EVALUATION OF NERC CENTRES 2013

IMPACT CASE STUDIES: BRITISH GEOLOGICAL SURVEY

Note: confidential aspects of the case studies have been deleted where necessary.

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BGS01: Carbon capture and storage (CCS)

1. Summary of the impact
BGS has influenced and informed Government by communicating research results and providing advice on the feasibility and safety of CCS as climate mitigation, leading to its adoption as policy. In 2011 BGS also contributed to the adoption of CCS in developing countries through the Clean Development Mechanism by providing information to the UN Framework Convention on Climate Change (UNFCCC) negotiators. BGS supports assessment of CO₂ storage in major CO₂-emitting developing countries such as China, India and South Africa. In Britain, BGS scopes the target formations in the UK North Sea where this potential £3–6.5 billion a year business would be based.

2. Nature of the impact
1. **Adoption of CCS as Government policy.** BGS is a world pioneer of CCS and has the largest and longest-established storage research group in Britain. Sustained BGS research has put CCS on the UK research map, and contributed to the adoption of CCS as one of the chief climate-mitigation policies of the UK government. If CCS develops as anticipated, benefits for UK-based firms have been estimated to be between £3 and 6.5 billion a year by the late 2020s. CCS also allows UK government emissions reduction commitments in law to be achieved at a significantly lower cost than other options.

2. **Adoption of CCS in the Clean Development Mechanism.** In 2011 BGS had a direct influence on the adoption of CCS in the Clean Development Mechanism (CDM). The incorporation of CCS into the CDM opens the door for deployment of CCS in the developing world allowing developed nations to finance CCS in some of the world’s potential big-emitting countries.

3. **Development of UK and EU CCS regulation.** BGS expert input has also strongly influenced the development of CCS regulation. BGS led the CO₂ storage part of the IPCC Guidelines for National Greenhouse Gas Inventories that influenced the regulations for CO₂ storage sites in the EU Directive on geological storage of CO₂, and acted as an advisor to government during the (1) OSPAR and (2) Protocol to the London Convention negotiations that allowed CO₂ storage in subsea geological formations. These were ratified in 2011 and 2007 respectively. BGS provided recommendations for the inclusion of CCS monitoring within the EC Emissions Trading Scheme. More recently, BGS has provided occasional ad hoc advice to the EC in the development of regulations for the EU Directive on CO₂ storage (implemented in 2009) and to the Department for Energy and Climate Change (DECC) in the development of the UK regulatory framework for CO₂ storage (implemented in 2012), as well as advice on DECC’s recent storage road map (2012). The direct beneficiaries of this impact are CO₂ storage operators and regulators in the UK and Europe, but ultimately good regulation ensures safe storage and public confidence in CCS. Regulation that aims at accounting for amounts of CO₂ stored enables emissions trading systems to operate, which in turn may provide the mechanism for funding CCS as a climate-change mitigation option in the long term.

4. **Overall safety and feasibility of CCS.** BGS has strongly influenced the way that CO₂ storage is seen by scientists, policy-makers and the public, and has contributed to the view that CCS is viable, feasible and safe. An example of this is our work with Statoil at Sleipner in the North Sea, the world’s first and longest operating CCS demonstration project. BGS has been continuously involved in the monitoring of the Sleipner CO₂ storage site in the North Sea since its inception. As well as showing that CO₂ can be imaged and quantified in the subsurface, the work at Sleipner has helped to portray CCS as more than just a ‘black box’, allowing it to be understood by a wider audience than before. Perhaps most crucially, the research shows that stored CO₂ can be successfully monitored and that the Sleipner store is not leaking.

5. **Direct response to claims of CO₂ leakage.** BGS also has the largest CO₂ surface monitoring research group in Britain using bespoke instruments to detect and measure CO₂ flow at the surface and in the atmosphere. Rumours of CO₂ leakage at the Weyburn CO₂-Enhanced Oil Recovery project in Canada were reported in the world’s media in 2011. BGS conducted leakage surveys, compared them with earlier baseline surveys and was able to refute leakage claims (2012). Demonstration that a storage site can be successfully monitored contributes to public and investor confidence. The beneficiaries of monitoring include oil companies, power companies, policy-makers and regulators, and environmental NGOs.
6. **Preparation for CCS as a major UK industry.** Recent BGS work concentrates on regional and site-specific problems of CCS at likely target storage formations in the North Sea, in preparation for CCS as a major UK offshore industry. The beneficiaries of this work are the UK storage regulator (DECC), site leaseholder (The Crown Estate) and potential storage operators.

7. **Feasibility of CCS in the largest potential CO₂ emitters in the developing world.** Whether CCS is taken up in developing countries which have very large potential future CO₂ emissions depends on their geological potential for storage. BGS has worked with local industry, government, universities, science institutes and international funding agencies in China, India and South Africa to develop maps and capacities of CO₂ storage formations. The beneficiaries include governments and industry as well as investors.

### 3. How the Centre contributed to the impact

1. **Adoption of CCS as Government policy** BGS has consistently carried out, published and reported research in CCS since the mid 1990s. BGS coordinated the first EU FP4 project Joule2 and provided an author for the IPCC Special Report on CCS. BGS co-ordinated the European Network of Excellence CO2GeoNet (2004–08), as well as working on projects and collaborations such as: (1) The EU Weyburn project (1999–2004) — long-term reservoir processes and assurance of containment; (2) Nascent (1999–2004) — long-term trapping and leakage; (3) Dynami (2006–09) — hydrogen and electricity production with CCS; (4) EU GeoCapacity project (2006–09) — assessing European capacity for geological storage of carbon dioxide; (5) CO2ReMoVe (2006–12) — storage site performance assessment and monitoring; (6) RISCS (2010 ongoing) — environmental impacts of geological storage of CO₂; (7) CO2CARE (2011 ongoing) — research requirements of CO₂ storage site closure; (8) SiteChar (2011 ongoing) — European storage sites and ‘dry-runs’ of storage permit development for operators and regulators; (9) CGS Europe (2011 ongoing) — pan-European coordination of CO₂ Storage. In 2008 BGS produced, edited and published ‘Best Practice for the Storage of CO₂ in Saline Aquifers’ — a much-quoted worldwide benchmark, which has recently been translated into Chinese. BGS researchers have published over 100 papers between 2007 and 2012 and contributed to over 200 conferences and workshops, as well as directly advising Government in many capacities (for example acting as the advisors to DECC on the UK CCS Competition Demonstration 1, 2007–2010). The thrust of this long history of research has shown that CCS is feasible and safe and this has contributed to CCS being taken up as Government policy.

2. **Adoption of CCS in the Clean Development Mechanism** BGS staff presented keynote lectures on storage and monitoring at the UNFCCC workshop in Abu Dhabi in September 2011 which shifted opinion at the workshop whose conclusions were fed forward to the UNFCCC CMP7 meeting in Durban. The EU Lead negotiator in Durban stated that the BGS contributions to the Abu Dhabi workshop were instrumental in UNFCCC CMP7 adopting CCS into the Clean Development Mechanism (CDM).

3. **Development of UK and EU CCS regulation** BGS contributed to the impact by providing expert advice to the Intergovernmental Panel on Climate Change (IPCC), DECC and EU.

4. **Overall safety and feasibility of CCS** BGS worked on time-lapse 3D seismic data from Sleipner acquired in 1994, prior to injection, and again in 1999, 2001, 2002, 2004, 2006, 2008 and 2010 with around 11 million tonnes of CO₂ in the reservoir at the time of the last survey. Through innovative processing and analysis, spectacular seismic images were obtained of the plume of injected CO₂ above and around the injection point. The reflections are interpreted as wavelets from thin (just a few metres thick) layers of CO₂ trapped beneath intra-reservoir beds of shale. The data shows the precise subsurface location of the CO₂ plume and confirms that, so far, the CO₂ is confined securely within the storage reservoir. Current research work at BGS is focused on understanding detailed migration processes within the plume by relating the seismic signals directly to CO₂ distributions and amounts in the reservoir and history-matching numerical-flow simulations with the observed data.

5. **Direct response to claims of CO₂ leakage** For the Weyburn CO₂-Enhanced Oil Recovery project, BGS undertook monitoring surveys (2011–12) measuring a number of key parameters, which were able to disprove the leakage claim (2012).

6. **Preparation for CCS as a major UK industry** In the Bunter Sandstone, a major southern North Sea reservoir, a methodology has been developed for assessing the pressure increase that CO₂ storage sites can tolerate without suffering adverse geomechanical effects such as fracturing (2012). BGS has also
modelled potential regional pressure rise in the Bunter Sandstone to develop ways of maximising storage while not ‘sterilising’ future storage structures.

7. **Feasibility of CCS in the largest potential CO₂ emitters in the developing world**

BGS coordinated research into the feasibility of CO₂ storage in north-east China, as part of the UK Near Zero Emissions China (NZEC) programme which finished in 2009. UK, Chinese and European policy-makers were provided with estimates of CO₂ storage potential. BGS carried out CO₂ storage-capacity assessments for India, Bangladesh, and is working with industry and government to realise CO₂ storage options in South Africa (BGS leads the FP7 SAfECCS project and has provided external reviews of other storage assessments in South Africa).

### 4. Evidence sources to corroborate the impact

1. **Adoption of CCS as Government policy**
   - IPCC special report on CCS (http://www.ipcc.ch/index.htm#.UK36GYYbR8E);
   - Dynamis website;
   - EU GeoCapacity project [http://www.geology.cz/geocapacity/project/management](http://www.geology.cz/geocapacity/project/management);
   - CO2ReMoVe [http://www.co2remove.eu/](http://www.co2remove.eu/);
   - SiteChar [http://www.sitechar-co2.eu/](http://www.sitechar-co2.eu/);

2. **Development of UK and EU CCS regulation**
   - OSPAR and Protocol to the London Convention
   - EU Directive
   - DECC’s storage road map

3. **Overall safety and feasibility of CCS**

A testament to BGS work in this area appears in the book *Challenged by Carbon* by Bryan Lovell (Cambridge University Press) p. 135: ‘...it should be noted that Drs Andy Chadwick, Sam Holloway and Nick Riley (BGS) have played a pioneering role...in technical matters....’, Lovell goes on to show how BGS has influenced views of CCS feasibility in Britain and globally.

Many BGS papers have been published on this topic but two important examples are: (1) Chadwick, et al., 2012. Measuring pressure performance of a large saline aquifer during industrial scale CO₂ injection: the Utsira Sand, Norwegian North Sea. (2) Chadwick et al., 2010. History-matching flow simulations and time-lapse seismic data from the Sleipner CO₂ plume.

4. **Direct response to claims of CO₂ leakage**


5. **Preparation for CCS as a major UK industry**


6. **Feasibility of CCS in the largest potential CO₂ emitters in the developing world**

CO₂ storage potential in selected regions of north-eastern China: regional estimates and site specific studies are in the Final report of the Near Zero Emissions Coal (NZEC) Project, Work Package 4 (2) COACH [http://www.co2-coach.com/](http://www.co2-coach.com/);

(3) India IEA GHG project published as report 2008/2 for the International Energy Agency.

### 5. Contact for further information

Dr A Chadwick, rach@bgs.ac.uk.
## BGS02 – Geomagnetic Field: Application in Hydrocarbons Production and Space Weather Hazard

### 1. Summary of the impact
NERC’s investment in long-term geomagnetic monitoring, combined with BGS expertise in core, crustal and external magnetic field modelling, has allowed BGS to build commercially successful 24/7 sub-surface navigation services for the oil and gas sector, and space weather hazard monitoring/analysis modelling services for the electricity industry. The **BGS Global Geomagnetic Model** (BGGM), together with **In-Field Referencing** (IFR) and **Interpolation In-Field Referencing** (IIFR) services have improved directional drilling performance, bringing economic benefit, and helped mitigate environmental and safety risks. BGS space weather data and services inform the Natural Hazards Partnership (NHP), the National Risk Assessment and supports National Grid in operational decisions.

### 2. Nature of the impact

#### A. IIFR/IFR/BGGM: Improving the cost-effectiveness and safety of drilling operations

**Summary of Impacts:** Improved business performance; business sector adopting new methodologies; losses mitigated in safety critical operations; mitigation of environmental (pollution) risks; IIFR patent.

**Beneficiaries:** Major oil and gas exploration and production companies, and service companies.

**Nature of Impact:** BGS-led development of IFR and IIFR has resulted in cost effective services for the oil industry able to compete with gyro-based surveys, and this has allowed the exploitation of small hydrocarbon targets, e.g. in the North Sea, that may otherwise have been left untapped. An offshore rig may (conservatively) cost £250k per day to operate. Gyro surveys require the drill string to be removed before the survey; wellbore surveys using magnetic tools, supported by BGS services, can be carried out with the drill string in place (measurement while drilling - MWD). Where down-hole magnetic surveys displace gyro surveys, many hours of rig time are saved on every hole drilled (and 50 wells may be drilled from an offshore rig). Drilling safety has been improved through reduced risk of blow outs from intersecting wellbores which have damaging consequences for the environment and operator reputation. IIFR and IFR services have had impact in terms of the environment, public policy and services, the economy, in new and improved business (e.g. expansion from the North Sea to worldwide).

**Sustainability:** Commercial use of IFR and IIFR services has grown since the mid 1990s (>£8M/£1M in the last/first 5 years). BGS involvement in the ESA Swarm satellite mission (2013) will lead to research that will improve BGGM magnetic field model accuracy, increasing the attractiveness of the IIFR/IFR/BGGM solution.

**Evidence and Dates of Impact:** IIFR has been applied in the drilling of >3500 oil wells worldwide during period of this review (and 5400 in total).

**Future Potential:** The demand for services has been steadily growing around the world; IIFR/IFR is used in the North Sea, Norwegian Sea, Barents Sea, Alaska, Gulf of Mexico, Canada, Far East, Australia and Africa.

#### B. Space Weather: Mitigating risk from geomagnetic hazards

**Summary of Impacts:** Improved management of electricity generation and transmission systems to mitigate losses from space weather damage to high voltage transformers through geomagnetically induced currents; policy debate stimulated; national risk reduction; stimulation of public discourse and interest; parliamentary and media debate; contribution to Government guidance.

**Beneficiaries:** Cabinet Office (Civil Contingencies Secretariat), Government Office for Science, Department of Energy and Climate Change, National Grid, Scottish Power, Met Office, European Space Agency.

**Nature of Impact:** BGS provides the primary UK capability in modelling and analysis of geomagnetically induced currents in electrical transmission systems caused by space weather, that can trip- or burn-out transformers. This expertise has been drawn on in developing extreme event scenarios and their impacts to support the Cabinet Office (for the National Risk Assessment) and other Government departments (e.g. Government Office for Science, DECC, DfT). Real time services have been developed for National Grid (aiding operational decision making) and for the UK Met Office (the NHP daily hazards assessment).

**Sustainability:** Space weather is an ever-present natural hazard with an approximate 11-year cycle of activity, but extreme and damaging events may occur at any time. The risk is changing rapidly as space- and ground-based technologies evolve (e.g. GNSS services, electricity grids), increasing vulnerability and exposure. Transitioning research to operations is a key demand from industry and Government.

**Evidence and Dates of Impact:** Commissioned service for National Grid (2011-present). Contributions to UK
3. How the Centre contributed to the impact

A. IIFR/IFR/BGGM: Improving the cost-effectiveness and safety of drilling operations

**Nature of Insight Leading to Impact:** The IIFR service was developed during the late early 1990s by BGS with the support of Halliburton (Sperry Drilling Services) and BP, resulting in a joint NERC/Halliburton patent. The industry requirement in extended reach directional drilling is to hit small (~100m) targets at large distances (~10km), for economic benefit. Well plans need a reliable ellipse of uncertainty along their entire path to show that hitting the target is feasible, and that collisions with other wells (potential blow-outs) will be avoided. The key breakthrough was demonstrating how a global core field model, (now the BGGM) could be combined with aeromagnetic survey data (via the application of novel analysis methods to generate vector field estimates from scalar measurements), and real-time magnetic observatory data (including from the BGS magnetic observatory network) to reduce well-path uncertainties, enabling MWD surveys to compete on accuracy with the gyro ‘gold standard’. The concept was to operate a ‘virtual’ magnetic observatory at the drill bit. The potential time (and hence cost) savings, motivated industry to fund the research. (IFR refers to cases where the magnetic observatory data ‘layer’ is not used because time variations are small.)

**Outline of Activities and Dates of Developments:** The annually updated BGGM (1990-present), at the core of the IIFR/IFR services, is based on world-wide magnetic measurements made on land (e.g. at the eight BGS observatories), sea, air and by satellites. BGS activities for the ESA ‘Swarm’ geomagnetic satellite survey mission during planning, and ahead of the operational phase, continues to support BGGM improvements (2003-present). (The BGGM is an off-shoot of BGS/US modelling for 5-year revisions of the World Magnetic Model used for navigation and in attitude and heading referencing systems by the UK Ministry of Defence, the US Department of Defense, NATO and the International Hydrographic Organization. It is used widely in civilian navigation and heading systems. The latest revision, WMM2010, is for 2010-15.)

**Funding for Developments:** National Capability (early-mid1990s), industry funded (mid 1990s-present).

**Wider Initiatives and the Centre’s Contribution:** BGS has built a consortium of users of IIFR/IFR and the BGGM. Service income supports five BGS magnetic observatories overseas and the Edinburgh World Data Centre for Geomagnetism. BGS’ reputation in geomagnetic research and technology transfer led ESA to invite BGS to participate in the Swarm satellite mission and to commission BGS to develop reference models/products during the five year mission for use by the global scientific community and others.

B. Space Weather: Mitigating risk from the natural geomagnetic hazard

**Nature of Insight Leading to Impact:** Space weather causes large and rapid geomagnetic variations and these are a (growing) concern for the power industry as the geomagnetically induced currents (GIC) flowing in grids can cause damage to transformers and result in blackouts, with severe economic consequences. The 9-hour blackout in Quebec in 1989 is the most high-profile case, with costs to the Canadian economy estimated at C$2bn. BGS recognised the potential to connect geophysical measurements and models of ionospheric source magnetic fields and crustal and ocean conductivity with engineering models of grid systems to simulate the flow of GIC in the UK’s transmission system. Support has been provided by Scottish Power, National Grid and ESA.

**Outline of Activities and Dates of Developments:**
- Geomagnetic and solar index forecast software developed for ESA (1990s) is still applied to mission planning and management of low-Earth-orbit (LEO) satellites.
- PhD studentship with Univ. Lancaster, modelling power grid response to space weather (2007-2010).
- Monitoring and analysis contract with National Grid, including BGS development of the MAGIC web-tool used by National Grid (2011-present).
- Extreme event analysis with National Grid and Government (2011-present).

**Funding for Developments:** National Capability funding augmented by industry & ESA funding (1998-2006,
2011-present); EPSRC grant 2007-2010; NERC New Investigators award, 2011-14.

**Context for Activities:** Industry, UK Government and inter-governmental (US-UK) concern about space weather hazard has escalated in the last three years, including discussions at Cameron-Obama meetings.

**Wider Initiatives:** BGS has contributed to a draft UK space weather strategy, devised by STFC and NERC (2012), and to Royal Academy of Engineering (2012) and Lloyds of London (2011) reports on space weather. BGS is a founder member of the Space Environment Impacts Expert Group (SEIEG), advising Government on space weather effects and provides expertise on the subject to the Natural Hazards Partnership.

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<td><strong>Public Domain Information (providing evidence of technical details)</strong></td>
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<td>• <a href="http://www.geomag.bgs.ac.uk/data_service/home.html">http://www.geomag.bgs.ac.uk/data_service/home.html</a></td>
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<th>5. Contacts for further information</th>
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<tr>
<td>Dr Alan Thomson, Head ofGeomagnetism, <a href="mailto:awpt@bgs.ac.uk">awpt@bgs.ac.uk</a>, 0131-650-0257</td>
</tr>
<tr>
<td>Dr David Kerridge, Science Director, Earth Hazards and Observatories, <a href="mailto:djk@bgs.ac.uk">djk@bgs.ac.uk</a>, 0131-650-0220</td>
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BGS03 – Earthquake Monitoring and Seismic Hazard

1. Summary of the impact
BGS has pioneered long term seismic monitoring and research in seismic hazard assessment that has helped inform regulatory decisions and setting of appropriate guidelines in high consequence industries. Improved models of seismic hazard have had cost benefits in the construction of critical facilities. BGS rapidly analyses data to provide objective information on significant seismic events 24/7, helping to allay public concern and to co-ordinate appropriate emergency response. Rapid access to information has helped to minimise economic losses and in developing safe operating practices in industry.

2. Nature of the impact
**Beneficiaries:** Government Departments, including, DCLG, DEFRA, DTI, DfID, FCO, MoD and DECC. Regulatory authorities for the nuclear and oil industries as well as non-departmental public bodies such as the Nuclear Decommissioning Authority (NDA). The nuclear industry, including EDF, Horizon, Magnox and Sellafield sites. The water and hydro-electric industries, e.g. SSE, Scottish Water, Scottish Power, and Jersey Water. Non-governmental humanitarian and development organisations, e.g. Concern Worldwide. The academic research community who use our data and products.

**Nature of the impact:** Rapid objective information distributed by BGS following significant earthquakes allays concern and has positive benefits for society. Near real-time, information helps nuclear and water industry operators rapidly identify false alarms, react appropriately, and minimise potential economic losses resulting from unnecessary and costly shutdown procedures or inspections of plant. Continuous long term monitoring and improved assessments of seismic hazard in the UK by BGS has helped inform regulatory decisions in the nuclear industry, where the consequences of failure are severe and reliable hazard assessment is critical. Greater understanding of uncertainties and the development of improved models for seismic hazard estimates have also resulted in reduced engineering conservatism, leading to significant cost benefits in construction of critical plant and infrastructure.

National seismic hazard maps compiled by the BGS have had an impact on the built environment and planning decisions through inclusion in the UK National Annexes to the structural Eurocode BS EN1998: Design of structures for earthquake resistance (EC8). BGS routinely undertakes commercial seismic hazard work for engineering projects, insurance or government all around the world, which has a significant impact on construction methods and operating procedures. BGS has contributed to several large international projects in the field of seismic hazard e.g. SHARE (Seismic Hazard Harmonisation in Europe) which will have an impact on all hazard assessment procedures and standards in Europe.

BGS has provided both data and scientific expertise to assess the hazards from induced earthquakes resulting from shale gas exploration and production, and has helped inform regulatory decisions by DECC on hydraulic fracturing operations in 2012. BGS contributed to the public enquiry following the Buncefield Explosion providing evidence helping to constrain the timing and size of the explosion. Commissioned research into induced earthquakes in oil production fields in the North Sea has had an impact on business performance and processes. BGS participated in COBRA/SAGE meetings convened after the Tohoku earthquake in Japan, March 2011, advising on aftershock probabilities and estimated ground motions around the Fukushima Nuclear Power Station.

The BGS UK School Seismology Project has stimulated public interest and engagement in science through enhancement of science education in schools by developing specific resources for teaching and learning seismology, and physics, in UK schools. BGS is a regular point of contact for the media following significant earthquakes and helps inform public discourse on this subject.

**Sustainability:** Earthquake hazard is unlikely to change in the future; potentially damaging and disruptive earthquakes will continue to occur in the UK. Improved understanding of the driving forces for earthquake activity in the British Isles together with better models for the expected ground motions from earthquakes are crucial to improved estimates of seismic hazard and to meeting the demands of industry and Government. Investment of over £1M to improve instrumentation, data acquisition and network performance has led to high quality data that can be used to resolve this. On the global scale, increasing populations and rural-to-urban migration means that the number of people (and infrastructure) at risk from
earthquakes is increasing. Seismologists will be required to play a major role in helping to inform decision-making at all levels (from globally to national to local government to community) to manage and reduce risk.

Evidence and Dates of Impacts:

- Continuous monitoring and reporting of significant earthquakes in the UK and immediate offshore area over the last 20 years: [http://www.quakes.bgs.ac.uk/publications/annual_reports/annual_reports_list.htm](http://www.quakes.bgs.ac.uk/publications/annual_reports/annual_reports_list.htm).
  For example, the Folkestone earthquake of 28 April 2007 resulted in emergency measures being taken by local authorities, power outages, transport disruptions and localised damage of a severity not seen in the UK in at least 50 years. BGS was able to provide rapid source parameters and expected ground shaking for the earthquake. This information was used to avoid costly shutdown of the nearby Dungeness Nuclear Power Station and the Channel Tunnel.


- Reports commissioned by Defra into tsunami hazard in the UK (2005 and 2006) led to later work on establishing the seismic component of an early warning system are providing information for current considerations (by Government)on the UK role in the Intergovernmental Oceanographic Commission of UNESCO North-eastern Atlantic, the Mediterranean and connected seas Tsunami Warning System (NEAMTWS): [http://archive.defra.gov.uk/environment/flooding/risk/tsunami.htm](http://archive.defra.gov.uk/environment/flooding/risk/tsunami.htm).


Future impact potential: Planning and construction of the next generation of Nuclear Power stations and other major infrastructure will require continued seismic monitoring and seismic hazard assessments informed by improved understanding of the driving forces for earthquake activity and better predictions of ground motions from earthquakes. The magnitude 5.8 Virginia earthquake of 23 August 2011 which resulted in damage and disruption in Washington and caused two nuclear reactors at the North Anna Power Station to be taken off line by safety devices is a good analogue for a credible future earthquake affecting a major city and wide area in the UK.

The potential for induced seismicity resulting from shale gas exploration in the UK as well as from other emerging technologies such as Carbon Capture and Storage (CCS), Coal-Bed Methane (CBM), geothermal energy and underground gas storage suggests that monitoring of man-made seismicity will continue to have important societal and economic impacts.

BGS currently hosts a NERC Knowledge Exchange Fellowship, which is increasing and improving the way in which seismological information is used in operational decision-making by humanitarian organisations. BGS seismologists work with a wide range of decision makers in countries throughout the Alpine-Himalayan belt through the NERC-funded Earthquakes Without Frontiers project, which aims to increase resilience to earthquakes in this very large region. As part of the Probability, Uncertainty and Risk in the Environment (PURE) project, BGS is working to improve the assessment and quantification of uncertainty and risk in natural hazards and to stimulate good practice guidance.

3. How the Centre contributed to the impact

Nature of the insight leading to the impact: Although seismic hazard and risk in the UK are low by world standards, there are numerous examples of earthquakes that have caused moderate damage and widespread public alarm (e.g. Folkestone, 2007), particularly when they have occurred in densely populated areas (e.g. Manchester, 2002; Dudley, 2002) or affected large areas (Market Rasen 2008). Objective information is essential to allay concern, to co-ordinate an appropriate emergency response and to plan for future events. Earthquake activity is also at a level that could pose a potential threat to sensitive structures such as nuclear facilities, chemical plants and dams.

Outline of activities and Dates of Developments: BGS began installing seismograph stations in the UK in the
late 1960s. Over the next thirty years the network grew in size, both in response to specific events, such as the Lleyn Peninsula earthquake in 1984, and as a result of specific initiatives, such as monitoring North Sea seismicity, reaching a peak of 146 stations by the late nineties. In 2005, BGS began the development of a network of broadband seismograph stations across the UK to provide high quality near real-time data for monitoring and research. Development of unique stochastic modelling software for probabilistic seismic hazard assessments (PSHA) using Monte Carlo simulation began in the late 1990s. This has continued to develop and continues to be used for modelling seismic hazard at numerous sites around the world.

**Funding for Development:** National Capability funding (1991-present) with additional funding from private and public sector partners has allowed BGS to develop a UK wide earthquake monitoring network and provide a 24/7 near real-time response to significant earthquakes, as well as developing methodologies for seismic hazard assessment. Funding from industry and Government has supported seismic hazard work in the UK and overseas. Research is supported by NERC Grants (Knowledge Exchange Fellowship, 2011-2013; Probability, Uncertainty and Risk in the Environment, 2012-2016; Earthquakes Without Frontiers, 2012-2017). EU Grants (SHARE, FP7, 2009-2012; NERIES FP6, 2006-2010; TRANSFER FP6, 2006-2009).

**Context for Activities:** Industry, Government and the public are concerned about the hazard posed by earthquakes and the immediate effects of felt or damaging vibrations on people and structures. BGS is the sole provider of UK-wide capability in detection and measurement of earthquake activity and is recognised internationally as an authority on seismic hazard through involvement in numerous seismic hazard projects in the UK and overseas. BGS has expertise in seismic data processing, analysis and interpretation, including near real-time determination of earthquake parameters (location, time and magnitude).

**Wider initiatives:** BGS contributes to the Global Earthquake Model, leading the Global Earthquake History module (http://www.globalquakemodel.org/landing/index.html), and is a partner in the European Plate Observing System (EPOS, http://www.epos-eu.org/) project, integrating national and trans-national research infrastructure across Europe in Earth Science. BGS provides information and expertise on earthquakes to the Natural Hazards Partnership (http://www.cabinetoffice.gov.uk/content/natural-hazards-partnership).

### 4. Evidence and sources to corroborate the impact

**Public Domain Information:**
- Near real-time earthquake information: http://www.earthquakes.bgs.ac.uk
- BGS UK School Seismology Project: http://www.bgs.ac.uk/schoolseismology/

**Individual users/beneficiaries:**
- Office for Nuclear Regulation
- Department of Communities and Local Government
- Department of Energy and Climate Change
- Government Office for Science
- Concern Worldwide

### 5. Contacts for further information

Dr Brian Baptie, bbap@bgs.ac.uk, 0131 650 0222
Dr David Kerridge, djk@bgs.ac.uk, 0131 650 0220
**BGS04: Response to volcanic eruptions in Iceland and on Montserrat, and planning for future eruptions.**

1. **Summary of the impact (maximum 100 words)**

BGS staff managed the Montserrat Volcano Observatory (1997-2008), advising the Montserrat and UK Governments, the aviation sector, and the public and media 24/7, gaining expertise in managing a volcanic crisis. BGS advice has underpinned developing UK Government policy on volcanic hazards over the last two years. BGS was a leading advisor in the Scientific Advisory Group for Emergencies (SAGE) during the Eyjafjallajökull eruption in 2010, gave oral evidence to the House of Commons Science and Technology Committee and assisted the Met Office with forecasting strategies. BGS regularly advises the Civil Contingencies Secretariat and the FCO on volcanic hazards and risk.

2. **a. Economic impact**

**Beneficiaries:** The aviation sector, Civil Aviation Authority, International Civil Aviation Organisation, International Air Transport Association, airlines, public and business, Volcanic Ash Advisory Centres, Montserrat local businesses.

**Nature of impact:** The first week of disruption during the Eyjafjallajökull eruption caused global losses of $5 billion. BGS advice, particularly on source terms for modelling, sometimes reduced the airspace forecast to be affected. BGS convened an expert group before a Bank Holiday weekend, and the advice provided lead to a dramatic reduction in aviation impact; this was widely reported in the media. In Montserrat, BGS staff provided 24/7 advice to ensure regional air traffic was safe and suffered minimal disruption. Advice on hazard and risk facilitated the effective management of local businesses near the volcano.

**Sustainability of impact:** Since 2010 there has been wide appreciation in Government of the need to assess the likelihood of Icelandic eruptions and their potential impact on the UK (and Europe). Evidence on these risk factors has led to the inclusion of volcanic risk in the 2012 UK National Risk Register. Regular meetings and interaction through the UK-Iceland MoU, IUGG-WMO workshops and other projects and committees are leading to greater monitoring and targeted research, often through collaborations, improving our ability to anticipate eruptions, develop new modelling methods, and give effective and timely advice.

**Evidence of impact:** BGS contributions are acknowledged in a Met Office-led research paper (Webster et al. 2011), and the impact of BGS input was a major reduction in aviation disruption (e.g. Daily Mail ‘What a difference a day makes’). There have been no aviation accidents caused by the thousands of explosive eruptions in Montserrat, despite a major regional hub airport being nearby (PIARve, Puerto Rico).

2. **b. Impacts on public policy and services**

**Beneficiary:** Cabinet Office Civil Contingencies Secretariat (CCS), GO-Science, Scientific Advisory Group for Emergencies, National Security Council and, through them, Government departments including the Department for Transport, DEFRA, Department of Health, Health Protection Agency, and the Civil Aviation Authority.

**Nature of impact:** As a result of BGS advice, volcanic hazards are in the 2012 UK National Risk Register, there is cross-governmental planning for future eruption scenarios, public health advice has been drafted and there is much greater awareness of volcanic hazards and risk in the UK, in UK overseas territories and elsewhere. BGS has presented on volcanic risk to OECD and UN-ISDR thus raising awareness internationally. Prompt and timely advice about health has been provided wherever BGS has worked, based on strong long-term relationships with health professionals. Advice has been drafted (by HPA) for future eruption scenarios (BGS advisors) and discussions have started among air pollution experts about volcanic air pollution.

**Sustainability of impact:** Regular meetings and interactions with Government departments, especially the Cabinet Office and the Foreign and Commonwealth Office have continued since 2010 to maintain the level of understanding of volcanic hazards, risk, monitoring and modelling as departmental staff change. The science behind this advice is current and supported by grants won from NERC and the EU. BGS has established a strong relationship with the Health Protection Agency, which is ongoing, and also works alongside the International Volcanic Health Hazard Network.

**Evidence of impact:** BGS has contributed to numerous reports and workshops. The CCS commissioned BGS to work on source terms for modelling a particular scenario. BGS provided oral evidence on CCS
performance under the Hyogo Framework for Action to a UN team. BGS contributed to an OECD report on Global Modelling of Natural Hazard Risks. BGS has been asked to contribute to the UNISDR Global Assessment Report on Risk 2015. HPA produced ‘Review of Evidence on the Potential Health Impacts of Volcanic Ash on the Population...’ with BGS advice, and a second report led by BGS has been delivered to the National Security Council and includes the potential future health impacts of a larger magnitude eruption.

c. Impacts on society, culture and creativity

Beneficiaries: The public and the scientific community.

Nature of impact: BGS has been proactive and successful in bringing different science disciplines together for novel research purposes, and bringing scientists and the public together to effectively respond to the challenges of volcanic ash (citizen science).

Sustainability of impact: Citizen Science is an area BGS is committed to and improving with new technology. We are developing ideas/methodologies in the UK and overseas as effective risk reduction measures and to enhance understanding of and engagement in science. We have won collaborative funding for several new and novel science projects bringing together disciplines that do not traditionally work together.

Evidence of impact: Congratulated by Science Media Centre in 2010 and good response to public appeals for volcanic ash samples across UK in 2010 and 2011. Schools and public at risk appreciate the interaction.

d. Impacts on the environment

Beneficiary: UK public, Government, health, environment and aviation sectors.

Nature of impact: BGS seismometers installed as part of the permanent Icelandic monitoring network have allowed deep seismicity (20-30km) at Katla volcano to be detected for the first time. This will improve short-term forecasting of eruptive activity giving the UK valuable preparation time. In the UK, existing monitoring networks are being enhanced (e.g. for sulphur dioxide) and BGS is leading collaboration of multiple agencies.

Sustainability of impact: The UK-Iceland MoU is effective and actions are arising from it, and environmental concerns and monitoring in both countries are included in several ongoing projects.

Evidence of impact: The efficacy of the BGS contribution is minuted in MoU meetings and opinion can be sought from the Icelandic Met Office and University of Iceland.

3. How the Centre contributed to the impact

a. Economic impact

- In Montserrat, BGS was in 24/7 contact with airports and the Washington Volcanic Ash Advisory Centre ensuring aviation was safe and disruption minimal. In the UK in 2010/2011, BGS explained volcanic processes, volcanic hazards and parameters relevant to ash dispersion modelling to stakeholders including the Met Office and Civil Aviation Authority. BGS rapidly convened a small expert group on 25 May 2011 to improve the ‘virtual’ source term for Met Office models as the existing model forecasts seemed unrealistic. The new source terms led to a reduction in the extent of airspace forecast to be affected resulting in a Bank Holiday with limited airspace restrictions.

b. Impacts on public policy and services

- In Montserrat, BGS advised the ‘Volcano Executive Group’ (Governor, Chief Minister, Attorney General and others) ensuring sound advice for risk management in all activities from policing and emergency management to health. BGS provided daily advice to the UK Government and institutes during the 2010 and 2011 Icelandic eruptions on volcanic processes, eruption evolution, source terms for ash dispersal models etc. BGS led the ‘geology’ subgroup of the SAGE tasked to consider volcanic risk. BGS oral and written contributions were made to the House of Commons Science and Technology Committee enquiry into ‘Scientific advice and evidence during emergencies’. CCS commissioned BGS to lead and coordinate a meeting of experts on effusive eruptions and modelling source terms (May 2012) resulting in a report on a Laki eruption scenario and its likely impacts. BGS has advised on regional and global volcanic unrest (e.g. in Santorini and Chile) and had a major role in facilitating development of planning and procedures for volcanic risk in Iceland, Santorini and Ethiopia. BGS contributed to Foresight discussions and reports on geophysical hazards and disaster risk reduction. BGS has given advice on volcanic ash, methods of sampling, analysis and evidence of impacts on health in relevant meetings (e.g. SAGE) and is on an HPA Steering Group compiling a report on potential health impacts of volcanic ash. Discussions on volcanic air pollution impacts on health and the likelihood of gas inhalation in the UK (including UK airspace) during future eruptions are ongoing.
c. Impacts on society, culture and creativity
- BGS provides excellent media engagement, reliable web output, and opportunities for the public to engage in timely scientific activities and research (citizen science). We have engaged with schools and the public across the UK and in UK Overseas Territories at risk. In Montserrat, many of those living closest to the volcano are engaged in citizen science facilitated by BGS.

d. Impacts on the environment
- BGS is working with collaborators in UK and overseas to enhance monitoring of volcanoes and to assess their impact on the environment. BGS initiated an MoU between the UK and Iceland, and requested a Memo (drafted by the Icelandic Met Office and the University of Iceland) outlining Iceland’s monitoring requirements. Because BGS was proactive in recognising IMO needs, and offering support in a timely and effective manner, an effective long-term collaboration has been established. Equipment installation began in 2010 and continues. BGS actions were guided by experience gained in running the Montserrat Volcano Observatory for more than a decade. BGS works with UK agencies to enhance UK monitoring of particulates and gas, especially at ground level.

4. Evidence and sources to corroborate the impact
a. Economic impact

b. Impacts on public policy and services
- National Risk Register of Civil Emergencies (2012 edition)
- House of Commons Science and Technology Committee: Scientific advice and evidence in emergencies, 2011
- 2012 Foresight report on ‘Anticipation of Geophysical Hazards’
- 2012 Foresight report on ‘Reducing Risks of Future Disasters...’
- OECD 2012 report on ‘Global Modelling of Natural Hazard Risks: enhancing existing capabilities to address new challenges’.

c. Impacts on society, culture and creativity
- Science Media Centre can corroborate the effectiveness of BGS Media Reports.
- Icelandic Met Office can provide a statement on the effectiveness and accuracy of BGS media reports.

d. Health impacts

e. Impacts on the environment
- Statements by Icelandic Met Office as to efficacy and value of BGS seismometers minuted in MoU meetings.
- Advice to the Volcanic Ash Network for DEFRA.

5. Contacts for further information
Dr Susan Loughlin, Head of Volcanology, [sclou@bgs.ac.uk](mailto:sclou@bgs.ac.uk), 0131-650-0417
Dr David Kerridge, Science Director, Earth Hazards and Observatories, [djk@bgs.ac.uk](mailto:djk@bgs.ac.uk), 0131-650-0220
# BGS05: BGS Groundwater science

## 1. Summary of the impact

The Living With Environmental Change (LWEC) accredited BGS Groundwater Science programme has made major contributions to improved understanding and characterisation of the fundamental properties of groundwater systems and to the investigation of the impacts of a changing environment. The programme’s work has directly influenced national legislation and government policy and decision-making. It has established standards for protection of groundwater and the environment and enabled evaluation of economic and societal impacts of environmental change on water resources. In developing countries impacts include improved access to clean and sustainable supplies of groundwater with direct benefits to human health and well-being.

## 2. Nature of the impact

### 1) Public policy and services

Advice to Government and evidence to the Royal Society/Royal Academy of Engineers review on environmental (groundwater) impacts of shale gas have led directly to recommendations and requirements for baseline monitoring as outlined in the recent Secretary of State’s Statement to Parliament and the UK Onshore Operators Group Guidelines (2013) ahead of development.

BGS science and expertise, through evidence to Parliamentary Select Committee, assisted in the development of the Flood and Water Management Act, 2010 which implement the EU Floods Directive; has helped steer the EA strategy on groundwater flood monitoring; and has developed a national assessment of groundwater flooding susceptibility (2009) which is used by local authorities for their Preliminary Flood Risk Assessments as required by the Regulations. These data are also used by developers and businesses to assess flood risk to properties and infrastructure in order to minimise future economic losses by improved professional services.

### 3) EU Water Framework and Groundwater Directives – UK and Europe

Expert advice and technical and scientific input to support UK Government and competent authorities – the Environment Agency (EA), the Scottish Environment Protection Agency (SEPA) and the Northern Ireland Environment Agency (NIEA) – with implementation of the EU Water Framework Directive (WFD) and Groundwater Directive (GWD) leading to establishment of UK groundwater quality standards (threshold values), delineation of groundwater bodies as formal reporting/management units (2007 and 2012), and development of technical methods via participation in UK Technical Advisory Group Groundwater Task Team (GWTT).

BGS input has directly influenced formal published European Commission (EC) Common Implementation Strategy (CIS) groundwater guidance for the WFD/GWD (2007 to present), led development and reporting of recommendations on revision to the GWD (2011), and co-ordinated EC science–policy interface activities for groundwater culminating in identification and prioritisation of future EU WFD/GWD research priorities (2012). Incorporation of UK-driven approaches into implementation to the CIS outputs has ensured cost-effectiveness and potential avoidance of infraction.

### 5) Water Resources in a changing climate

Modelling of the potential impacts of climate change on UK groundwater resources over the next 50 years were used to support the development of the Government’s Water White Paper and the EA’s supporting technical justification – ‘Case for Change’. The model outputs are also being used by Water Companies to undertake the OFWAT Periodic Review 2014 and will have significant implications for future infrastructure investment and pricing.

Research on resilience of groundwater in Africa to climate change (published 2012) stimulated global debate on water availability following the conclusion that that groundwater storage is a freshwater resource 100 times larger than is usually used in water scarcity assessments (paper downloaded 45 000
times, BBC top news story for three days with 300+ comments). The research was quoted by Chris Witty (Head of the Department for International Development (DfID) research) as “one of three clear examples of new knowledge making a difference”. It is also being used by donor agencies (e.g. WaterAid) to inform actions and priorities, and it has informed debate within DfID, the World Bank and the Gates Foundation and been included in high level ministerial meetings on groundwater resources within Africa.

6) Groundwater, Human Health and the Environment
Our research has shown that in developing countries access to improved water supplies has a significant beneficial impact on human health. Collaboration with an interdisciplinry team of medical and engineering scientists led directly to the publication of an authoritative paper on the subject and the launch of the research findings was used by the DfID Minister to announce extra funding for water supply and sanitation in Africa (2011). 2) Health risks associated with poor quality water have been communicated through guidance to WaterAid through guidance on water quality issues in a range of African countries in which it works. Funded jointly by BGS, DfID and WaterAid, the guidance is in the form of published leaflets on the BGS website (on-going).

Our research to develop an understanding of natural systems processes and change has led to improved management and protection of water resources and the natural environment. Our science has informed the remedial standards for the clean-up of contaminated land and groundwater implemented through Part IIA Contaminated Land Regulations, delivered vital information and tools to enable achievement of the WFD’s environmental objectives (see “impacts on public policy and services” above) (on-going) and directly input into the UK National Ecosystem Assessment – the Director of Groundwater Science was a contributing author (2011). We are also leading the Measures Component of the Defra Demonstration Test Catchment (DTC) initiative with the aim of delivering sustainable food production and environmental benefits across whole river catchments (2012 -).

7) Impacts on practitioners and professional services:
Participation in national and international science–policy interface (SPI) activities leading to UK and European best practice guidance (see above) with further impact demonstrated by demand for experiences around the World including the US, India, Kosovo and New Zealand (on-going).

On-going Input to national/international expert groups and advisory panels on issues related to research, management and protection (e.g. UKCNIH - UK Committee for National and International Hydrology, UK Groundwater Forum, UK Water Research and Innovation Partnership (UKWRIP), EC Groundwater Working Group (WG C), UKTAG Groundwater Task Team, Scottish Hydro Nation Forum, CIWEM Water Resources Panel.

3. How the Centre contributed to the impact
The internationally recognised BGS Groundwater Science programme has broad expertise on UK Hydrogeology and also in critical regions of the World, such as Africa. It has a consistent and a long history of published research which ranges from studying the physical properties of aquifers (Aquifer Properties Manuals), evolution of natural groundwater chemistry (UK Baseline reports), contaminant behaviour, understanding levels/flows and ecology and process-based model development. The science outputs and supporting information are routinely used in abstraction licensing, water-resource modelling, planning applications and contaminated land/groundwater remediation. Coupled with our extensive datasets the programme provides a unique research capability.

We work in partnership with LWEC and other stakeholders to undertake fundamental science as well as developing practical tools to support decision-making, e.g. drinking water source protection (2007–2009), groundwater vulnerability maps (2010), and shale gas risk screening tools (2012). We also lead the on-farm improvement measures component of the Defra-funded Demonstration Test Catchments initiative and have invested significant National Capability to develop essential understanding of catchment behaviour (2012 onwards) in association with this initiative. Working with CEH, we operate the national hydrological monitoring programme (NHMP) and analyse groundwater levels to produce
regular reports on hydrological conditions throughout the UK, financially supported by a range of organisations (e.g. Defra and OFWAT). This information underpins the scientific advice we provide to Government and others on issues such as flooding and droughts (National Droughts Group, Cabinet Office and Government Chief Scientist) (2010–2012). Staff from the BGS Groundwater Science Programme also appear regularly in the media (on-going).

Working with research partners (e.g. Imperial College, UCL and Reading University) we continue to develop innovative methods for the modelling of hydrological response to climate variability, e.g. the “Hydrological extremes and feedbacks in the changing water cycle” project as part of the NERC-funded Changing Water Cycle research initiative (2011–14). We have also completed collaborative research – “Future Flows Hydrology” – with Defra, UKWIR (UK Water Industry Research Ltd), EA and CEH to examine the impact of climate change on groundwater levels in the major aquifers of England and Wales for the coming century (2010–12). This represents the first UK-scale assessment of climate impacts on groundwater. The data are being used by the EA to underpin policy and by water companies, Natural England and others within the Wetland Vision partnership project (2012).

For groundwater quality we have undertaken a comprehensive evaluation of the natural (baseline) quality of groundwater across the UK jointly-funded with the Environment Agency and SEPA. These data support the assessment of risks from a wide range of industrial activities with the potential to impact on groundwater, establishment of environmental permit limits and the derivation of remedial targets for remediation of contaminated land/groundwater (2007 onwards). More recently (2009 onwards) the information has been used to establish groundwater threshold values (standards) as part of a formal requirement of the EU WFD and GWD, and for status assessment and initiate a UK-wide baseline for shale gas. The BGS baseline methodology has also been adopted in EC’s WFD Common Implementation Strategy (CIS) guidance (2010).

We are also actively involved in a wide range of projects on the sustainable management and protection of groundwater in developing countries around the World. Our work on resilience of African groundwater to climate change and the links to livelihoods and well-being has received worldwide attention with both the public and the media becoming much more informed about groundwater resources in Africa (2012). The launch of the research outputs was used by DfID to announce extra funding for water supply and sanitation in Africa and the project leader invited to write an opinion piece for the New York Times on the subject (2012).

4. Evidence and sources to corroborate the impact Selected examples and links to external sources

Water Framework Directive/Groundwater Directive:

1. Groundwater flooding
   - BGS Groundwater Flood Susceptibility Dataset (on BGS website)
   - Groundwater Flooding Science Briefing
   - DEFRA/Environment Agency – Making Space for Water report
   - Example use of BGS Groundwater Flooding Susceptibility maps/data: Wiltshire CC

2. Natural Quality of Groundwater - Baseline
   - Environment Agency website: Use of Baseline information.
   - BGS website outputs – England/Wales and Scotland
   - UK Government Direction (2010) establishing threshold values for groundwater. Values for natural substances directly derived from BGS baseline studies

3. Groundwater in developing countries
4. Quantitative maps of groundwater resources in Africa – paper downloaded 50 000 times, BBC top story for three days with 300+ comments. E.g. UK (BBC), Europe (Le Monde, Der Speigel) and International (Al Jazeera, Chicago Tribune).

5. Impacts of climate change on groundwater
   - http://www.bgs.ac.uk/research/groundwater/change/FutureFlows/home.html
   - Beneficiaries include: DfID, Environment Agency, Thames Water Utilities Ltd

6. Wider programme outputs
   - BGS Groundwater Science website – www.bgs.ac.uk/groundwater
5. Contacts for further information

Dr Rob Ward (rswa@bgs.ac.uk), Dr John Bloomfield (jp@bgs.ac.uk)
1. Summary of the impact

Synthesised mineral resource and production information, and material-flow and supply-risk analysis from BGS has assisted the UK manufacturing and construction sectors in assessing supply security and sustainability issues. These outputs have also informed resource-management policy at local, national and EU levels. BGS is a globally recognised provider of mineral statistics, commodity information and analysis which is widely downloaded and quoted by the international mining, investment and regulatory communities.

2. Nature of the impact

Global supply risk:

- BGS global mineral and metal production data have been used to develop a commodity supply disruption risk estimate for materials databases utilised by a number of major global aerospace and defence manufacturers (2012).
- The House of Commons Science and Technology Committee report on ‘Strategically Important Metals’ published in 2011 contained considerable input from BGS, which led on the written RCUK submission to the inquiry. This report precipitated the ‘Resource Security Action Plan’ published by Department of Environment, Food and Rural Affairs (Defra) and Department of Business, Innovation and Skill (BIS) in 2012. Evidence note 1.
- BGS provides information on primary metal supply, demand and associated risks to the Defra ‘Critical Resources Dashboard’ which will give UK manufacturing small and medium size enterprises information on resource risk issues. Manufacturing is worth about £140 billion (Gross Value Added) to the UK economy and employs about 2.6 million people (2012). Evidence note 2.
- In 2010, BGS provided advice and information on mineral resource security which fed into the UK Ministry of Defence ‘Global Strategic Trends out to 2040’ report. Evidence note 3.
- Along with the mining investment community, a number of major UK manufacturers utilise BGS outputs such as the ‘Risk List’ annual global supply risks index of economic elements and element groups (28 000 downloads in 2011–2012; referred to on 313 separate websites between September 2011 and November 2012). Also widely used are BGS ‘Mineral Commodity Profiles’ such as ‘Rare Earth Elements’ (7000 downloads in 2011–2012) and ‘Tantalum-Niobium’ (3000 downloads in 2011–2012). Evidence notes 4 and 5.

Sustainable development of domestic minerals:

- New mapping of UK offshore mineral resources will be used by marine planners as a vital tool in balancing conservation, renewable energy and aggregate mineral supply requirements in the Southern North Sea. Over 56 per cent of sand and gravel aggregate used in London and south-east England is dredged from the sea bed (2012).
- A number of English local authorities refer specifically to BGS Mineral Planning factsheets within their planning policies and guidance for sustainable domestic mineral supply (2009).
- Devolved governments in Wales and Northern Ireland are utilising national spatial mineral resource datasets from BGS to revise national policies and associated guidance on mineral extraction permitting and management (2011). Evidence notes 6 and 7.
- Historic Scotland and a number of local authorities in Scotland utilise a building stone ‘health check’ and stone-matching methodology developed by BGS to evaluate applications for repair and restoration of historic buildings (2008). Evidence note 8.

3. How the Centre contributed to the impact

Global supply risk:
Long-term monitoring of global mineral and metal production has given BGS a large database of time-series data stretching back to 1913. Coupled with collaborative metallogenesis research and analysis of technical and economic factors, BGS has developed a unique insight into risks related to global supply of primary minerals and metals. As well as compilation and publication of annual production statistics on a country and commodity basis, plus more detailed study of European and UK production and trade, BGS produce a series of individual ‘commodity profiles’. These synthesise key scientific, technical and economic information on some metal and mineral commodities. Along with metallogenetic studies, this intelligence-gathering (NERC NC-funded) forms the basis for collaborative research with HEIs (such as the BGS/ Exeter University ‘Critical Metals Alliance’) and other institutions. In turn, these activities underpin a strong programme of knowledge exchange with policy-makers, industry and civil society funded in part by a NERC KE grant.

Key contextual information:

- The UK is 6th largest global manufacturer by output. The UK is strong in sectors such as aerospace, defence and automotive where access to secure a stable supply of raw materials is vital. Current supply chains tend to heighten vulnerability ‘from just in time to just not there’.
- Consumption rates of ‘critical metals’ required for green technologies are growing very rapidly e.g. rare earths for wind turbines, lithium for electric vehicle batteries, or tellurium for thin film photovoltaics.
- London is the major global centre for mining finance. Forty mining companies are listed on the main LSE market. A further 160 mining companies are listed on the London AIM. In 2008, £63 billion was raised in London to finance mining activities around the world.

*Sustainable development of domestic minerals:*

Between 2007 and 2012, BGS has compiled and updated a spatial dataset of onshore mineral resources in the UK at a scale of 1:50k. This work was co-funded by DCLG (England), the Scottish Government, the Welsh Government and the Northern Ireland Government. These data have primarily been compiled to assist the spatial planning system in resource management and in dealing with individual planning applications for mineral extraction. Minerals can only be worked where they occur and, because of environmental and amenity considerations, are usually a contentious form of land use. Mineral resource information, particularly when combined with spatial data on other land uses and designations, is a powerful tool in balancing the environmental and economic issues associated with domestic mineral extraction. With the advent of marine spatial planning in 2009, BGS have carried out a 1:500k-scale assessment of offshore mineral resources with the same purpose as the onshore dataset. From 2008, BGS has used a novel survey methodology to identify areas of stone decay on historic buildings. Used in a number of Scottish towns and cities, this has allowed the development of cost-effective restoration programmes, calculation of the volume of stone needed, and estimates of the amount of labour required for repairs.

Key contextual information:

- In its 2011 National Infrastructure Plan (NIP) HM Treasury sets out the importance of infrastructure networks to national economic performance. Most of the 500 transport, energy and flood defence projects set out in the NIP rely heavily on construction. Ninety per cent of UK domestic mineral production (including aggregates, cement, gypsum and clay) is used by the construction sector.
- The National Planning Policy Framework (England) and equivalent planning policy documents published by the devolved administrations all emphasise that ‘Minerals are essential to support sustainable economic growth and our quality of life. It is therefore important that there is a sufficient [domestic] supply of material to provide the infrastructure, buildings, energy and goods that the country needs.’
- The United Kingdom has been a producer of building stone for many hundreds of years. Because
of our varied geology, a wide range of building-stone types have been used and this has influenced architectural style throughout Britain. The importance of this local distinctiveness is becoming increasingly recognised and built heritage is now a significant issue to society.

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<th>4. Evidence and sources to corroborate the impact</th>
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<td><strong>Global supply risk:</strong></td>
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<td>4. Independent web statistics gathered by ‘Meltwater’ news service (to which BGS subscribes).</td>
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**Sustainable development of domestic minerals:**


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<th>5. Contacts for further information</th>
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<td>Andrew Bloodworth (<a href="mailto:ajbl@bgs.ac.uk">ajbl@bgs.ac.uk</a>); Paul Lusty (<a href="mailto:plusty@bgs.ac.uk">plusty@bgs.ac.uk</a>); Jo Mankelow (<a href="mailto:jmank@bgs.ac.uk">jmank@bgs.ac.uk</a>)</td>
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**BGS07: Safe geological disposal of radioactive waste**

### 1. Summary of the impact

Sound decision-making regarding the siting of a deep geological disposal facility (GDF) for radioactive waste relies on the prediction of how materials in a GDF will react with the surrounding rocks and groundwater over very long timescales. BGS research has contributed to better-informed debate and decisions by governments, regulators, industry and civil society regarding deep geological disposal of radioactive waste in the UK and elsewhere. The research contributes to a better-designed characterisation programme and a more robust safety case for a GDF for UK higher-activity waste. It provides input to the construction and operational design of a safe, cost-effective underground GDF, ensuring long-term isolation from the surface of waste and the radioactivity it contains.

### 2. Nature of the impact

BGS research activity and datasets underpin the UK Government’s approach to safe management of radioactive waste. Impacts include:

- **Provision of advice to help develop the UK policy framework:** The ‘Managing Radioactive Waste Safely’ (MRWS) White Paper published by the UK Department of Energy and Climate Change (DECC) in 2008 includes a definition of geological factors that would make a potential site clearly unsuitable for the deep geological disposal of radioactive waste in the UK. In 2007, BGS was a key member of the ‘Criteria Proposals Group’ set up in early 2007 by the Department for Environment, Food and Rural Affairs (DEFRA) which defined these factors. Evidence notes 1, 2.

- **Scientific advice to help decision-making by communities:** As part of the DECC MRWS policy framework, in October 2010 BGS published a subsurface screening study intended to inform decisions by communities in west Cumbria as to whether or not to participate further in the MRWS process (applying the geological criteria as described above). Evidence note 3.

- **Generic reviews and advice to improve quality of site characterisation design:** Since the publication of the 2008 MRWS White Paper, BGS has made an extensive contribution to the development of the UK approach to a future site characterisation programme. This includes provision of expert advice including writing review reports on geological assessments undertaken as part of 3rd country national disposal programmes and the potential impacts of future natural change.

BGS undertakes specialist collaborative research and training relating to the safe disposal of radioactive waste for a range of international bodies and 3rd country national programmes. Examples of impacts include:

- **International Atomic Energy Agency (IAEA):** BGS has contributed to international nuclear collaboration and sharing of best practise within member state nuclear waste management organisations through IAEA-sponsored training and visits related to natural analogues and data management.

- **European Union:** Improved design criteria and safety case for engineered barriers and geological containment in low permeability rocks: BGS coordinates and has a major scientific involvement in the FP7 Euratom Programme ‘Fate of Repository Gases’ (FORGE) project (2009 to 2013). This large project (12M Euro, 24 partners from 12 EC countries plus associates from Japan and Canada) is increasing understanding of the behaviour of gas in a repository context from gas generation though engineered barriers, disturbed and undisturbed host rocks. Evidence note 4.

- **European national nuclear waste management organisations:** BGS carries out a range of research on behalf of several European waste management organisations. This includes gas and water permeability testing to help assess the suitability of target geological formations and the
integrity of proposed engineered waste containment systems. BGS also helps develop improved data management and stakeholder methodologies to enhance safety cases and accelerate permitting processes. Evidence note 8.

3. How the Centre contributed to the impact
BGS delivers research on topics important to the future safe geological disposal of radioactive waste in collaboration with universities and radioactive waste management organisations. With over 50 years’ experience in this field, BGS also provides advice to government, regulators, industry and civil society on geological aspects related to disposal. Through study of engineered barriers (such as clays and cements), potential repository host rocks and overlying geology, BGS has developed good understanding of the physical, chemical and biological processes that affect how rock properties change over long time periods. In particular, BGS has an international reputation for its work on the testing of low permeability materials. For example, recent BGS research has confirmed that gas flow through a variety of low permeability materials is, at least under some circumstances, through discrete dilatant pathways rather than by advection. This finding has safety case implications for national disposal programmes that intend to use mudrocks for hosting a facility and those using bentonite-based buffer/backfill materials because most modelling of repository systems is based on advective two-phase flow.

Key contextual information as follows:

- The UK currently has 17 reactors generating about 18 per cent of its electricity; all but one of these will be retired by 2023. The UK also has full fuel-cycle facilities including enrichment and fuel fabrication and has major reprocessing plants. More than sixty years of operation of the civil nuclear programme has resulted in the accumulation of a significant waste inventory.
- The UK government is committed to implementing a safe solution for the management of higher activity radioactive waste (both legacy, and any that might arise from a new nuclear programme) and accepts that deep geological disposal is internationally recognised as the preferred approach for the long-term management of this type of radioactive waste.
- It is estimated that undiscounted lifetime costs of deep underground disposal of radioactive waste in the UK will be around £12 billion.
- Since the formation of Nirex, now known as the Radioactive Waste Management Directorate of the Nuclear Decommissioning Authority (NDA-RWMD) in 1982, BGS has provided both information and advice and has undertaken contracts relating to the disposal of radioactive waste in the UK.

4. Evidence and sources to corroborate the impact
4. European Union (Euratom) FORGE project: http://www.FORGEproject.org

5. Contacts for further information
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**BGS 08 - Seabed resources: Marine Geoscience and Technology**

1. **Summary of the impact (maximum 100 words)**

BGS (with NOC and SAMS) is leading a long-term Marine Environmental Mapping Programme (MAREMAP), with support from government (Marine Scotland, MCA, CEFAS and others), universities and industry to provide detailed geological maps and models of the UKCS to underpin the development of marine resources, marine spatial planning, conservation and environmental monitoring (e.g. Marine Strategy Framework Directive, setting up MCZs) and geohazards. MAREMAP outputs support the UK marine sector, which makes a growing contribution to the UK economy. New developments include the development of technology for international exploration for deep-water minerals and energy sources.

2. **Nature of the impact**

**Marine Spatial Planning and Government policy (DEFRA, DECC, FCO, MOD).** Competition for use of the seabed, based on the value of many commercial activities and the need to balance development with conservation of environmentally sensitive areas, has resulted in a series of EU Directives and UK legislative action to develop marine spatial planning. Most of the seabed geology maps of the UK marine sector that can assist planning/policy decisions were developed by BGS in the 1970-90s at a level that has insufficient detail to support current resource exploitation or environmental assessments. Technologies such as multibeam echosounders (MBES) are now used to acquire data needed for very detailed maps and models that are necessary to underpin future marine activities, although only ~30% of the UK sea-floor has such data. BGS is jointly leading a pan-Government initiative to increase collaboration across government and industry to maximise the impacts of new mapping and science within NERC (MAREMAP). The partnership currently includes the Maritime and Coastguard Agency (MCA), the Centre for Environment, Fisheries and Aquaculture Services (CEFAS), the Channel Coastal Observatory (CCO) and the universities of Plymouth and Southampton.

**European policy.** BGS is leading the geological input to the European Marine Observation and Data Network (EMODnet) by co-ordinating a consortium of 37 partners from 30 countries who have won a competitive tender to supply geological information from the sea-floor/sub-seabed and coastal zone of Europe. The preparatory phase of this work was from 2009-2012 and the next phase will continue until 2016 although, under the EC’s proposal for a new European Maritime and Fisheries Fund, the Commission aim to make EMODnet a continuous process until at least 2020, with priorities defined by ‘the needs of industry, public authorities and the research community’ (Green Paper: Marine Knowledge 2020). The impact of the EMODnet geology group was recognised by the EC’s Commissioner for Maritime Affairs and Fisheries, Maria Damanaki in her speech to the EurOCEAN 2010 Conference ([http://europa.eu/rapid/press-release_SPEECH-10-542_en.htm?locale=en](http://europa.eu/rapid/press-release_SPEECH-10-542_en.htm?locale=en)) in which she identifies the benefits of the collaboration (saving money, promoting innovation and reducing uncertainty).

**Marine Industries.** The UK marine economy is growing (e.g. aggregates, fishing, aquaculture, renewable energy, oil and gas, tourism). BGS provides expert services to support the assessment of resources and geohazards. This includes evaluation of shallow gas (oil and gas; marine renewables), and ground conditions (site investigation) models. For example, BGS input to three of DEFRA’s Marine Aggregate Levy Sustainability Fund (MALSF) projects contribute to the economic, social and environmental costs and benefits of the UK marine aggregate industry, which dredges about 21 million tonnes of sand and gravel from the UK seabed under licence by the Crown Estate (CE). These reports are used by the CE to inform the aggregates industry of sea-bed conditions and BGS is also working with the Crown Estate to map aggregate resources ([http://www.thecrownestate.co.uk/marine/aggregates/](http://www.thecrownestate.co.uk/marine/aggregates/)). BGS’s contract with Forewind (see below) is providing detailed geological information in the largest of the Round 3 licence zones for renewable energy.

**Integrated Ocean Drilling Program (IODP).** BGS plays a leading role in the Integrated Ocean Drilling Program, the largest geoscience programme in the world, currently funded by 24 countries. BGS leads the European Consortium for Ocean Research Drilling (ECORD) Science Operator, which...
provides management of the science, operations (including technology development), data and outreach related to the mission-specific platform expeditions of IODP. The impacts of IODP research that the BGS-led consortium make possible is of global significance, addressing climate-change and sea-level rise modelling, understanding ocean acidification processes, long-term monitoring of geohazards and the understanding of deep-sea resources. The IODP/ECORD strategy for the next 10 years aims to focus on societal needs and will develop closer links with industry, such as through the ECORD Industry Liaison Panel, which will be part of the strategy-forming group at the centre of ECORD’s management system. Issues of common interest include the global gas-hydrate reservoir, thought to exceed the known extent of conventional hydrocarbons (oil, gas and coal combined). Seafloor spreading centres host geothermal reserves, albeit difficult to harness with current technologies, and seawater-rock interactions can form major base (Cu, Zn, Pb) and precious metals (Au, Ag). The use of remotely operated sea-bed drills, some of which are developed by BGS, will be increasingly applied to the investigation of these issues.

3. How the Centre contributed to the impact

**UK Government.** BGS marine scientists contribute to the DEFRA UK Marine Monitoring and Assessment Strategy through participation in the Healthy and Biologically Diverse Seas Evidence Group (HBDSEG) and by chairing the Sea-bed Mapping Working Group established by HBDSEG to advise on national mapping programmes. BGS contributed to Charting Progress 2 (2010), an assessment of the UK seas based on robust peer-reviewed evidence that describes progress towards the vision set out in 2005 for clean, healthy, safe and productive and biologically diverse oceans and seas. BGS scientists also contributed to the 2008 report on the state of Scotland’s seas.

As a direct result of the MAREMAP collaboration, BGS and partners have been involved in a DEFRA-funded programme (2012) to assess techniques that provide robust information necessary to select Marine Conservation Zones (MCZs). BGS is specifically developing a camera system combined with software that can analyse sea-floor sediment types and help to reduce the costs of monitoring MCZs. The new environmental products and services being developed by MAREMAP are based on a data-sharing agreement established by DEFRA, under which the public-sector organisations can freely exchange MBES information to derive maximum benefit under the ‘collect once, use many times’ principle. The partnership approach has also led to joint projects with Marine Scotland (acquiring and interpreting data to inform the renewable energy sector).

BGS also works with the FCO and other Government Departments on the impact of international marine geohazards on UK nationals. This is based on research into recent major tsunami in the Indian and Pacific oceans, where BGS leads and contributes to the study of the impact, hazard and risk of future events.

**Marine Industries.** BGS expertise has resulted in joint research projects on the detailed geology of the marine geology and geohazards of the North Sea to evaluate ground conditions for the largest planned offshore windfarm in the UK (Dogger Bank). The huge database is available to BGS who have a team of PhD students co-supervised by four universities to support this work, which is providing training and expertise to underpin the development of marine renewables for the UK. Dogger Bank is the largest of the Round 3 zones, with potential for approximately 4GW development capacity in less than 30m water depths and 8GW in less than 35m water depths. BGS work has improved the management of environmental risk or hazards in this area by interpreting the Quaternary and recent sediments. Other projects include specialist assessments of ground conditions for oil rigs, pipelines and cable routes. A key project, funded by DECC, is investigating the impact of shallow gas blow-outs caused by petroleum exploration.

**The Crown Estate.** BGS has been mapping the aggregate resources of the UK Continental Shelf on behalf of the Crown Estate. Since the 1960s, developers have been increasingly reliant on marine sources to supplement demand. Today, approximately 20 per cent of the sand and gravel used in England and Wales is supplied by the marine aggregates industry. Marine aggregates are also used to provide coastal protection as well as enhancing the amenity value and supporting the local economy. Marine sediment is used in land reclamation schemes to infill areas in ports and harbours.
or to reclaim land from the sea prior to engineering works.

**EU policy.** BGS led the geological input to the preparatory phase of the EC-funded EMODnet Programme from 2009-2012, co-ordinating a group of 14 geological survey organisations to provide seabed/sub-seabed geology, coastal behaviour, geohazards, minerals and earthquake information from the northern European seas. This successful phase has led to participation in the full EMODnet Programme starting in 2013. BGS also contributed to a project providing a “routemap” for future deep seas and subseafloor research (DS3F).

**IODP and marine technologies.** BGS managed the first scientific deep coring in the Arctic (ACEX), jack-up drilling offshore New Jersey and reef drilling near Tahiti and the Great Barrier Reef. The results of ACEX have provided more scientific outputs than any other IODP expedition, and the ice-management techniques have been used by industry. BGS scientists and technologists have contributed to the shaping of the next phase of IODP 2013-2023 by contributing to the IODP Science Plan and the Future of ECORD. The next phase of IODP will see much closer collaboration with the International Continental Scientific Drilling Programme (ICDP) and the proposed ‘Distributed European Infrastructure for Subseafloor Sampling and Monitoring’. BGS subsea robotic coring systems (sea-floor drill and vibrocorer), have been used by UK and international industry and science groups to sample marine rocks and sediments on global basis. BGS has a major innovative development co-funded by industry nearing completion which will provide a corer for hard rocks and sediments capable of working in 4000 m water depth, sampling fluids and the deep biosphere, collecting geophysical logs and coring to depths of 50 m from platforms such as the **RRV James Cook**.

### 4. Evidence and sources to corroborate the impact

1. MAREMAP website. [www.maremap.ac.uk](http://www.maremap.ac.uk)
4. Forewind website. [http://www.forewind.co.uk/](http://www.forewind.co.uk/) (ttjelta@statoil.com)
5. The Crown Estate. BGS reports. [http://www.thecrownestate.co.uk/marine/aggregates/](http://www.thecrownestate.co.uk/marine/aggregates/)
6. UKSeaMap. [http://jncc.defra.gov.uk/ukseamap](http://jncc.defra.gov.uk/ukseamap); EUSeaMap: [http://jncc.defra.gov.uk/page-5040](http://jncc.defra.gov.uk/page-5040)

### 5. Contacts for further information

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**BGS09: NERC Isotope Geosciences Laboratories – Depleted uranium (DU) contamination and its mobility in the environment, human exposure quantification and impacts on health**

1. **Summary of the impact**

NIGL developed a urine, soil and particle assay for detection of DU munitions pollution and applied this to Gulf War veterans to quantify exposure to DU munitions. None of the 466 Gulf War veterans tested in a UK MoD study had detectable DU; the test was also applied to munitions factory workers and quantified exposure to DU in exposed individuals and environmental materials, even 20 years after exposure. The impact to the UK government is that DU exposure was limited, and that the harm to veterans was small, although residual environmental issues of chronic exposure have yet to be quantified.

2. **Nature of the impact**

**Beneficiaries:** Beneficiaries of this work are primarily the UK and US governments who have learned that the DU exposure sustained by Gulf War veterans is more limited than thought. Other benefits are directly to those veterans with Gulf War Illness who can achieve more clarity about whether DU played a role in their illness. Other beneficiaries are the New York Department of Health who are in a better position to design and apply analogous tests to exposed individuals near a DU munitions factory.

**Background to Impact:** During the period 1997–2008 there was considerable concern that exposure of military personnel and collateral exposure of civilians, to armour-penetrating DU munitions might contribute to illness of veterans (Gulf War Illness, cancer, birth defects, etc.) and have other deleterious environmental effects. These concerns were clearly documented by reports of the Royal Society and the United Nations in 2001–2002. In 2005 the UK Government appointed the Depleted Uranium Oversight Board (DUOB) to commission a study (done substantially by NIGL) to both develop a high sensitivity assay and apply this to veterans to find out if DU exposure was widespread; the MoD also commissioned a joint NERC research programme on the environmental impacts. No such test was available worldwide at that time.

**Direct impacts:** NIGL developed the most sensitive U isotope test for urine, particles and other media and applied this to several threads of this general DU-contamination issue. NIGL research showed that no tested veteran had detectable DU (none out of 466 tested, documented in the final report of the DUOB, section 4), allowing the UK government to conclude the study and be satisfied that significant exposure to veterans by DU could not be substantiated. This allowed the UK MoD to largely draw a line under this particular issue, and reduce future expenditure related to DU-related issues. This is substantiated by a letter from Prof B Spratt FRS stating “The Depleted Uranium Oversight Board were particularly impressed by the high performance of NIGL in testing for uranium isotopes ....which has resulted in a much clearer view of the levels of exposure to DU on the battlefield (which subsequently have been supported by uranium isotope measurements by Harwell on urine from veterans of the 2001 Gulf War) and have very largely eliminated further consideration of DU exposure as a contributor to Gulf War diseases.” Subsequent work done at NIGL showed that 1) where DU aerosols were significant around a DU manufacturing plant in New York, exposure to humans and the environment was significant and detectable even after 25 years since the inhalation exposure happened; 2) DU pollution migrated very slowly in soil; and 3) DU is also incorporated into biological tissue (plants, animals, humans). The work showed that particles arising from combustion of DU in the factory were fully oxidised and amongst the least soluble, explaining why the pollutant persists for decades in the environment and the human body. None of these conclusions were known until this work was done, yet earlier policy decisions needed to rely on such evidence. The NIGL research proved as **entirely incorrect**, the conclusions of the US Agency of Toxic Substances and
Disease Registry which stated that the DU contamination legacy surrounding the New York manufacturing plant could not be quantified and that detection in humans after 20 years would be impossible.

The long-term health and environment effects of chronic DU-inhalation or ingestion exposure are as yet unquantified, because no health study has been conducted on putatively-exposed humans, even though numerous animal studies show mutagenic and teratogenic effects. The NIGL study caused the New York State Department of Health in 2011–12 to develop a similar assay and apply this in a limited way to the local population to begin to address the continuing health concerns of that locality in order to begin the initial stages of a proper health study of DU-exposed individuals. The US Congress Committee on Science and Technology sought testimony from Parrish (NIGL) on 12 March 2009 concerning these new developments in order to learn lessons about how to quantify exposure and document the DU pollution within the environment. The method development done at NIGL prompted a currently active follow-up testing study to a $20M study of the Southwestern Medical Centre, University of Texas, to test for DU exposure in 160 putative US veterans suffering all the brain abnormality and physiological symptoms of Gulf War Illness. The study will define the role, if any, of DU in this illness and conclude in 2013. Finally, NIGL is following this research by developing Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) methods to make more efficient the analysis of uranium particles in nuclear forensic safeguard testing. This capability of using LA-ICP-MS for U particle isotope composition is a priority topic of the International Atomic Energy Agency (IAEA) (Vienna) and the nuclear forensic safeguards community because of the very high cost and time-consuming nature of doing this work by the alternative FT-TIMS or SIMS methods, which are the only methods currently accredited by the IAEA; LA-ICP-MS offers similar sensitivity but faster turnaround and more rapid analysis even for minor isotopes at potentially much lower cost, important considerations for nuclear safeguards testing by the IAEA.

A further specific impact is that the PhD student who participated in part of this work and was trained in advanced mass spectrometry skills, was then quickly employed by a major mass spectrometry manufacturer as a key applications scientist and is now involved in developing and marketing the type of instruments used in the study at NIGL to other scientific establishments worldwide. This is a tangible impact of the high level training delivered at NIGL as part of its ongoing research.

3. How the Centre contributed to the impact

None of these impacts would have occurred without the innovative development of uranium isotope assay of urine, particles, and other media using advanced mass spectrometry, work entirely developed by NIGL and its staff. This impact grew over a period of years, starting with the development of a reliable, high sensitivity urine uranium isotope test and its validation using international Institute for Reference Materials and Measurements (IRMM) (EU) round-robin blind testing exercises. This then evolved by developing a rapid, reasonable precision soil U isotope test with the BGS geochemistry labs. Subsequent work progressed to the uranium isotope analysis (including the minor isotopes $^{234}\text{U}$ and $^{236}\text{U}$) of single particles less than 1 µm in size, this being useful for both analysis of DU and other particles within the environment but also having a significant impact internationally in the nuclear forensic uranium particle analysis community overseen by the IAEA. The NIGL urine assay remains the most sensitive in the world and is currently being used to address the Gulf War Illness problem at the University of Texas. The study in New York was conceived and undertaken entirely within BGS using the advanced capabilities and experiment design expertise of NIGL scientific staff. The particle analysis using LA-ICP-MS methods was developed at NIGL and is being expanded by collaboration with the University of Loughborough. In 2012 NIGL adapted the urine test and applied this to hair as a uranium biomarker.

All of this themed work has been aiming to (1) address an important but difficult-to-study environmental health problem caused by human intervention; (2) develop methods for
environmental and biological media that are fit for purpose to detect and quantify the contaminant and its isotope variability so as to allow tracing back to source, given that exposure took place 10–25 years earlier; (3) work with the medical community to better measure historic exposure to uranium and toxic metal exposure to inform health effects and (4) to demonstrate whether brain function damage intrinsic to Gulf War Illness has any connection to DU exposure, in addition to exposure to the nerve agent Sarin, the current main contender. This work contributes to the goal of improving the evidence base for government decision-making concerning balancing the advantages of munitions deployment against the deleterious environmental and health effects.

4. Evidence and sources to corroborate the impact

Publications


Media, and letters


Letter from Rep Brad Miller, Chair of US Congress Subcommittee on Oversight to Parrish – Hearing correspondence, 26 March 2009.

Letter from Prof Brian Spratt, Chair of Royal Society Working Group on Depleted Uranium, and member of the Depleted Uranium Oversight Board, dated 7 December 2007.

Press Release

March 12, 2009 Investigations and Oversight Subcommittee Examines the Failures of the Agency for Toxic Substances and Disease Registry, US Congress Committee on Science and Technology Hearings; [there have been many other related press releases related to the NIGL DU work, not itemised].

5. Contacts for further information

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Dr Matt Horstwood (particle isotope analysis for uranium) msah@nigl.nerc.ac.uk 0115 936 3008
NIGL website: http://www.bgs.ac.uk/nigl/
# BGS 10: Geological Survey of Northern Ireland (GSNI)

## 1. Summary of the impact

GSNI has provided geoscience advice to the Northern Ireland Government since 1947. GSNI promotes investment in the exploration for minerals and energy resources by geoscience mapping and research and the supervision of exploration licensing. GSNI’s work has prompted or contributed to £32 million of investment in industrial mineral exploration between 2007 and 2012. GSNI is a statutory consultee to the Planning Services and comments on all applications with a geological component, and annually responds to some 600 other requests for information, mostly from industry. GSNI manages and monitors groundwater resources in the Province on behalf of the NI Environment Agency (NIEA).

## 2. Nature of the impact

### Beneficiaries

GSNI provides geoscience advice and undertakes applied research under several agreements with the Government of Northern Ireland. Two additional projects, each exceeding £4 million, have been concluded or begun in the period 2007–12, funded or co-funded by the NI government and the European Regional Development Fund (ERDF). GSNI also provides an enquiries and information supply service to external industrial and academic stakeholders. In the financial year 2011/12, GSNI had 11 staff fully funded by the Department of Enterprise, Trade and Investment (DETI)(external income value to NERC approx £774 000); 2 staff 80 per cent funded by NIEA (external income £118 000) and three staff funded by ERDF (external income £178 000).

### Nature of impacts

Impacts are: promotion and oversight of national mineral exploration; improved management of geohazards and old mines; groundwater management; and improved information supply to end-users. Examples are:

1. **Tellus project** ([Tellus Project](#), [Tellus2](#) and [Tellus Border Project](#)). The Tellus project has produced new geochemical and geophysical maps that have extended and deepened knowledge of the geology, soils, natural resources and environment of Northern Ireland. This supports the exploration for, and development of, mineral and hydrocarbon resources, informs land-use planning and provides a country-wide environmental baseline. Impacts include:
   - Since publication of the Tellus results in 2007 the area of Northern Ireland licensed for mineral exploration increased from 15 to 70 per cent. Company spending on exploration increased since the publication of data in 2007 was, from 2007 to 2011: £1.8m, £3.5m, £4.0m, £8.2m, and £9.3m.
   - The results have prompted increased geothermal exploration, through GSNI’s input into [IRETHERM](#).
   - A new environmental baseline of terrestrial geochemistry, identifying areas with potentially toxic levels of heavy metals and areas where essential nutrient elements are deficient.
   - A new resource for health research and public health management; an improved means of mapping the distribution of radon; detailed mapping of potentially harmful elements and radiation.
   - An ERDF award of £4 million (2010–13) for the next phase, ‘Tellus Border’, to extended the surveys and provide integrated cross-border datasets for integrated resources and environmental management (focus on soil-carbon stocks; wetlands; groundwater protection).

2. **Management of natural resources exploration in NI.** Since 1947, GSNI has advised DETI and its predecessors on the management of mineral (i.e. other than construction materials) and energy exploration in NI. NI is currently the most heavily explored region of any in UK, with 47 per cent of its land areas licensed for mineral exploration. Impacts of GSNI in these sectors include:
   - Promotion of NI mineral potential to industry, increase in exploration licensing/investment (1 above).
   - The Mineral Prospecting Licences include three where companies are assessing the potential for establishing underground energy storage (local compressed air from wind farms and imported gas) in salt caverns, operations that have attracted major inward investment (£15 million since 2007).
   - GSNI supervises existing metal and salt mining. There is one salt mine and one gold mine currently operating and expanding; a second gold mine is an advanced stage of development.
   - GSNI’s work is central to development of onshore hydrocarbons resources by 1) policy advice to DETI, 2) advice to developers, 3) award and oversight of Petroleum Licences.
   - Improved guidance to Planning Services through production in 2012 of six new Mineral Resource Maps of Northern Ireland (funded by the Department of the Environment (DoE) and supported by an industry
forum). They provide a context for assessing planning applications that may potentially affect the future exploitation of resources. These maps provide a framework for future economic development.

3 Groundwater management in NI
For 12 years GSNI has closely assisted the NIEA with NI’s obligations under the Water Framework Directive (WFD), resulting in improved coherence of groundwater management, improved characterisation of groundwater resources, better understanding of threats and improved abstraction control. Impacts include:
- Delineation of groundwater bodies.
- Production of groundwater related map products.
- Development of methods for characterising and classifying groundwater bodies as part of the first River Basin Management Plans.
- Establishing a regional groundwater chemical and level monitoring system.
- Improved understanding of groundwater-dependant terrestrial ecosystems.

3. How the Centre contributed to the impacts
1 Tellus Project (Tellus Project, Tellus2 and Tellus Border Project)
Key activities, dates and funding
- Tellus Project, 2004–2007, value £5.8 million, 100 per cent financed by DETI and the Department of Agriculture and Rural Development (DARD) (from an ERDF fund); detailed geochemical and airborne geophysical mapping of all NI; publication and promotion of results.
- Tellus2, 2008–11, value £2.3 million, 100 per cent financed by DETI and the Chancellor’s NI Fund for Innovation: further analysis and promotion of information.
- Tellus Border, 2010–13, value £4 million, 100 per cent financed by ERDF: Tellus mapping of the 6 northern counties of the Republic of Ireland (RoI), integration of data with NI Tellus data, integrated interpretation of RoI and NI results.

How activities made a contribution to impact (how they came to influence users or beneficiaries, or how they came to be exploited, taken up or applied)
- Tellus data are licensed to end-users; 98 data licences were issued in 2007–12.
- Results were presented and publicised in annual seminars, a final project conference, 90 BGS/GSNI publications, reports and conference presentations in the period 2008–11; presentations to District Councils, presentations to other stakeholders, a website, newsletters, press coverage; and permanent exhibits at W5 Interactive Discovery Centre, Belfast.

BGS contribution and partners
- All Tellus work was done by GSNI and BGS staff, although some selected specialised survey and analytical services were contracted out. Some public communications functions were also contracted out.
- Tellus Border: GSNI instigated the project and is lead partner; other partners: GSI, QUB, DkIT

2 Management of natural resources exploration in NI
Key activities, dates and funding, staffing
- GSNI contributes to this ongoing function by providing staff who scrutinise applications for Mineral Prospecting Permits, work with companies in their implementation; review progress and advise DETI on progress and continuance. GSNI is central to the development of NI policy on minerals and hydrocarbons exploration, most recently in the drafting of the Petroleum Production (Amendment) Regulations (Northern Ireland) 2010, and in advising DETI on policy with regard to shale-gas exploration.
- The Mineral Resources Map project entailed compiling all available maps and information on NI mineral resources and delineating historical mines and quarries, areas of potential resources and other relevant data. A complementary database was compiled. The project was funded by DoE between Sept 2011 and March 2012 (project cost £280 000).

How activities made a contribution to impact
- GSNI directly provides advice to DETI and provides information and advice to developers.
- The Mineral Resources Maps and database provide an essential framework for assessing the potential effects of Planning Applications in areas where there is a potential mineral resource.

BGS contribution
- Two GSNI staff (Bands 5 and 6) are fully funded by DETI for this function. The Band 5 also manages
hydrocarbons licensing in the same way. Specialist support is sometimes provided by BGS Minerals staff.

- The Mineral Resources Map project was undertaken entirely by BGS and GSNI staff, under a Steering Committee including BGS, GSNI, DoE, DETI and QPANI personnel.

### 3 Groundwater management in NI

**Key activities, dates and funding, staffing**

- Activities include collecting and collation of groundwater data; monitoring groundwater boreholes; hydrogeological mapping; liaison with the Water Management Unit of NIEA; liaison with partners in the Republic of Ireland; reporting.
- The agreement has run since 2000 and was extended for a further three years in 2012; 80 per cent of staff costs are covered by DoE, allowing 20 per cent staff time to engage on BGS or other GSNI projects.

#### How activities made a contribution to impact

- Results are delivered directly to NIEA and managed by a quarterly steering committee chaired by a NIEA PSO.

##### BGS contribution

- Two GSNI staff (Bands 6 and 7) are engaged for 80 per cent of their time on this work, under the direction of a GSNI Band 4.

### 4. Evidence and sources to corroborate the impact

**1 Tellus Project (Tellus Project, Tellus2 and Tellus Border Project)**

- See [www.bgs.ac.uk/gsni/tellus](http://www.bgs.ac.uk/gsni/tellus) and [http://www.tellusborder.eu/](http://www.tellusborder.eu/)
- More than 90 publications, lectures and one book produced
- Mineral prospecting licences of NI: [map](http://www.bgs.ac.uk/gsni/tellus)
- Project final report and post-project evaluation reports of the Tellus Project and Tellus2 projects
- Awards: 2008 (mining); 2008 (GIS); 2012 (communications)

**2 Management of natural resources exploration in NI**

- Mineral Prospecting Licences of NI: [map](http://www.bgs.ac.uk/gsni/tellus).
- New Mineral Resources Map and BGS Report
- [Submissions to Select Committee of the NI Assembly](http://www.bgs.ac.uk/gsni/tellus) on shale gas exploration (2012); responses to Assembly Questions (2011–12).

**3 Groundwater management in NI**

- Periodic reports to NIEA, minutes of quarterly meetings.

### 5. Contacts for further information

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BGS11: BGS international geoscience activities: export earnings, supporting UK foreign policy, development aid objectives, and UK industry

1. Summary of the impact
Many developing and post-conflict countries have large natural resources the exploitation of which can be fundamental to sustainable development. Any investment in mineral or hydrocarbon extraction requires reliable baseline geological data, and good local governance. BGS has carried out a number of major international projects which aim to provide the basis for natural resource development. These projects have included rebuilding of local institutions, collection, analysis and databasing of baseline geological data, promotion of resources, and review of extraction methodologies. Considerable inward investment to the countries involved and growth in the extractive industries have been direct consequences of the work.

2. Nature of the impact
In many developing or post-conflict countries, economic growth and poverty reduction can be underpinned by the extractive industries (oil and gas, and mining). Consistent, widely accessible baseline geological data are fundamental to the sustainable development of such industries in any country. The BGS is a world leader in the collection, interpretation and long-term archiving of geological data, and has carried out large-scale projects that support development in a number of countries. Some key examples are given here.

i) Capacity building in Afghanistan. Afghanistan has extensive mineral resources, but instability in the country means that geological data have not been widely available, and geological institutions were severely weakened. Between 2004 and 2008, BGS (funded by DFID) worked with the USGS within the Afghanistan Geological Survey to train local scientists, to evaluate mineral resources, and to create modern databases and GIS. A focus on known mineral resources led to the development of a comprehensive mining information package on the world-class Aynak Copper Deposit, which has been the focus of small-scale copper working since ancient times. This package included a 3D model of the copper deposit, showing its extent and structure, and the distribution of copper. The information package formed the basis of a tender for the deposit, which was won by the China Metallurgical Group. A mining and infrastructure contract was signed in 2008, and was followed by a feasibility study; construction is now underway and the mine is expected to start producing in 2016. The World Bank estimates that the mine will contribute around $250 million per year to the Afghan economy, and create around 5000 jobs, as well as bringing in major infrastructure investment. This major boost to the Afghan economy could not have been achieved without the provision of geological baseline data for the deposit.

ii) Strengthening the mining sector in sub-Saharan Africa. Mining sector reform can be vital to enable developing countries to attract private sector investment and to set up long-term, sustainable mineral development programmes. The International Council for Mining and Metals states that “Investment in mining and mineral resources can be a significant driver of economic growth and poverty reduction.... the most important determinant of whether mining will contribute...... is the overall governance framework”. To achieve this, the World Bank funds technical assistance programmes in several countries with aims including strengthening of national institutions such as geological surveys and mining departments, training of local staff, creation of baseline geoscientific databases, and national geological mapping. In recent years, the BGS has played a major part in such programmes in several countries including Mozambique, Madagascar, Mauritania and Nigeria. World Bank completion reports clearly show that during the impact period, these programmes led to improved governance in the mining sectors of these countries, and increased investment in mining by the private sector. In Madagascar, the World Bank noted that “Results such as...... contribution to legal and regulatory frameworks .... the geological mapping......
are likely to have a lasting positive impact on the development of the sector”. As an example, inward investment in mining in Madagascar has increased from $10 million in 2003 to $2.9 billion in 2012.

**iii) Best practice in artisanal gold mining in Ghana.** Throughout the world, artisanal gold miners use mercury to recover gold from ore, and this causes distinct pollution and health problems. In Ghana, artisanal gold mining has contributed some $500 million to the economy between 1989 and 2008, but almost 100 tonnes of mercury have been discharged into the environment. BGS carried out an EU-funded project to assess artisanal gold mining in Ghana and to develop an alternative method of gold recovery. The project demonstrated that direct smelting is simple and safe, and since 2007 basic smelters have been manufactured and distributed among Ghanaian gold miners, significantly reducing the amount of mercury used. This has had a positive impact in ameliorating the negative aspects of artisanal mining, through lower exposure of the miners to mercury and its toxic oxides, and reduced discharge of mercury into watercourses and water supplies.

**iv) Increased exploration activity on the Falklands shelf.** BGS has advised the Falkland Islands Government (FIG) on oil exploration since 1992. A significant amount of 3D seismic surveying by oil companies, augmented by two extended drilling campaigns, has produced huge quantities of data that BGS have analysed to provide FIG with the independent advice they need to manage offshore exploration. Recent years have seen significant increase in exploration around the Falkland Islands, largely due to promotional activities undertaken and supported by BGS. 21 wells have been drilled since January 2010, resulting in seven oil, gas or condensate discoveries. One of these discoveries, the Sea Lion field, has been evaluated with eight appraisal wells, and is being readied for development drilling and production, with first oil predicted as early as 2017. The Falklands is already benefitting from the oil exploration activity, with approximately £30 million being injected into the local economy as a result of exploration activity over the last three years; production around the islands will undoubtedly provide further economic benefits for years to come.

### 3. How the Centre contributed to the impact

**i) Capacity building in Afghanistan.** BGS, funded by the Department for International Development (DFID) worked extensively with the Afghanistan Geological Survey, training a large number of staff so that they could continue to develop the country’s geological data holdings. The BGS team was responsible for translating, digitising and collating extensive data on Aynak that had been collected by Soviet geologists, and developing brochures, a website, and the information package that provided the basis for the Aynak tender. The 3D model that provided information on the extent of the copper deposit was also built by BGS. BGS staff were involved in advising the Afghan government throughout the tendering process. A DFID review of the BGS project in 2007 stated “...Unambiguously, this project has contributed to the overall goal and purpose of creating a viable Afghan minerals industry through institutional strengthening and capacity building of the AGS....”

**ii) Strengthening the mining sector in sub-Saharan Africa.** During the period 2003 to 2012, BGS was employed by World Bank-run programmes in a number of countries including Mozambique, Madagascar, Mauritania and Nigeria. In partnership with other geological surveys (from the US, South Africa, Norway and Finland), BGS carried out extensive geological and geochemical mapping programmes; trained local staff from geological surveys, universities and government departments; assessed mineral potential; and developed national geoscience databases. This work provides the fundamental baseline data that underpin growth of the mineral sectors in these countries, as well as enabling local institutions to work effectively and to oversee sustainable development.

**iii) Best practice in artisanal gold mining in Ghana.** BGS led an EU-funded project in Ghana which surveyed artisanal miners across the country and assessed the character of the gold deposits being worked. Following this, possible methods for gold recovery without using mercury were considered.
Direct smelting was identified as a potential method and this was tested both in laboratory experiments and in the field\(^\text{10}\). Following project completion in 2007, simple smelters were constructed and distributed for the use of miners in Ghana.

**iv) Increased exploration activity on the Falklands shelf.** BGS leads the technical assessment of commercial petroleum geosciences offshore from the Falkland Islands on behalf of, and funded by, the Falkland Islands Government. This includes analysis of seismic and well data from all previous exploration work. Much of the technical work is confidential, but the BGS undertakes extensive promotion of prospectivity through presentations at industry conferences and publications, and also hosts the website that makes Falkland Islands data widely available\(^\text{11}\). BGS work has led directly to a second phase of drilling with new licensees commenced in 2010, leading to the declaration of the ‘Sea Lion’ well as an oil discovery after a well test in September 2010. BGS advises the FIG on licensing and acts on their behalf in discussions with operators, as well as monitoring operations. Thus, BGS activities have played an important part in this crucial development for the Falkland Islands economy.

4. Evidence and sources to corroborate the impact

**i) Afghanistan**
1: [Afghanistan Project completion report](#)
2: [Case study on the Aynak Tender by the World Bank](#)
3: [Afghanistan Investment promotion website](#)

**ii) Sub-Saharan Africa**
4: [ICMM Mining: Partnerships for Development report](#)
5: [World Bank website on Mining Sector Reform](#)
6: [World Bank Nigeria completion report](#)
7: [World Bank Madagascar completion report](#)
8: [World Bank Mozambique completion report](#)
9: [BGS International Activities report for 2010](#)

**iii) Ghana**
10: Amankwah et al. (2010), International journal Environment & Pollution Vol. 41

**iv) Falklands**
11: [Falklands Department of Minerals website](#)

5. Contacts for further information

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General: Martin Smith, BGS Global, 0131 650 0320, msmi@bgs.ac.uk
BGS12: 3D geological models and associated modelling technologies

1. Summary of the impact

3D models have diversified the application and impact of BGS national geological survey capability. Models have directly led to new groundwater abstractions and flood management schemes, and are critical components of decision-making tools for regulating radioactive waste disposal and shale gas exploration. BGS leads international best practice in use of 3D models to inform sustainable management of the urban subsurface. Engineering response teams use BGS mobile mapping technology in the immediate aftermath of major disasters to direct remediation efforts. 3D visualisation software developed by a BGS/commercial venture informs outreach and operational design for high-value mining operations and radioactive waste repositories.

2. Nature of the impact

Since 2005, BGS has redirected its UK geological survey programme to develop and populate the National Geological Model (NGM), an integrated set of 3D geological models at various resolutions that is progressively replacing the 2D geological map as the primary spatial knowledge base on the UK’s geology (Ref 1). To build capability in 3D geological modelling, BGS has also developed and customised technologies for digital field data recording (BGS•SIGMaMobile), 3D modelling (GSI3D) and 3D visualisation (GeoVisionary). Various commercialisation and knowledge exchange approaches have secured impact from both the 3D geological models themselves and these associated technologies.

Managing groundwater abstractions and quality, and mitigating risks of groundwater flooding – BGS 3D geological models are embedded in the conceptual groundwater models used by the Environment Agency (EA) to implement Catchment Abstraction Management Strategies (CAMS), meet the obligations of the Water Framework Directive (WFD), and manage groundwater flooding risks. The models enable the Agency to simulate, forecast and quantify the behaviour and responses of aquifer systems with greater confidence, enabling enhanced decision-making performance and implementation of CAMS that balance opportunities and risks. Two NERC-commissioned case studies highlight the value of these models and provide examples of wider economic impacts during the period 2007–10. For example, a BGS 3D model of the Chalk aquifer below London used by the EA and its consultants supports risk-based decision-making on new groundwater abstraction licences, leading to additional abstractions valued at £27 to £40 million (Ref 2). A geological model built using GSI3D underpins a groundwater conceptual model for forecasting groundwater flooding in Oxford, helping the EA and local planning authorities to mitigate risks for property valued in excess of £46 million (Ref 2). Similarly, a GSI3D model underpins a groundwater model for Forres, north-east Scotland, informing measures to alleviate risk from groundwater flooding to properties worth £112.0 to £130 million and supporting a case for a £30 million flood alleviation scheme (Ref 3).

Informing site selection and outreach for radioactive waste disposal – The Department of Energy and Climate Change Framework for Managing Radioactive Waste Safely uses the NGM to inform the desk-based assessment process for identifying volumes of potentially suitable rock that could be used to host a geological disposal facility within a participating Community Siting Partnership area (Ref 4). The French National Radioactive Waste Management Agency (ANDRA) has licenced GeoVisionary since 2010 for use as a spatial data integration and visualisation tool to support research and design operations at its Bure test facility (Ref 5). ANDRA also exploit the high visual impact and data-streaming capabilities of the software to provide dynamic, 3D visualisations of the design and operation of the test facility, informing public and stakeholder awareness and understanding of France’s proposals for long-term storage of radioactive waste, critical for approval to proceed with construction of a repository.

Informing safe and sustainable development of urban areas and major infrastructure – Long-standing collaboration between BGS and Glasgow City Council (GCC) has firmly embedded BGS 3D models into the Council’s development planning and control processes. The models provide the essential, public domain knowledge base on ground conditions that enables the Council, neighbouring local authorities, Scottish
Environment Protection Agency and potential developers to work together to remediate and redevelop challenging brownfield sites. GCC are partners with BGS in a pioneering knowledge exchange network (ASK) (Ref 6) to maximise use of 3D models by the wider public and private sectors and facilitate improved engagement with the environmental research community. A European Union (EU) COST Action recently approved under the Transport and Urban Development Domain (Ref 7) will fund (c. EUR 1 million) development of a multinational partnership (currently 12 countries) led by BGS, with GCC involvement, to spread these established best practices in 3D geological modelling, subsurface management and custodianship to city authorities throughout Europe and beyond. BGS 3D models inform ongoing management of ground-related risks for Crossrail (Ref 8), one of the UK’s largest infrastructure projects. The models and associated BGS staff expertise guide design of cost-effective ground investigations to resolve challenging and uncertain ground conditions that may pose substantial health and safety risks to tunnelling teams and considerable financial risk to the project.

**Bringing world class mineral resources into production** – BGS•SIGMAmobile and GeoVisionary are being adapted for use by Vale Mining, the world’s largest iron ore mining company, for near-mine exploration data recording, resource modelling and visualisation, informing executive-level decisions on bringing new, high-value ore prospects into development (Ref 9). GeoVisionary is also used to demonstrate Vale’s environmental management plans to regulators, facilitating approvals of new mining operations. A Department for International Development-commissioned BGS 3D model of the Aynak copper deposit in Afghanistan formed the core reference source on the geology, extent and structure of the prospect. The model was integral to the tender documentation and supporting data pack, exhibitions and prospectuses that encouraged investment in development of this world-class resource. The China Metallurgical Group acquired rights to the deposit in 2007 and is pledged to make a US$ 3 billion in the Afghan economy as a result (Ref 10 – see also BGS Impact Case Study BGS11).

**Informing response and follow up to alleviate natural disasters** - The Global Earthquake Model (GEM) Inventory Data Collection Tools (IDCT) initiative is adapting BGS•SIGMAmobile for deployment in earthquake and tsunami disaster zones by rapid response and relief teams such as the Earthquake Engineering Research Institute (EERI) and Earthquake Engineering Field Investigation Team (EEFIT). The tool enables rapid recording and risk assessment of secondary hazards such as activated landslides, damaged buildings and weakened infrastructure, enabling relief teams to communicate data in real time and manage further risks to affected communities and key infrastructure in the critical first few days following a major natural disaster (Ref 11).

### 3. How the BGS contributed to the impact

The BGS secures about half of its funding by proactive exploitation of its national geoscience knowledge base and science capability through a range of client-funded applied geoscience projects, services and information products. This business model has built numerous long-standing partnerships with government, regulators and industry in the water, environment, energy and minerals sectors. To deliver impacts from the NGM, BGS has built on these established relationships by working alongside clients and partners, most notably the EA, to develop a full understanding of their business and regulatory priorities, and to adapt outputs from 3D models to meet their specific needs. Since 2006, the EA has funded targeted enhancements of the NGM, enabling the Agency to embed BGS models directly into their decision-making tools, improving the effectiveness of CAMS and meeting the regulatory requirements of the WFD.

The award winning (Ref 12) BGS•SIGMAmobile software application was developed in 2003–5 and has been deployed on BGS mapping and modelling projects since 2005. BGS•SIGMAmobile was used by BGS fieldworkers following-up the Christchurch New Zealand Earthquake in 2011 (Ref 13), and on a NERC Urgency Grant funded project following up and the Japanese tsunami in 2011 (Ref 14). Both projects demonstrated the capabilities of the system to the disaster relief and engineering remediation teams operating alongside BGS, influencing the choice of BGS•SIGMAmobile as the platform for the GEM IDCT project.
GSI3D (developed by Insight GmBH) has been deployed by BGS from 2003 onwards for modelling the geology of the shallow subsurface. From 2007 to date, BGS has been in partnership with Insight to adapt GSI3D for building and exploiting the NGM. In 2010 an international not-for-profit consortium (Ref 15) was established to broaden the licensed user base of GSI3D to other survey and research organisations with national roles comparable to BGS, and to develop and share best practice on both the research and societal applications of GSI3D and enhance its impact internationally. The consortium continues to grow and currently has 32 members, of which 20 are national or state geological surveys, mainly in North America (including the USGS) and the EU.

GeoVisionary, developed by a commercialisation partnership between Virtalis Ltd and the BGS (Ref16), exploits a gap in the market for integrating and visualising multiple, high-resolution surface and subsurface datasets, including not only geology but also subsurface services, infrastructure and excavations, broadening its appeal and impact for high-value/high-risk, large-scale mining and radioactive waste applications. Commercialisation of GeoVisionary has generated substantial software and VR hardware licence sales since first release in 2009, building on a comparatively modest investment by the BGS.

4. Evidence sources to corroborate the impact (numbers refer to citations in sections 2 and 3)
1. BGS 3D Models website: http://www.bgs.ac.uk/services/3Dgeology/home.html?src=ep
2. NERC case study economic evaluation report, ‘Modelling the UK in 3D’ http://www.nerc.ac.uk/business/casestudies/reports.asp
6. ASK Network webpage: http://www.bgs.ac.uk/science/landUseAndDevelopment/urban_geoscience/Clyde/asknetwork/home.html
7. COST TU1206: Sub-Urban – A European network to improve understanding and use of the ground beneath our cities http://www.cost.eu/domains_actions/tud/Actions/TU1206
10. BGS Afghanistan Project completion report: http://nora.nerc.ac.uk/14493/1/OR11038.pdf
11. GEM Inventory Data Collection Tools (IDCT) website: http://www.globalquakemodel.org/node/1166
13. BGS website article: http://www.bgs.ac.uk/research/earthquakes/newzealandFeb2011visit.html
14. BGS website article: http://www.bgs.ac.uk/research/highlights/2011/japanTsunamiFieldWork.html
15. GSI3D Consortium website: http://www.gsi3d.org.uk/

5. Contact for further information
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1. Summary of the impact

The National Geological Repository’s (NGR) collections from onshore UK and the continental shelf are used extensively by industry and academia. They generate impact by underpinning exploration for, and management of, natural resources (oil, gas, minerals, groundwater), supporting critical investment decisions, facilitating the development and growth of existing and new businesses, and informing subsurface risk and site investigation evaluations. The NGR is instrumental in the implementation of policy and regulation for government departments and agencies, has delivered efficiencies in public service provision, supports the training of petroleum geoscientists, and creates public engagement impacts.

2. Nature of the impact

2.1 Economic impacts

The NGR holds the only publicly accessible collections of borehole cores, cuttings and related data from the UK continental shelf, which are used extensively by companies and consultants engaged in exploration for oil and gas resources. Between January 2007 and December 2012 at least 238 unique commercial users examined cores, samples and related geophysical data to quantify potential hydrocarbon resources, and to evaluate rock properties (porosity, permeability etc.) that indicate potential ease of recovery. The NGR therefore has a direct impact in underpinning critical investment decisions that have to be made by companies related to the economic viability of deposits, costs of production, whether to go to the investment markets to raise capital, and whether to bid for a production licence in the Department of Energy and Climate Change (DECC) offshore oil and gas licensing rounds.

The NGR also holds the unique archive of UK geophysical, seismic, borehole, coal seam, coal sample and chemistry data. The seismic data were originally written to the now obsolete nine-track tape format, and are progressively being remastered. Modern reprocessing techniques greatly enhance the original data enabling its use in the exploitation for unconventional gas in former coal-mining prospects, and these data have been used by numerous private sector companies in the past five years. This re-use of old data reduces start-up costs considerably, improving project viability. Many oil and gas companies (including BP, Exxon-Mobil and EOG Resources Inc.) have recently sampled and analysed NGR cores for organic carbon content to evaluate onshore unconventional gas reserves.

An additional economic impact of the NGR collections is their use in support of petroleum geoscience teaching and training by UK universities, which in turn contributes to the supply of suitably skilled professionals. Each year UK universities (e.g. Imperial College, Universities of Manchester and Derby) bring parties of petroleum geoscience students to the NGR to log samples of petroleum-bearing cores and to correlate them with geophysical well data. This forms the practical element of their MSc course work.

National and international mining companies regularly examine NGR core and sample collections related to UK metalliferous mineral deposits. The main objective of such visits is to make preliminary assessments of the economic potential of minerals deposits based on publicly available data. This is a precursor to deciding whether more detailed geological site investigations are justified, that may require significant capital investment.

Since 2009, digital versions of some key NGR datasets have been released through the BGS website free of charge. Two notable examples are the collection of over 1.3 million UK onshore borehole logs, and about 125 000 high-resolution images of the entire UK continental shelf offshore hydrocarbon core collection. Releasing such data online on open-access terms has created economic impact in a number of ways. It has greatly increased the efficiency of service provision by significantly reducing the cost of supply and by eliminating access barriers. Drilling and geotechnical companies now use the onshore borehole dataset in support of their services for ground-source heat pump and water-well installations.
2.2 Impacts on public policy and regulation

The NGR directly supports government, its departments and agencies, in the implementation of legislation, regulation and codes of practice relating to **subsurface data acquired by private operators** during groundwater and mineral (including oil and gas) exploration. The Water Resources Act 1991 requires that 'the Natural Environment Research Council be notified of the intention to sink new wells and boreholes for water to a depth of fifty feet (15 metres) or more in England and Wales’, that 'journals be kept of the programme of work, including measurements of any water levels and flow rates’, and that ‘these journals together with details of water levels and yields be provided to the Council’. Sections 3 and 4 of the Water (Scotland) Act 1946 stipulates similar requirements. All such data are stored and managed in the NGR, and made available for general use. There are additional provisions within the Mining Industry Act 1926 and the Science and Technology Act 1965 to ensure that all information obtained from the sinking of boreholes and shafts for minerals including petroleum is made available to the British Geological Survey (i.e. National Geological Repository).

Since 2001 the NGR has managed under a 50-year agreement the ‘**NIREX geological archive**’ of cores, samples and related data acquired by NIREX during its geological investigations at Sellafield and Dounreay into a deep repository for long-term storage of nuclear waste.

**Petroleum Operations Notice (PON) 9** is a regulation that sets out DECC’s specific requirements and licensee reporting obligations with regard to seaward (offshore) well and seismic data. The notice applies to all seaward surveys and all exploration, appraisal and development wells in seaward areas. The specific requirements were agreed through consultation with industry, Oil & Gas UK and PILOT in the PILOT Data Lifecycle Initiative. PON 9B is the parallel regulation for landward surveys and wells. Under PON 9 operators are specifically required to deposit **samples and related data for released wells** at the NGR, so facilitating DECC’s objectives of ‘enabling industry and members of the public to view and inspect this material’ at the NGR for further exploration and research purposes, and enabling annual checking of compliance of operators with the requirements of PON 9. The NGR also supplies well and related data to DECC’s licensed data resellers, so contributing to the development of their commercial activities. Through its role in the various DECC regulations the NGR directly supports government’s objectives of maximising the exploitation of the UK’s own hydrocarbon reserves, so delivering significant economic and energy security impacts.

The sudden and unexpected flow of water from abandoned mine workings into new workings (an ‘inrush’) has caused fatal accidents in UK mines in recent decades. An inrush at the Lofthouse mine, Yorkshire, in 1973 killed seven miners, and an inrush at the Gleision Mine in South Wales in 2011 caused four fatalities. In order to avoid such accidents the Health and Safety Executive has published an ‘**Approved Code of Practice on the Prevention of Inrushes in Mines**’. This code of practice stipulates that planning for new mining must ‘require a rigorous approach to information gathering which should include…..examination of records held by the Natural Environment Research Council (British Geological Survey) which might be relevant to proposed workings’. Such records are housed and managed in the NGR, and made available to users on request. Through this role the NGR plays a key role in the evaluation of subsurface risk. The British Standard 5930 (Code of Practice for Site Investigations) places similar obligations on developers to consult materials held at the NGR during the planning phase of site investigations.

2.3 Societal and cultural impacts

The NGR collections provide inspiration and source materials for cultural and artistic initiatives, including an ‘**artist in residence**’ who created works based on geological sampling techniques including rock peels. The collections also underpin a two-year project, ‘Look About’, led by Portsmouth based artist/geologist Jon Adams as part of the London 2012 Cultural Olympiad. The products of such artistic collaborations go on public display, raising the visibility of the collections and the science base, and expanding its impacts beyond the purely scientific. Events such as open days in support of the national **Archives Awareness Campaign** present opportunities to bring the general public into the research centre. The sheer size of the NGR core stores creates a strong and very impressive visual impact, and the facilities have been used as a filming
location for TV series featuring presenters including Sir David Attenborough, Prof Iain Stewart and Alan Titchmarsh.

3. How the Centre contributed to the impact
The NGR is an integral part of the BGS, and is a long-term, national science facility. The ongoing services provided by the NGR to generate the impacts described above are funded principally from National Capability budgets, from a DECC baseline transfer to NERC, and from income from commercial users. These services include management and online publishing of metadata describing the collections, online publishing of parts of the collections available digitally (e.g. offshore core images, onshore borehole scans), conservation of collections, liaison with key stakeholders (e.g. DECC, Nuclear Decommissioning Authority), provision of facilities for core, sample and record inspection, sampling and analysis, and ingestion of new collections.

4. Evidence and sources to corroborate the impact

5. Contacts for further information
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# BGS14: Digital geoscience information products

## 1. Summary of the impact

The digital geological map of Great Britain, DigMapGB, is used widely by consultants, businesses, and public sector bodies for diverse purposes ranging from mineral resource assessment to the assessment of ground conditions. Building upon DiGMapGB, BGS has produced a series of spatial information products which characterise shallow geohazard potential. These focus on societally relevant themes such as ground instability, radon, flooding and mining hazards. They deliver very substantial economic and health benefits to information economy businesses, the insurance sector, local and regional government, and the public.

## 2. Nature of the impact

BGS publishes a range of information products, of which three examples are described here.

**DigMapGB** is the baseline Digital Geological Map of Great Britain, produced at scales from 1:625 000 to 1:10 000. DiGMapGB-50, the 1:50 000-scale output, presents the most up-to-date understanding of the bedrock and superficial geology, and is continually updated to incorporate new data and interpretations made by the BGS and the external community. DiGMapGB-50 is used by a very broad range of users (public bodies, HEIs, private sector) in decision-making related to natural resource management (including minerals and groundwater), site investigation, and infrastructure planning. DiGMapGB-50 is the baseline dataset from which a set of separate derived information products have been developed (see below). DiGMapGB-50 is also used for teaching purposes in UK university geology departments. It is served to UK HEIs through EDINA; their ‘Digimap’ service has 25 000 users who view about 1 million maps containing BGS data each year. Since September 2010, DiGMapGB-50 has been served free of charge through iGeology, an application developed by BGS specifically for mobile platforms (described more fully in the impact case study ‘BGS15: Open data’). It is clear from feedback on the iGeology download pages that DiGMapGB-50 is being used daily for many commercial purposes including drilling, site investigations, structural surveying and field archaeology, and ‘promoting the potential of English/Welsh wines’. The same feedback provides evidence that the impacts of DiGMapGB extend beyond these specialist fields into support for teaching of geology in HEIs, raised public awareness of geology and the environmental sciences in general. DiGMapGB-50 has generated significant income for BGS since its launch in 2003. Licensees include local authorities, government departments, public sector bodies, commercial companies and consultancies, and value-added resellers.

**GeoSure** comprises six spatial information layers that characterise susceptibility to shallow geohazards for low-rise structures at a 25 m ground resolution for the whole of Great Britain. This information is used during the planning and development stage for both green- and brown-field sites to assess their suitability for development and to specify building design requirements. BGS supplies GeoSure information to customers, but the principal route to market is through a group of value-added resellers (VARs, e.g. LandMark Information Group and GroundSure). These VARs supply > 500 000 site-specific reports containing BGS data to private individuals and commercial property development businesses annually. The principal beneficiaries of the economic impacts created by GeoSure are two-fold. The end-consumers of the information use it to inform decisions on property/land purchase and design, while intermediary companies (VARs, insurers) have used GeoSure to widen their commercial service provision, improve business turnover and increase profitability. In 2006 the GeoSure information product was used as a case study by the economists PricewaterhouseCoopers (PwC) in an investigation commissioned by NERC into the economic benefit of environmental research. PwC concluded the following:

- By using this information decision-takers are empowered to make better-informed decisions, and can avoid future costs and prevent loss of investment by avoiding or mitigating subsidence incidents.
- BGS information on subsidence risk, provided at postcode and household level, is ‘accurate and relevant to user needs’, responsive to climate change impacts, and ‘meets the needs of the information age’.
- By using this information financial and social costs can be minimised through avoiding investing in
areas at risk of subsidence, or taking pre-emptive action and mitigating subsidence.

- Using this information created wider societal benefits including avoidance of stress, injury and disruption associated with loss of property.

Noting that the average annual cost of subsidence to the UK insurance industry is about £300 million (Association of British Insurers), PwC concluded that use of the BGS ground stability information could save UK insurers between £70 million and £270 million in reduced payouts between 2006 and 2030. When the effects of inflation are factored in it can be reasonably concluded that comparable present-day figures would be significantly in excess of these values.

**Radon** is a naturally occurring radioactive gas that enters buildings from the ground and which, unless vented, can accumulate to dangerous levels. Exposure increases the risk of lung cancer, and a study of lung cancer from indoor radon in England and Wales (HPA, 2009) concluded that about 1100 lung cancer deaths were caused directly by radon per year. The Health Protection Agency (HPA) recommends that radon levels should be reduced in homes where the average is at or above 200 becquerels per m³: this is termed the action level. The Health Protection Agency defines radon affected areas as those with 1 per cent chance or more of a house having a radon concentration at or above the action level of 200 Bq m⁻³.

The BGS–Health Protection Agency natural radon hazard potential information product for England and Wales was produced using an innovative methodology that combines empirical radon measurements with digital geology and was launched in 2007. It provides the current definitive map of radon affected areas in England and Wales, and gives a probability that an individual property in England and Wales is at or above the action level. Property owners can use the information to find indicative natural radon potential levels at their properties or locations, and to decide on remedial action if necessary. Similarly, builders and developers of homes and commercial premises can factor the same information into the designs of new buildings to mitigate the effects of radon. The information also provides an answer to one of the standard legal enquiries on house purchase in England and Wales, known as CON29 standard equity of local authority; 3.13 radon gas: location of the property in a radon affected area. The Radon Potential Dataset also provides information on the level of protection required as described in the latest Building Research Establishment guidance on radon protective measures for new buildings (BR 211 2007). Building regulations under the Building (Scotland) Act 2003 set mandatory standards to ensure buildings are designed and constructed to minimise the threat from radon gas. The HPA–BGS digital Radon Potential Dataset for Scotland technical handbooks provide guidance on achieving the standards set in the Building (Scotland) Regulations 2004 and subsequent Buildings (Scotland) Amendment Regulations.

The principal benefits of the radon hazard potential information product are reduced numbers of deaths and illness through lowered incidence of radon-induced lung cancers, which in turn have significant economic and social impacts. The immediate beneficiaries are clearly the people (and their dependents) who avoid lung cancer. The treatment of an estimated 1100 annual cases of radon-induced lung cancers places great financial burdens on the healthcare system. Additional economic benefits accrue from reduced healthcare expenditure as the number of cases of lung cancer declines as a consequence of using the radon hazard potential information product.

### 3. How the Centre contributed to the impact

BGS’s information products are developed using in-house scientific and technical expertise through consultation with a range of stakeholders to help address their specific requirements. All development was funded directly through NERC National Capability BGS work. DiGMapGB-50 incorporates a vast amount of data and is based on thousands of man-years of effort. The DiGMapGB digitisation project itself was started in 1998, and Version 1 published in 2001 with Version 6 in 2010. GeoSure incorporates many years of process research on shrink-swell clay behaviour, landslides, soluble rocks, compressible ground, collapsible ground and running sand deposits. Detailed geological property understanding, event databases, digital terrain models, GIS multiparameter analysis and informatics expertise are all brought
together to produce data for the whole of Great Britain at a 25 m resolution. The natural radon hazard potential information product was developed in collaboration with the HPA. It required the development of an innovative radon potential mapping method based on statistical assessment of indoor radon measurements within a digital geological framework. This work was undertaken between 2003 and 2012. The HPA funded their contribution to the joint work.

4. Evidence and sources to corroborate the impact


EDINA – the JISC funded data service for Higher Education publishes annual reports regarding use and popularity of its services, one of which is the geology maps service based wholly upon DiGMapGB. The latest of these reports is available: [http://edina.ac.uk/impact/docs/Geology_Digimap_2012.pdf](http://edina.ac.uk/impact/docs/Geology_Digimap_2012.pdf)

Latest figures from EDINA show 2 million screen maps used since June 2010 (when the service started) and 24,000 active users in higher education institutions.

Feedback on commercial and non-commercial uses of DiGMapGB-50 through the iGeology mobile app available from the Apple iTunes store at: [https://itunes.apple.com/gb/app/igeology](https://itunes.apple.com/gb/app/igeology)

[http://www.bgs.ac.uk/products/digitalmaps/DiGMapGB.html](http://www.bgs.ac.uk/products/digitalmaps/DiGMapGB.html)

[http://mapapps.bgs.ac.uk/geologyofbritain/home.html](http://mapapps.bgs.ac.uk/geologyofbritain/home.html)


5. Contacts for further information

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BGS15: Open data

1. Summary of the impact
In late 2009 BGS implemented open data policy, releasing free of charge for the first time, a large number of datasets through a dedicated open data website, OpenGeoscience. Significant additional data and resources continue to be released on open data terms through OpenGeoscience. Some of these are now used by the private sector to expand existing information services, develop new services, and improve business performance, so delivering economic impacts. Other data are used to support teaching in secondary and tertiary education, while the high uptake of mobile data provision has greatly raised public awareness and engagement in geological sciences.

2. Nature of the impact

**Private sector companies are using newly released BGS open data** to expand existing information services or offer new services. In the past year, for example, international oil and gas support companies have expanded their information service provision to industry by linking to the UK onshore borehole dataset and UK continental shelf hydrocarbon images. UK site investigation consultancies also now uses the UK onshore borehole dataset in offering services for ground-source heat pump and water well installations. The same dataset is also used by private sector consultants for site investigation and environmental assessment purposes, often carried out as part of local planning or development applications and referenced by local authorities such as Brent, where borehole records have been downloaded and included in a report produced by a commercial consultancy and referenced through the local authority site; a Google search returns about 40 recent examples of this. Collectively this evidence indicates that businesses within the private sector are increasingly using BGS data, newly released under open use terms, to expand their existing services, develop new services, and increase their business efficiency.

It is clear from feedback provided by users of BGS data and from the amount of traffic to the [OpenGeoscience](http://www.opendata.gov.uk) website that the BGS open data initiatives have delivered significant impacts in stimulating public awareness and engagement with the geological and environmental sciences. The OpenGeoscience website receives about 80 000 visitors per month (equal to about one million visitor sessions per annum, which equates to about 12 million hits per annum). Approximately 50 000 UK onshore boreholes are downloaded each month, and the OpenGeoscience DigMapGB-50 web map service receives over 40 000 visitor sessions per annum. In December 2012 BGS was the fourth most important data publisher on the pan-government data website [www.data.gov.uk](http://www.data.gov.uk) with 364 different datasets, behind the Office for National Statistics, the Department for Communities and Local Government and the National Health Service.

Serving DigMapGB data as a web map service allows it to be integrated with data from other sources in ‘mash-ups’. The OpenGeoscience mash-up gallery provides examples where BGS open data has been integrated with horticultural data by ‘Grower’s Nation’ to create a new mobile app, and shows the use of BGS data to create separate land-use, seismological, geological, topographical, soil science, caving and other environmental applications. BGS open data is also now being used to support teaching in universities, as exemplified by the Open University’s ‘Virtual microscope’ initiative which serves several BGS (and other) datasets in packages structured around the OU’s teaching curriculum.

Delivery of BGS data to mobile platforms through bespoke ‘mobile apps’ is a key element of our open data delivery. User feedback on both the data served and the apps themselves indicates that the iGeology app in particular (see section 3 below for further details) has created economic benefits for its commercial users and stimulated very significant public engagement and interest in the geological sciences. Commercial customers use iGeology each working day to access geological
map and subsurface borehole information from field or site locations, mostly in support of site investigation and structural surveying work. Non-commercial users include educators and a broad range of public interests. The download data for iGeology evidences its popularity and reach: between its launch in 2010 and November 2012, the iGeology app had been downloaded more than 110 000 times in over 110 countries, and had delivered over 44 million requests for DiGMapGB-50 information.

The technology developed from iGeology has been used in another mobile app, ‘mySoil’, which serves data from the BGS and Centre for Ecology and Hydrology. MySoil contains ‘citizen science’ functionality enabling users to submit their own soil texture and chemistry observations, and has been successful in raising public engagement and awareness of soil science.

3. How the Centre contributed to the impact

In December 2009 BGS launched the OpenGeoscience website, a major open data initiative through which large numbers of datasets, hitherto inaccessible or accessible only on commercial terms, were made available free of charge. All OpenGeoscience resources are now available under the Open Government Licence terms and conditions, allowing unrestricted use and re-use. This initiative marked a significant departure from previous BGS business practises characterised by a strongly commercial and somewhat restrictive approach to use and re-use of data, information and copyright. BGS’s open data initiative predated by over two years HM Government’s Open Data White Paper and the Department for Business, Innovation & Skills’ ‘Open Data Strategy 2012–2014’ (both published in June 2012).

At the outset the main datasets available made through OpenGeoscience were the baseline digital geological map (DigMapGB-50, described more fully in the Information Products impact case study), technical reports, many thousands of high quality geological images including archival materials, and the BGS SIGMA digital field data capture software. By serving DiGMapGB-50 through OpenGeoscience the UK became the first country in the world to have free access to national coverage vector-based geological mapping at this high resolution. Since its launch a large number of additional datasets have been added to OpenGeoscience, including baseline geophysical data for the UK, hydrogeological data, seismological and geomagnetic data, over one million onshore borehole logs, and a collection of high resolution images of cores from UK continental shelf hydrocarbon wells. All these data are searchable through onshore and offshore GeoIndex web-GIS applications.

Significantly, in September 2010, BGS developed in-house and launched, a mobile application iGeology (version 1) which is available free of charge for both Apple and Android operating systems. Version 3 of iGeology was launched in October 2012, and allows ‘in-app’ purchasing of BGS site-specific shallow geological hazard information. In June 2012 a separate mobile app, mySoil, was launched following in-house development by BGS in partnership with the Centre for Ecology and Hydrology.

The key activities that underpin BGS’s open data initiatives are principally the creation of digital datasets and information products (e.g. DigMapGB), the digital capture and conditioning of data available previously only in hard copy (e.g. the UK onshore borehole records collections), and the construction of web-based delivery systems. The creation and conditioning of digital data started in earnest in the 1990s and is an ongoing activity at the BGS, with plans to carry out further digital capture of analogue data collections. Conditioning involves quality control to ensure the data are fit for business purposes, and the creation of index-level metadata to enable searching.

The OpenGeoscience website is a bespoke area of the main BGS website dedicated entirely to the
discovery and delivery of open data. The **OpenGeoscience** idea and name were conceived in August 2009, and the OpenGeoscience site was launched in December 2009. OpenGeoscience includes bespoke applications such as the onshore **GeoIndex** search interface which was developed in 2005, and other applications such as the ‘Geology of Britain viewer’ and offshore GeoIndex search interface which were developed specifically for OpenGeoscience. BGS has since been commissioned by other government bodies, such as the Coal Authority, to develop the viewer to serve other types of spatial information.

All work related to the conditioning and delivery of data released through OpenGeoscience, and the development of the iGeology and mySoil suite of mobile applications, was undertaken by BGS and funded by NERC National Capability resource.

### 4. Evidence and sources to corroborate the impact

OpenGeoscience website: [www.bgs.ac.uk/opengeoscience](http://www.bgs.ac.uk/opengeoscience)

OpenGeoscience mash-up gallery: [http://www.bgs.ac.uk/data/services/mash-ups/](http://www.bgs.ac.uk/data/services/mash-ups/)


Open University Virtual Microscope: [http://www.virtualmicroscope.co.uk/](http://www.virtualmicroscope.co.uk/)

User feedback on commercial and non-commercial use of iGeology mobile app: [https://itunes.apple.com/gb/app/igeology](https://itunes.apple.com/gb/app/igeology)


### 5. Contacts for further information

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