4)

Task 4 of Project B examined impacts from UGEE projects/operations on other areas not specifically addressed in other sections, such as the evaluations of impacts and mitigation measures on water quality and resources as outlined in Tasks 1 and 2.

The new Environmental Impact Assessment (EIA) Directive (EC, 2014a) came into force on 15 May 2014 to simplify the rules for assessing the potential effects of projects on the environment. The new approach results in greater attention to threats and challenges that have emerged since the original rules came into force some 25 years ago, such as climate change. A full EIA, including a comprehensive and detailed assessment of impacts, can only be carried out at a project proposal and specification stage at which proposed project details are available. However, many of the potential impacts requiring assessment were found to be similar to those managed in other greenfield construction projects, and it is worth noting that, in the majority of cases, a large body of knowledge exists with respect to the successful design and application of these measures. While assessment of potential impacts and associated mitigation measures at this stage is, by necessity, generalised, it is nonetheless estimated that most potential impacts range from imperceptible to moderate, depending on proximity to receptors and magnitude of cumulative impacts. One of the main areas assessed as part of Task 4, where uncertainties are liable to remain, relates to the quantification of long-term greenhouse gas (GHG) emissions. An overview of potential impacts relating to UGEE activities is provided in Table 3.1.

Final Report 4: Impacts and Mitigation Measures of the UGEE JRP lists possible measures which could be used to mitigate these impacts. However, it is acknowledged that the specification of an appropriate suite of mitigation measures would be dependent on the location and details of any proposed project as required under the EIA Directive (EC, 2014a). Measures would have to be monitored to ensure active management of the mitigation process.

3.5 Life Cycle Assessment (Task 5)

Task 5 of Project B evaluated the life cycle environmental assessment of UGEE projects/operations using a literature review and experience from other jurisdictions and compared this with similar published assessments of other energy sources. Life cycle assessment is a multi-step procedure for measuring the environmental footprint of materials, products and services over their entire lifetime, i.e. from “cradle to grave”.

The overall goal of a life cycle assessment is to compare the full range of environmental impacts in order to improve development and operations, support policy and regulatory needs, and provide a basis for decisions. The process is naturally iterative as the quality and completeness of information and its plausibility is constantly being evaluated and tested.

Human activities result in emissions of four principal GHGs: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and the halocarbons (a group of gases containing fluorine, chlorine and bromine). These gases accumulate in the atmosphere, with the result that concentrations increase with time (IPCC, 2007). The predominant GHGs related to UGEE activities are CO_2 and CH_4.

Published estimations of GHG emissions were reviewed for the activities associated with UGEE projects such as transport of materials, drilling, flowback and production. Significant variability was seen in reported estimates, which are sensitive to process management practices and the variations therein. The well completion stage was found to be the most significant source of emissions of the assessed activities, followed by drilling and hydraulic fracturing. Effective implementation of mitigation measures relating to these activities would, therefore, have the most impact on overall levels of emissions. Emissions during the UGEE stages are as follows:

- Stage 1: well pad identification and site preparation. The emissions associated with site preparation are generally small in comparison to other stages in the life cycle. GHG emissions from this stage are dominated by CO_2 from energy use, with some small amounts of methane and nitrous oxides also arising from combustion.
- Stage 2: well design and construction, hydraulic fracturing and well completion. Energy for this stage is typically provided by large, diesel-fuelled internal combustion engines. This drilling step of the process is the same as for conventional and unconventional gas wells. CO_2 emissions during the fracturing stage are primarily a result of fuel combustion.

Table 3.1. Overview of other potential impacts relating to UGEE activities not addressed under water quality and resources

Stage	Environmental aspect	Potential impact
Stage 1	Flora and fauna and biodiversity	Habitat loss or fragmentation
		Transport/growth of invasive species
		Increase in suspended and benthic sediments
		Stormwater runoff of contaminants
		Noise impacts on sensitive species
		Light impacts on sensitive species
		Vehicle movements and disturbance from site operations
	Air quality	Emissions released from off-road diesel engine use and heavy equipment
		Fugitive emissions to air in the event of an equipment fuel or oil spillage
		Fugitive dust emissions
	Landscape and visual	Negative visual impacts of new landscape features, e.g. heavy plant, stockpiles, fencing, site buildings
	Material assets and land use	Impact on local land uses, e.g. recreation and amenity
		Deterioration of road conditions
	Archaeological and cultural heritage	Disturbance/damage through excavation
		Impact on viewshed/landscape surrounding heritage features
	Noise	Disturbance of local wildlife
		Increased noise levels at sensitive receptors
	Traffic	Increase in local traffic/congestion
		Increase in roadside air emissions
		Increase in traffic-related noise
		Potential road safety issues
		Risks of spillages/accidents
	Human beings/community character	Potential influx of workers causing local population growth
		Increased demand for local housing
		Potential disturbance issues
	Agriculture and domestic animals	Loss of available agricultural land
		Potential noise impacts on farm animals
		Potential negative impact on perception of area as clean and unpolluted with associated impact on agri-food products
Stage 2	Flora and fauna and biodiversity	Noise and disturbance
	Air quality	Diesel exhaust fumes from well drilling equipment
		Emissions from diesel-engined plant
		Fugitive emissions to air in the event of an equipment or storage tank fuel or oil spillage
		Proppant can emit significant quantities of dust
		Emission of the fluid components which can be volatile under atmospheric conditions
		Emissions during the well completion process, e.g. benzene, toluene, ethylbenzene, xylene (BTEX)
	Landscape and visual	Negative visual impacts of new landscape features, e.g. heavy plant, stockpiles, fencing, site buildings
	Material assets and land use	Impact on local land uses, e.g. recreation and amenity
		Deterioration of road conditions
	Archaeological and cultural heritage	Impact on viewshed/landscape surrounding heritage features
	Noise	Disturbance of local wildlife
		Increased noise levels at sensitive receptors

Table 3.1. Continued

Stage	Environmental aspect	Potential impact
Stage 2	Traffic	Increase in local traffic/congestion
		Increase in roadside air emissions
		Increase in traffic-related noise
		Potential road safety issues
		Risks of spillages/accidents
	Human beings/community character	Potential influx of workers causing local population growth
		Increased demand for local housing
		Potential disturbance issues
		Potential impact on amenity sites, walking/cycling routes
	Agriculture and domestic animals	Potential negative impact on perception of area as clean and unpolluted with associated impact on agri-food products
Stage 3	Flora and fauna and biodiversity	Disturbance
		Transport/growth of invasive species
		Sediment runoff into streams
		Abstractions and contamination of streams from accidental spills
	Air quality	Emission sources can include well-head compressors or pumps that bring the produced gas up to the surface or up to pipeline pressure
		Well pad equipment bleeding and leaks
		Flare emissions
		Maintenance emissions
		Compressor station emissions
		Dehydrator regeneration vents, venting from pneumatic pumps and devices
		Leaks
		Liquid unloadings and during workovers
		High surface level ozone concentrations, produced by increased NOx and VOC abundance
	Landscape and visual	Negative visual impacts of new landscape features, e.g. heavy plant, stockpiles, fencing, site buildings.
	Material assets and land use	Impact on local land uses, e.g. recreation and amenity
		Deterioration on road conditions
	Archaeological and cultural heritage	Impact on viewshed/landscape surrounding heritage features
	Noise	Disturbance of local wildlife
		Increased noise levels at sensitive receptors
	Traffic	Increase in local traffic/congestion
		Increase in roadside air emissions
		Increase in traffic-related noise
		Potential road safety issues
		Risks of spillages/accidents
	Human beings/community character	Potential influx of workers causing local population growth
		Increased demand for local housing
		Potential disturbance issues
		Potential impact on amenity sites, walking/cycling routes
	Agriculture and domestic animals	Potential negative impact on perception of area as clean and unpolluted with associated impact on agri-food products
Stage 4	Flora and fauna and biodiversity	Loss or fragmentation of a sensitive natural habitat
	Agriculture and domestic animals	Potential negative impact on perception of area as clean and unpolluted with associated impact on agri-food products
	Stray gas, methane emissions/leaks	Post-closure leaks may potentially contribute to GHG effects

NOx, nitrogen oxides (NO and NO_2); VOC, volatile organic compound.

- Stage 3: well production. Methane emissions during production and processing can come from compressors, pumps, dehydration equipment, chemical processing and incidental leaks. Additional GHG emissions may arise from fugitive methane in the form of natural gas migration from a gas well in the event that well integrity has been compromised, especially through failure of the surface casing or the cement used to cap the well.
- Stage 4: project cessation, well closure and decommissioning. Following well closure, there is potential for methane emissions to escape due to cement or well deterioration. Gas may migrate upwards through a cracked or deformed cement sheath into the atmosphere. Emissions data are sparse and there is a resulting lack of quantification of emissions of this nature.

Existing life cycle assessment information and published assessments that focus on the examination and comparison of life cycle assessments relevant to UGEE processes were also reviewed.

Available data were reviewed by comparing UGEE-generated electricity to other methods of electricity generation using 10 lifecycle indicators. Results were seen to be highly variable depending on both the lifecycle indicator under consideration and the method of power generation.

UGEE-generated electricity is reported to have a much greater impact than conventional gas on life cycle indicators such as human toxicity potential (2.9–4.4 times worse), marine aquatic eco-toxicity potential (2–5 times worse) and terrestrial eco-toxicity potential (13–26 times worse) (Stamford and Azapagic, 2014). However, this reported high impact is associated with the disposal of drilling waste to land (landfarming) in the jurisdictions considered; for example, disposal of drilling waste to land accounts for 65% of the marine aquatic eco-toxicity potential. This would not, however, be permitted in Ireland or Northern Ireland, so any terrestrial eco-toxicity associated UGEE-generated electricity would therefore be lower than the value reported by Stamford and Azapagic (2014). The legislative framework with which any UGEE activities would have to comply is further discussed in *Final Report 5: Regulatory Framework for Environmental Protection* (of Project C of the UGEE JRP).

UGEE generation of electricity was estimated to have a significantly reduced impact on other life cycle indicators compared with other methods of production (Stamford and Azapagic, 2014), for example:

- freshwater eco-toxicity potential associated with UGEE was estimated to be an order of magnitude lower than any of the non-gas technologies;
- eutrophication potential was estimated to be between 2 and 13 times better; emissions were estimated to be significantly lower (41% to 49%); and the depletion of fossil fuels was estimated to be between 43% and 49% lower than for coal power;
- abiotic depletion of elements was estimated to be around 19–244 times lower than offshore wind.

3.6 Chemical Use, Impacts and Mitigation Measures (Task 6)

Hydraulic fracturing involves the injection of fluid under pressure to fracture the source formation. Hydraulic fracturing fluids contain chemical additives that are required for different purposes, for example to thicken fluids to increase viscosity, or to reduce the potential for corrosion of pipes and casings. The use of chemicals, particularly additives to hydraulic fracturing solutions, has been a major concern of the public, regulators and the scientific community in recent years. The primary concern has been the use of chemicals that may have the potential to impact human health and/or the environment through the potential contamination of groundwater and the large number of different chemicals used. In addition, the focus of much of the public concern has been the lack of disclosure of the chemicals that were used in the past and the reluctance of UGEE operators to release what they consider commercially sensitive information concerning their additives. An evaluation of chemicals used in UGEE projects including both hydraulic fracturing fluids and drilling fluids was carried out in Task 6 of Project B.

Many potential pathways exist that result in humans and/or the environment being exposed to chemicals, including chemical spills on-site and potential underground contamination of groundwater. Task 6 specifically dealt with the hazards of the chemicals and their potential for causing harm in the event of human exposure or release into the environment; the pathways and potential impacts on surface waters and groundwater are examined in greater detail in Chapter

4, entitled "Environmental Water Quality Impacts and Mitigation (Task 1)".

The hazard classifications of the chemicals were assessed based on existing European legislation. The existing regulatory framework for the management and classification of chemicals is presented, as well as the existing requirements for chemical disclosure. For further analysis of the regulatory framework for UGEE projects, please refer to *Final Report 5: Regulatory Framework for Environmental Protection* of the UGEE JRP, which is designed to assist regulators (both in Ireland and Northern Ireland) in fulfilling their statutory roles.

There are currently no regulations in Ireland or Northern Ireland for the public disclosure of chemicals used in UGEE operations. In "Well guidelines for the exploration and appraisal phase", UKOOG (2015) have recommended that the following information is disseminated on a well-by-well basis:

1. any authorisations for fluids and their status as hazardous/non-hazardous substances;
2. safety data sheets information;
3. volumes of fracturing fluid, including proppant, base carrier fluid and chemical additives;
4. the name of each additive and its purpose in the fracturing process; and
5. maximum concentrations in percent by mass of each chemical additive.

The Environment Agency (EA) and the Scottish Environment Protection Agency (SEPA)[3] have powers to obtain full disclosure of chemicals used in hydraulic fracturing (DECC, 2013). Therefore, it is likely that the EPA and the NIEA have similar powers that they can invoke.

This section also presents the findings of the review of emerging alternatives such as green (or environmentally friendly) and non-toxic chemicals, as well as the viability of chemical-free hydraulic fracturing. This review was based on existing peer-reviewed articles and reports. There are a few examples of fracturing processes that do not use chemicals or certain groups of additives; however, studies concluded that these non-chemical fracturing processes are not mature enough and that much more research will be required before fracturing fluids that do not rely on chemical additives are commercially viable. In addition, it should be noted that eliminating the use of chemicals in hydraulic fracturing fluids does not eliminate the risks from the flowback and produced waters, and their potential pathways.

3 The Environment Agency requires full public disclosure, whereas the Scottish Environment Protection Agency requires disclosure to them, but not to the public.

3.7 Treatment and Disposal of Flowback and Produced Waters (Task 7)

Disposal and treatment of UGEE flowback and produced water are a key vector for potential impacts. Task 7 identified and assessed the success of treatment and disposal methods for flowback and produced water and provided specific case studies from around the world, with specific reference to European examples. Linking with Task 6 (Chapter 9, entitled "Chemical Use, Impacts and Mitigation Measures"), Task 7 also identified the treatment technologies available that can adequately treat typical chemicals used in the fracturing process in combination with likely constituents in produced water. Disposal options linked to the available treatment options were also reviewed and assessed.

The currently used treatment and disposal methods for flowback and produced water were evaluated by completing the following assessments:

- composition of flowback and produced waters;
- wastewater discharge regulations:
  - surface water discharge;
  - deep well injection (DWI) disposal;
  - publicly owned treatment works (POTW) effluent;
- treatment and disposal alternatives:
  - municipal or city treatment plants (so-called POTW in the USA);
  - regional or centralised treatment centres, carrying out treatment and disposal to surface water (multiple processes) and treatment and disposal to DWI;
  - on-site treatment technologies carrying out treatment for recycle and reuse and treatment and disposal to DWI;
  - description of treatment technologies that are components of the treatment schemes described above: oil and solids removal, physicochemical treatment, oxidation, membrane technologies and evaporators/crystallisers.

The review of case studies and operations of publicly owned or municipal treatment plants in the USA shows that flowback and produced waters cannot be adequately treated prior to discharge into streams to prevent human health and environment impacts. As a result, several states in the USA have regulations banning treatment of UGEE flowback and produced waters at municipal treatment plants. (The USEPA has also proposed similar regulations.) In Ireland and Northern Ireland, DWI would not be a viable disposal option for flowback and produced waters based on current regulations, the absence of permitted disposal wells and the outstanding need for technical information and evaluations, including the hydrogeology of potential deep disposal formations. Generally, however, technologies do exist to adequately treat flowback and produced water for reuse as hydraulic fracturing fluids or for direct discharge into streams and lakes (i.e. current Ireland and Northern Ireland water quality standards can be achieved). Based on the probable extent of UGEE development in Ireland and Northern Ireland, and volumes of flowback and produced waters, Project B concluded that the best management option would be the use of centralised treatment facilities with the proper treatment technologies. One centralised treatment facility would be required in the CB (one lease area) and two to three facilities in the NCB (one per each lease area depending upon the timing of development). On-site treatment at individual well pads of the flowback and produced water using modular units would likely be implemented during initial development in the study areas until adequate volumes of waters are produced to maintain centralised treatment facilities.

3.8 Best Practice for Environmental Monitoring of Potential Impact – Linking Projects A1, A2 and A3 (Task 8)

Sub-regional baseline monitoring is described in Final Report 1 of the UGEE JRP for groundwater, surface water and associated ecosystems; in Final Report 2 for seismicity; and in Final Report 3 for air quality. Task 8 co-ordinates the recommended sub-regional baseline monitoring programmes in Project A with baseline, operational and post-operational monitoring at the local scale in Project B. The best practice and effectiveness of monitoring associated with individual UGEE sites are outlined, including the nature and timing of site-specific monitoring in relation to exploration, pilot tests and full scale UGEE development, as well as operations and post-closure operations.

Environmental monitoring is needed before, during and after UGEE activities (exploration drilling, hydraulic fracturing and potential production) at both sub-regional and local scales. There are three types of environmental monitoring which relate to the different stages of UGEE activity, as follows:

- baseline monitoring conducted prior to any construction or operations, to establish pre-existing environmental conditions;
- operational monitoring conducted during construction, drilling, hydraulic fracturing and production activities, in order to be able to identify and track changes from the baseline and determine if such changes can be linked to a particular activity; and
- post-closure monitoring conducted after completion of gas production, well decommissioning and site restoration, to check for potential impact in the long term and verify that mitigation measures have been effective.

In addition to the temporal aspect of monitoring, consideration of scale is also important. UGEE activity is site-specific, so monitoring is needed at the scale of individual well pads and hydraulic fracturing operations. However, UGEE activity also involves operations at several sites in a given region; therefore, it also has a larger footprint with potential for cumulative impact. Accordingly, monitoring at the sub-regional scale is also needed.

The EC recommendations “on minimum principles for the exploration and production of hydrocarbons (such as shale gas) using high-volume hydraulic fracturing” (EC, 2014b) lays down the minimum principles needed to support Member States who wish to carry out exploration and production of hydrocarbons using high-volume hydraulic fracturing, while ensuring that the public health, climate and environment are safeguarded, resources are used efficiently and the public is informed.

The recommendations can be summarised as follows:

- Prior to the commencement of hydraulic fracturing, the baseline or environmental status of the site and its surrounding surface and underground areas that have potential to be affected by the activities should be established.
- The operator should regularly monitor both the installation and the surrounding surface and underground areas during exploration and production.
- The baseline monitoring should be used for subsequent monitoring.
- The operator should monitor the impacts of hydraulic fracturing on the integrity of wells and other manmade structures.
- All monitoring results should be reported to the relevant competent authorities.
- A survey should be carried out after each installation's closure to compare the environmental status of the installation site and its surrounding surface and underground area potentially affected by the activities with the status prior to the start of operations as defined in the baseline study.

The principles and approach towards monitoring are thus risk-based. Accordingly, Project B identified that operators must consider, implement and demonstrate to the competent authorities that risks to the environment and human health from UGEE activity are acceptable and/or manageable. UKOOG (2015) considered that the risk of an incident occurring should be reduced to "as low as reasonably practicable" which moves away from the minimum standards to a continuous effort for improvement. In other words, risk management is objective-driven rather than target-driven.

In addition, specific recommendations are made in Project B with respect to monitoring of the following issues, as well as the general conclusions described below.

- Groundwater
  - Details of the recommended baseline monitoring programme for groundwater are provided in *Final Report 1: Baseline Characterisation of Groundwater, Surface Water and Aquatic Ecosystems* of the UGEE JRP and summarised in Chapter 11.
  - Monitoring groundwater during the construction and operational stage should be carried out to detect any potential impacts on groundwater quality or related receptors due to the UGEE activities; this would require an assessment of the water quality in relation to environmental water quality standards and an evaluation of any changes from the baseline as well as longer-term trends.
  - Post-closure monitoring of methane gas is considered especially important at the wellhead of production wells in the post-closure stage, and dissolved methane gas monitoring in other wells should be continued to be compared to baseline conditions.
- Soils and subsoils
  - Soils and subsoils are relevant in the context of potential impacts from surface sources on contamination of shallow receptors (groundwater resources, surface waters, ecosystems, and water supplies); soil and subsoil types, permeability and thickness describe groundwater vulnerability (EPA, 2011) and are important factors to be considered in the UGEE context.
  - Soil and subsoil sampling is a one-off activity for site-characterisation purposes and should follow best available technology and standard methods, e.g. as described by BS ISO 10381 (BSI, 2009) and BS 5930:2015 (BSI, 2015).
- Ground gas
  - A site-specific baseline ground gas sampling and analysis programme should be developed in line with current best practice guidance for landfills and with BS 8576:2013. The site-specific geology and soil pathway considerations developed from conceptual site models should be taken into account.
  - A long-term methane monitoring programme should be developed to detect possible cement or well deterioration post decommissioning which would need continuous monitoring for ground gas.
- Surface water and discharges
  - Surface water bodies are important potential receptors to UGEE projects. There are potential sources of pollution in direct discharges of treated wastewaters and indirect discharges from the storage, handling and use of fuels, chemicals and drilling additives.
  - It is important to develop a clear conceptual site model to understand the linkages between groundwater and surface water in the hydrogeological setting at a site-specific scale prior to the undertaking of any UGEE projects.

- The list of parameters to be considered for analysis and the monitoring frequency for each are described in *Final Report 1: Baseline Characterisation of Groundwater, Surface Water and Aquatic Ecosystems* of the UGEE JRP and are reproduced in Table 11.1 of *Final Report 4: Impacts and Mitigation Measures*.

- Ecosystems
    - Characterisation of the impacts on ecosystems and wildlife would depend on the location of the well pad and its proximity to sensitive habitats or species. The development of an appropriate suite of mitigation measures would depend on the baseline ecological environment and the potential impacts at an individual site.
    - Monitoring the environmental-supporting conditions of freshwater and wetland habitats may also be required if there is potential for an impact from surface water discharges or underground contamination. This would also be determined during the development of the site conceptual model, where the source-pathway-receptor linkages would have to be examined in detail.
- Air quality
    - Baseline monitoring of air quality is addressed in Project A3 of the UGEE JRP (see Final Report 3).
    - Published studies report that air quality impacts vary from significantly detrimental (Gilman *et al*., 2013; Katzenstein *et al*., 2003; USEPA, 2014; Werner *et al*., 2015) to little or no impact (Bunch *et al*., 2014; Pacsi *et al*., 2013; Pennsylvania Department of Environmental Protection, 2013; Zielinska *et al*., 2011). It is therefore recommended that a precautionary approach must underpin the recommendation of compounds for monitoring (which are covered in more detail in Chapter 11 of *Final Report 4: Impacts and Mitigation Measures* of the UGEE JRP).
- Seismic conditions
    - Building on the work carried out as part of Project A2 of the UGEE JRP, recommendations for seismic monitoring are summarised in section 11.9 of *Final Report 4: Impacts and Mitigation Measures*. These include adequate baseline monitoring to characterise the regional seismic characteristics as well as the implementation of a traffic light system during operation.

3.9 Assessment of Existing and Potential Monitoring and Mitigations Techniques (Task 9)

Task 9 of Project B (Chapter 12 of *Final Report 4: Impacts and Mitigation Measures*) examined the validity and range of existing and potential monitoring and mitigation techniques including, but not limited to, geophysical techniques (down-hole and surface) for use in monitoring, control, horizon selection, and injection management. This section should be read in conjunction with *Final Report 5: Regulatory Framework for Environmental Protection* of the UGEE JRP (Task 4). Project C addresses the regulatory framework covering UGEE operations and reviews the regulatory approach in five case studies.

Monitoring and mitigation measures were compiled from a literature review of measures and techniques being used or recommended for UGEE operations (see Chapter 11 of *Final Report 4: Impacts and Mitigation Measures*). These measures and monitoring techniques are not considered to be prescriptive in scope and specifications, but represent measures which may be considered in the specification of an Operational Management Plan and Environmental Management Plan.

The validity of each measure or technique was considered with respect to its applicability to contexts in Ireland and Northern Ireland, and the scale at which the measure applies. While, in general, not enough information exists to evaluate the effectiveness of individual standalone mitigation measures thoroughly, it was found that extensive documentation exists with respect to the management of risks, the effective mitigation of potential impacts and the specifications of best practices.

However, in order to effectively and safely manage risks, a comprehensive, multi-pronged approach is necessary, involving five distinct, mutually reinforcing elements (Council of Canadian Academies, 2014):

1. Materials, equipment and products must be adequately designed, installed in compliance with specifications and reliably maintained.
2. Materials, equipment and processes associated with the development and operation of UGEE sites must be comprehensively and rigorously managed to ensure public safety and reduce environmental risks.

3. An effective regulatory system based on sound science is required and UGEE developments must be strictly approved, monitored and enforced.
4. Drilling and development plans must reflect local and regional environmental conditions, including existing land uses and environmental risks; some areas may not be suitable for development whereas others may require specific management measures.
5. Public engagement is necessary not only to inform local residents of developments but also to identify which aspects of quality of life and well-being residents value most, in order to protect what is valued by local communities.

Monitoring and mitigation measures were considered under the following groupings:

- Predevelopment: well pad identification and initial site access:
  - Well pad location and design. These mitigation measures relate to the locations of UGEE infrastructure such as well pads, pipelines, access roads, compressor stations and other ancillary facilities. Location and design can limit the magnitude of environmental effects or remove them entirely. Certain ecologically important areas, recreational areas, archaeological resources and sources of drinking water may only be fully protected if certain activities are precluded in proximity to the receptors. It should be noted that the application of horizontal setback distances without considering a site-specific risk-based approach may not be appropriate where a more goal-orientated approach is preferred.
  - Seismic conditions and geology. Investigations and associated evaluations enable accurate predictions of the likely effects and scale of risk to groundwater and to rock formations. A thorough understanding of the geological and hydrogeological environment, together with an appropriate monitoring programme can minimise environmental risks.
- Well/well pad construction and fracturing. Risk management and mitigation measures reduce the likelihood of well failure, which could result in significant underground and surface air and water contamination. These measures focus on structural well design and integrity testing. Management and monitoring of fracturing/flowback operations is important to ensure that the fracturing is proceeding as planned and that associated impacts are avoided, such as well construction or operational failure resulting in hydraulic fracturing fluids or substances mobilised from the underground environment being released to groundwater (via well casing).
- Operational management and production. In common with the development of any industrial site, good site management practices are important to minimise potential environmental impacts. Proper management of flowback fluids is also critically important to the protection of the environment, including both surface and ground water. Measures relating to post-hydraulic fracturing operations, water management and solid waste management should also be included as part of a suite of mitigation measures.
- Project cessation, well closure and decommissioning. Decommissioning of the well should be considered at the design stage; UK legislation requires “design for abandonment”, i.e. that the well should be constructed in such a way that it can be safely and satisfactorily decommissioned. Funding for post-closure monitoring is proposed to be arranged through the provision of a bond by the developer, with a provisional monitoring programme set out for the first 5 years (quarterly at appropriate times of the year in years 1, 3 and 5), to be reviewed at 5-year intervals thereafter, pending review of results and agreement between the regulatory bodies and developer.

4 Conclusions

Project B identified and examined the potential impacts of UGEE projects and operations on the environment and human health, as well as mitigation measures to counteract these impacts, with particular reference to the case study areas identified. Probable commercial scenarios were used to assess the potential impacts on the environment and human health and to assess the mitigation measures. This approach standardises assumptions made about future UGEE activities given the uncertainty of whether or not developments will proceed in Ireland and, if so, how.

The planning and prior authorisation phase of UGEE-related activity was identified as, arguably, the most important phase of UGEE development. Whereas implementation of prevention and mitigation measures safeguard against spills and leaks (and thus their potential impact), planning establishes rules, expectations and common understanding.

Water quality is potentially affected by several UGEE activities: storm water runoff occurring from roads and drilling pads can be addressed by mitigation measures which are typically available and would significantly limit the potential impacts if implemented and maintained properly. Surface chemical spills and leaks will occur and operators must be prepared with appropriate responses and mitigation measures. Fluids associated with drilling and hydraulic fracturing operations together with natural gas constituents that are present or released represent potential sources of contamination of groundwater if these migrate to the near-surface environment via natural, induced or artificial pathways. Accidental spills of flowback and produced water can be expected from UGEE-related activities, and although the overall risk of impact from transportation-related spills of flowback and produced water is considered to be low, these could result in an environmental impact. All of the issues above require appropriate regulation and enforcement.

Generally, deep hydraulic fracturing is not likely to result in a direct flow pathway into shallow aquifers if adequate separation distances are maintained. The primary risk of groundwater quality impact is stray gas migration from the gas production zone due to improper, faulty or failed production casing and/or poor or improper cement grouting of the casing.

The risks of impact from lake abstractions are considered to be small for the larger lakes, although site-specific studies would be necessary to take account of ecosystems and water balance. The majority of streams in the two study areas would be sensitive to stream abstractions. It appears unlikely that the total water demand for UGEE-related activities can or would be sourced from a single catchment or stream, especially during low-flow conditions. Existing groundwater abstractions in the two study areas are low, and groundwater would be a viable source of water to meet demands, at least in part. The recycling and reuse of flowback and produced water is potentially an important measure to reduce the impact of water resource requirements for UGEE projects and operations. However, this may be limited by current regulations in Ireland and Northern Ireland.

Impacts on other receptors not specifically addressed in other sections of the work (such as water quality and water resources) were also addressed (and are summarised in Table 3.1). The assessment of potential impacts and associated mitigation measures is site-specific and so, at this stage, can only be generalised. Nonetheless, it is estimated that most potential impacts range from imperceptible to moderate, depending on the proximity to receptors and magnitude of cumulative impacts. One of the main areas where uncertainties are liable to remain relates to the quantification of long-term GHG emissions.

Technologies exist to adequately treat flowback and produced water for reuse as hydraulic fracturing fluids or for direct discharge into streams and lakes. Based on the probable extent of UGEE development in Ireland and Northern Ireland and the likely volumes of flowback and produced waters, the best management option is likely to be the use of centralised treatment facilities with the proper treatment technologies. On-site treatment at individual well pads using modular units would likely be implemented during initial development.

Environmental monitoring is needed before, during and after UGEE activities at both sub-regional and local scales. This is required at each stage: baseline monitoring prior to any construction or operations; operational monitoring during construction, drilling, hydraulic fracturing and production activities; and post-closure monitoring conducted after completion of gas production, well decommissioning and site restoration. Monitoring and mitigation measures were compiled from an extensive literature review of measures and techniques being used or recommended for UGEE operations. They were considered in the context of different activities in UGEE projects and operations and, while these measures and monitoring techniques are not considered to be prescriptive in scope and specifications, they do represent a range of measures that may be considered in the specification of an Operational Management Plan and Environmental Management Plan.

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Abbreviations

CB	Clare Basin
DCCAE	Department of Communications, Climate Action and Environment
DCENR	Department of Communications, Energy and Natural Resources
DfE	Department for the Economy
DWI	Deep well injection
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
GHG	Greenhouse gas
JRP	Joint Research Programme
NCB	Northwest Carboniferous Basin
NIEA	Northern Ireland Environment Agency
POTW	Publicly owned treatment works
UGEE	Unconventional gas exploration and extraction

Summary Report 4: Impacts and Mitigation Measures

Roinn Cumarsáide, Gníomhaithe ar son na hAeráide & Comhshaoil
Department of Communications, Climate Action & Environment

Northern Ireland Environment Agency
www.daera-ni.gov.uk

Authors: Roger Olsen, Dawn Keating, Carlos Claros, Henning Moe and Lorraine Gaston

Unconventional gas exploration and extraction (UGEE) involves hydraulic fracturing ("fracking") of low permeability rock to permit the extraction of natural gas on a commercial scale from unconventional sources, such as shale gas deposits, coal seams and tight sandstone.

The UGEE Joint Research Programme (JRP) (**www.ugeeresearch.ie**) is composed of five interlinked projects and involves field studies (baseline monitoring of water and seismicity), as well as an extensive desk-based literature review of UGEE practices and regulations worldwide. The UGEE JRP was designed to provide the scientific basis that will assist regulators - in both Northern Ireland and Ireland - to make informed decisions about whether or not it is environmentally safe to permit UGEE projects/operations involving fracking. As well as research in Ireland, the UGEE URP looks at and collates evidence from other countries.

The JRP is funded by the Department of Communications, Climate Action and Environment, DCCAE (formerly the Department of Communications, Energy and Natural Resources (DCENR) and the Environment Division of the Department of Environment, Community and Local Government (DECLG)) and the Northern Ireland Environment Agency (NIEA). The research programme was managed by a steering committee comprising the EPA, representatives from DCCAE, the Geological Survey of Ireland, Commission for Energy Regulation, An Bord Pleanála, NIEA, the Geological Survey of Northern Ireland and the Health Service Executive.

List of Outputs:

- Final Report 1: Baseline Characterisation of Groundwater, Surface Water and Aquatic Ecosystems
- Summary Report 1: Baseline Characterisation of Groundwater, Surface Water and Aquatic Ecosystems
- Final Report 2: Baseline Characterisation of Seismicity
- Summary Report 2: Baseline Characterisation of Seismicity
- Final Report 3: Baseline Characterisation of Air Quality
- Summary Report 3: Baseline Characterisation of Air Quality
- Final Report 4: Impacts & Mitigation Measures
- Summary Report 4: Impacts & Mitigation Measures
- Final Report 5: Regulatory Framework for Environmental Protection
- Summary Report 5: Regulatory Framework for Environmental Protection
- UGEE Joint Research Programme Integrated Synthesis Report

EPA Research: McCumiskey House, Richiew, Clonskeagh, Dublin 14.

Phone: 01 268 0100
Twitter: @EPAResearchNews
Email: research@epa.ie

www.ugeeresearch.ie