Can shale gas be extracted safely?

Groundwater, well integrity, use of water

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Introduction

• Groundwater in the UK in relation to shale gas

• Environmental issues associated with Shale Gas:
  - Water requirements and demands
  - Potential pollutants and sources
  - Pollutant pathways
  - Wastewater treatment
Shale and aquifer distribution
Groundwater protection

- Risk-based approach to management and protection: groundwater quality and resources
- Environmental objectives established by EU and UK legislation (e.g. WFD, GWD)
- Proactive and reactive resource protection:
  - Groundwater Protection Policy (GP3)
  - Legal instruments: regulations, permits and notices
  - Supporting tools:
    - Risk assessment tools: GWV maps, SPZs, models
    - Industry codes of practice and guidance
    - Monitoring
Water consumption

- Each well may require 250 – 4000m$^3$ of water to drill, then 7000–23,000m$^3$ for hydraulic fracturing$^a$. Example of published estimates (per well)$^b$:

<table>
<thead>
<tr>
<th>Shale Play</th>
<th>Drilling (m$^3$)</th>
<th>Fracking (m$^3$)</th>
<th>Total (m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barnett (US)</td>
<td>950</td>
<td>14000</td>
<td>14950</td>
</tr>
<tr>
<td>Haynesville (US)</td>
<td>2300</td>
<td>19000</td>
<td>22300</td>
</tr>
<tr>
<td>Fayetteville (US)</td>
<td>250</td>
<td>19000</td>
<td>19250</td>
</tr>
<tr>
<td>Marcellus (US)</td>
<td>300</td>
<td>21000</td>
<td>21300</td>
</tr>
<tr>
<td>Eagle Ford (US)</td>
<td>500</td>
<td>23000</td>
<td>23500</td>
</tr>
<tr>
<td>Bowland Shale (UK)</td>
<td>900</td>
<td>8400</td>
<td>9300</td>
</tr>
</tbody>
</table>

- Variation reflects complexity of drilling, geological conditions, total depth/number of fracking stages.

$^a$ Range obtained from various published sources (mostly US).

$^b$ University of Texas (2012) and Cuadrilla
Water demand

- To meet 10% UK demand from shale gas over 20 year period - projected water requirement\(^a\):
  
  \[25 - 33 \text{ million cubic metres}\]

- Equivalent to an annual water demand of:
  
  \[1.2 - 1.6 \text{ million cubic metres}\]

- Licenced annual water abstraction for England and Wales (2010) :
  
  \[12.2 \times 10^3 \text{ million cubic metres}\] \(^b\)

\(^a\) Estimate from Tyndall Centre report (2011)

\(^b\) http://www.defra.gov.uk/statistics/environment/inland-water/
Water resource availability

Surface water and groundwater

Groundwater only


Environment Agency – WFD, 2009
Contamination concerns

- Methane (shale gas)
- Fracking chemicals
- Flowback fluids and produced water

Potential routes to groundwater (and other receptors):
- Geological as a result of fracking
- Well casing failure
- Release at surface – preparation, storage, transport, disposal
## Composition of shale gas

<table>
<thead>
<tr>
<th>Name</th>
<th>Formula</th>
<th>Typical content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>CH\textsubscript{4}</td>
<td>70–90</td>
</tr>
<tr>
<td>Ethane</td>
<td>C\textsubscript{2}H\textsubscript{6}</td>
<td>0–20</td>
</tr>
<tr>
<td>Propane</td>
<td>C\textsubscript{3}H\textsubscript{8}</td>
<td>0–8</td>
</tr>
<tr>
<td>Butane</td>
<td>C\textsubscript{4}H\textsubscript{10}</td>
<td>0–5</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>CO\textsubscript{2}</td>
<td>0–8</td>
</tr>
<tr>
<td>Oxygen</td>
<td>O\textsubscript{2}</td>
<td>0–0.2</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>N\textsubscript{2}</td>
<td>0–5</td>
</tr>
<tr>
<td>Hydrogen sulphide</td>
<td>H\textsubscript{2}S</td>
<td>0–5</td>
</tr>
<tr>
<td>Rare gases</td>
<td>Ar, He, Ne, Xe</td>
<td>Trace</td>
</tr>
<tr>
<td>Radon</td>
<td>Rn\textsuperscript{222}</td>
<td>?</td>
</tr>
</tbody>
</table>

from Natural Gas Supply Association, 2010

- Hydrocarbons explosive – 5-10% methane in air is explosive
- Radon – radioactive gas and carcinogenic
Fracking fluid

### Composition of Hydraulic Fracture Fluid (by volume)

- **Water**: 94.60%
- **Sand**: 5.30%
- **Additives**: 0.37%
  - a. Scale inhibitor: 0.03%
  - b. Acid: 0.03%
  - c. Biocide: 0.01%
  - d. Friction reducer: 0.07%
  - e. Surfactant: 0.04%

**Constituent** | **Composition (% by volume)** | **Example** | **Purpose**
--- | --- | --- | ---
**Water and sand** | 99.50 | Sand suspension | “Proppant” sand grains hold microfractures open
**Acid** | 0.123 | Hydrochloric or muriatic acid | Dissolves minerals and initiates cracks in the rock
**Friction reducer** | 0.088 | Polycrylamide or mineral oil | Minimizes friction between the fluid and the pipe
**Surfactant** | 0.085 | Isopropanol | Increases the viscosity of the fracture fluid
**Salt** | 0.06 | Potassium chloride | Creates a brine carrier fluid
**Scale inhibitor** | 0.043 | Ethylene glycol | Prevents scale deposits in pipes
**pH-adjusting agent** | 0.11 | Sodium or potassium carbonate | Maintains effectiveness of chemical additives
**Iron control** | 0.004 | Citric acid | Prevents precipitation of metal oxides
**Corrosion inhibitor** | 0.002 | n,n-Dimethyl formamide | Prevents pipe corrosion
**Biocide** | 0.001 | Glutaraldehyde | Minimizes growth of bacteria that produce corrosive and toxic by-products
**Breaker** | 0.01 | Ammonium persulphate | Allows a delayed breakdown of gel polymer chains
**Crosslinker** | 0.007 | Borate salts | Maintains fluid viscosity as temperature increases
**Gelling agent** | 0.056 | Guar gum or hydroxyethyl cellulose | Thickens water to suspend the sand
**Oxygen scavenger** | - | Ammonium bisulphite | Removes oxygen from the water to prevent corrosion

- Estimates of additives component: 0.1 – 2.0%
- Continued development
- Greater openness now in the US
- UK regulation requires authorisation
- Fate of injected fluids:
  - 20-80% returns as flowback
  - Remainder stays in formation

*after Gregory, 2011 and Ground Water Protection Council and ALL Consulting, 2009*
Flowback/produced water

- Flowback – reflects fracking fluid composition modified by residual material from drilling and fracking, and some formation water
- Produced water increasingly reflects formation water over time. This may include: metals (e.g. zinc, chromium, nickel), arsenic, sodium, calcium, magnesium, chloride, and NORM (U, Ra)
- Safe handling, storage and disposal of wastewaters is required by EA:
  - Small volumes – industrial wastewater treatment plants
  - Larger volumes – specialist processing for disposal and/or re-use
Sources of methane in sub-surface
Methane – basic geochemical props

- **Biogenic/bacterial** (e.g. wetland, landfill):
  - high $C_1/C_{2+}$ ratio
  - low $\delta^{13}C$ values ($>-64\%$) and $\delta^2H$ ($>-175\%$)
  - Measurable $^{14}C$

- **Thermogenic** (e.g. natural gas, coalbed methane):
  - low $C_1/C_{2+}$ ratio
  - higher (less negative) $\delta^{13}C$ ($<-50\%$) and $\delta^2H$ values ($<-240\%$)
  - No $^{14}C$
Methane in groundwater

- Methane in groundwater is well known: multiple examples in literature
- Interpretation of the data should consider all possible sources and pathways
- Sub-surface provides multiple potential sources and pathways – natural and engineered
- Multiple lines of investigation/evidence needed
Pathways - geological

- Extent of induced fractures limited
- Distance between source and receptor ‘000s metres
- Multi-layered complex geological sequence

Min separation $>1200m$
Well design

- Shale gas well design principals same as other oil/gas well design
- Industry standards: API, BS:ISO, HSE
- Well Integrity: material selection and well completion
- Casing: conductor/surface/intermediate/production
- Well testing:
  - Formation integrity testing
  - Cement bond (CBL/VDL)
Pathways – poor design

• Example of Poor well location, design and construction

• Pavillion, Wyoming

• US EPA investigation into groundwater pollution from unconventional gas production

• Exploitation of gas from 372 m bgl

• Aquifer exploited to 244 m bgl

• Poor design, location, construction:
  • Storage pits
  • Surface casing too shallow
  • No or poor cement seals

• Contamination by methane and other hydrocarbons, fracking chemicals and deep formation waters

Draft report: EPA 600/R-00/000 (USEPA, 2011)
EA/BGS Baseline Project

- 29 reports
- Range of aquifer types
- Common format:
  - geology/hydrogeology
  - environmental data
  - historical/current data
  - hydrochemistry plots
  - geochemical controls
  - evolution of chemistry
  - depth profiles
  - trends

www.bgs.ac.uk/research/groundwater
1. Waters characterised using:
   - Dissolved concentrations of CH$_4$ and CO$_2$ plus general water chemistry
   - DOC
   - C and H stable isotopes of CH$_4$, C-14, stable isotopes of CO$_2$ and DIC
   - Trace organics
   - Groundwater residence time indicators (CFCs, SF$_6$)
   - Microbiological indicators

2. Collation of other data

Location of existing groundwater methane analyses (red circles), current onshore UK Petroleum Exploration and Development Licences (grey areas), and key areas of shale gas interest (green outlines)
Summary

- Some potential shale gas areas identified in the UK underlie aquifers. Groundwater protection measures exist and are effective.
- Water demand for shale gas production is projected not to be significant relative to other uses but local availability may be an issue.
- Shale gas exploration/production uses/mobilises chemicals/substances that are potential pollutants. The risks need to be assessed and managed effectively.
- Risk assessment needs to consider all potential sources of pollution, potential pathways and receptors.
- Based on available literature the biggest risks appear to be from activities on the surface, followed by lack of regulation, poor well design/completion.
References

• Cuadrilla Resources web site. www.cuadrillaresources.com
• Defra environmental statistics: http://www.defra.gov.uk/statistics/environment/inland-water
• Baseline - the Natural Quality of Groundwater in England and Wales. A joint programme of research by the British Geological Survey and the Environment Agency. www.bgs.ac.uk/research/groundwater