UK-Environmental Observation Framework (UK-EOF) Statement of Need

Lithosphere & Pedosphere Observation Requirements

Alongside development of Towards a Statement of Need, the UK-EOF has also developed Observation requirements tables to capture more detailed information to help articulate:

- The UK's requirements for observing the natural environment
- The questions that we need to answer
- How close we are to being able to provide the evidence via a balanced suite of observations.

For ease, information gathering has been split into environmental domains and for each domain, what the specific issues or sub issues that are of importance for the headline issues identified in the UK-EOF Statement of Need.

Information has been gathered from experts in their field via correspondence, a workshop and open consultation. The tables are not final and some gaps exist in the information. The UK-EOF will work to fill these gaps and revise the tables accordingly.

Some of the sub-issues identified fall under several fundamental issues and there are key dependencies with other environmental domains.

Observation requirements captured within the tables have not been prioritised in any way, nor has current capability been identified. Prioritisation will be addressed via a decision support framework which is also being developed under the UK-EOF and capability or current activities are searchable within the UK-EOF Environmental Observation Activity Catalogue (www.ukeof.org.uk).

Summary of Requirements (under each UK-EOF headline issue)

Pressure on all environments in the light of <u>Population Growth</u> and associated pollution.

With increasing population, or changes in population density (as a result of migration/immigration), there are increasing pressures on soils and the underlying lithosphere. Such pressures include: pollution, increased demand for habitable land or access to recreational areas, industrial intensification and waste management. Some of the issues and pressures are also influenced by human behaviour, for example the number of people living in the same household is decreasing, and as a result there is increasing demand for housing stock and development. The development of land itself raises issues such as which substrates will provide the safest and most suitable ground conditions, what will be the percentage of soil sealing and associated impacts for flooding or water supply, and should soils and resources particularly suited for other functions (e.g. food production, strategically valuable minerals) be sealed by development and permanently prevented from such applications in the future? Population growth also places increasing demands on suitable underground space for infrastructure and storage of resources or waste.

Baseline information on subsurface properties and processes are needed along with the ongoing monitoring of impacts from anthropogenic change.

There are increasing and diversifying demands for resources associated with the lithosphere, such as minerals, energy, raw materials for infrastructure and groundwater. To address these issues we need to monitor these pressures, their interactions and impacts. Underwriting this, baseline mapping of resources, monitoring and statistics of current usage and forecasts of future demands are all required. Although much information is already collected for key resources, there are significant gaps and it is apparent that collection is undertaken by a variety of organisations (private and public). Therefore improved coordination and the addressing of data discovery, access and interoperability issues need to be addressed.

Supporting economic growth reconciled with sustainable use of natural resources

Many of the issues require a better understanding of the properties, processes and change in our soils, marine substrates and the deeper subsurface. In order to determine whether our soils are 'fit for purpose' and can deliver the required goods and services we must assess the condition of the soil, similar to the land suitability surveys that are conducted for agriculture. By conducting assessments for other services such as biodiversity or carbon storage information would be generated to aid our understanding on how soils function and how threats may impact these functions.

Spatial information on properties of soils, superficial deposits and bedrock provide essential baseline information on ground and subsurface conditions. This can be used for spatial planning and safe development both onshore and offshore. The quality and resolution of baseline survey information on the UK's lithosphere is generally good. However significant gaps remain where augmentation is required to ensure that the evidence base is fit for purpose in terms of policy, regulation and wealth generation. Additional monitoring and periodic surveys are required in the shallow subsurface zone of human interaction. This is where infrastructure development, resource exploitation, waste disposal and a historical legacy of uncontrolled contamination create a dynamically changing environment with complex pathways for transport of resources and pollutants. The associated impacts and risks are poorly understood and much relevant data is held by the private sector. Bringing this data into the public domain is a key requirement.

Much of the information regarding where our geological resources are located are also held by the private sector. To ensure security of supply in the long term, baseline resource mapping needs to be coupled to the ongoing collection of information on trends in global supply and demand. New technologies will create new demands for raw materials e.g. rare earths and the UK will require strategic access to these resources to support economic development and growth.

Soils and geology are intrinsically linked to water and water supply. As mentioned under population growth, development and soil sealing can impact upon both water and soil resources. There is a need to monitor how much land – and of what nature - is being 'lost to development' and the impact that this is having on surrounding water

supplies. Better understanding could lead to the development of effective mitigation against the impacts of soil sealing.

As the UK moves towards alternative energy supplies, the impacts of increasing biomass/biofuel production need to be understood. Other 'renewables' such as wind, solar and tidal energy require full life cycle monitoring of impacts and footprints, much of which will be offshore. The growing use of shallow geothermal energy requires baseline knowledge and monitoring of subsurface properties and heat potential to support effective resources evaluation, deployment and regulation.

Understanding future states of the Earth, particularly the Carbon Cycle (but not excluding other element cycles)

There is a need to determine whether soils are acting as sinks or sources of carbon and other greenhouse gases, and also to what extent? To answer questions regarding the fluctuation, controls and potential mitigation options, long term monitoring across the UK, which should include both marine sediments and salt marshes, will be required. The erosion or exploitation of peat beds could also lead to the release of carbon and greenhouse gases. To be able to determine the extent of this issue periodic monitoring of the carbon content, spatial distribution and erosion rates are necessary.

Work is in progress to identify potential carbon dioxide storage sites and capabilities for the UK, (most or all of which will be offshore). This needs accelerating if the power generation industry is to meet demands for emissions reduction. When sites are selected and in use, real time monitoring programmes to assess whether there is leakage will need to be put in place. Associated with this is a need to increase our knowledge on how soils process carbon and other elements. Improved understanding of their flows through the soil and the natural fluctuations could be used to provide information surrounding the consequences and mitigation of potential leakage from carbon dioxide storage sites.

Natural leakage of carbon dioxide and methane from permafrost melt and marine hydrates also require monitoring to not only assess the rate of release, but also links to climate forcing, feedbacks and tipping points. These issues are of great concern in the Arctic and therefore cross-cut requirements within the cryosphere domain. International collaboration may be needed to address such cross cutting issues.

Fisheries, Agriculture, Food Security and Water Supply

There is an important link between soil health, quality and functioning. Periodic soil inventories could provide information on the health, quality and which soils are most productive; the timescales for these will vary according to the parameters being considered.

The relationship between productivity and function within different soils and for example, water conservation, pollutant or climate buffering, are not well understood. Nor do we adequately understand how threats and pressures may impact upon such functioning. This is further complicated by the fact that different soils will respond differently to threats and therefore the threats will vary across the country. Defra are currently looking at soil functionality however it was suggested that broadscale indicators could be used to identify when there is a problem - when triggered these 'monitoring indicators' could then trigger further investigation, which would provide an

integrated view of what is happening within the system (akin to 'Tier' concepts). Periodic surveys (e.g. every 5 years) could be undertaken however they may need to be increased to address more precise questions.

Recently there have been moves to encourage local food sourcing. However some areas are naturally nutrient or trace-element deficient and this could have impacts on both land management and human health. Different forms of land management themselves will have different impacts on different soil types and there is a need to understand which techniques are most destructive or restorative for the different soil types.

The UK has dependencies on food imports and as soil degradation overseas would affect global food security, it could be a bigger threat to the UK than small changes in UK soil productivity. Although the UK should focus on managing our own natural resources, it is important that the UK has access to appropriate global observations which monitor such issues and that there is a national capacity to respond to associated threats (intelligence approach).

Forestry falls within this headline issue, however little information has been gathered in this area and further work is needed to identify the relevant observation requirements.

Human Health, Wealth and Wellbeing

Soils and the deeper lithosphere can be both a source and sink of pollutants and can provide pathways, buffers or barriers for pollutant transport. Measurements to determine which soils are the sources of pollutants are necessary both on a national and local scale for soils that may be subject to pollution from waste disposal, contaminated land or accidental spillages. The latter would require more frequent (daily) monitoring, whereas information on pollutant loads could be collected via a periodic inventory. Within the UK both soil and sediment inorganic geochemistry baseline inventories are deficient and baseline information on organic or radiological contaminants is absent for much of the nation.

Pathogens also reside in the soil and increased understanding of loads, risks and potential spread via vectors in contact with the soil (for example by livestock - grazing on the land) are required on both a regional and national level.

Atmospheric pollution caused by wind erosion of rock or soil dust is a problem for respiratory disease and therefore links need to be made with observations carried out for the atmosphere [environmental domain].

It is thought that there are links human wellbeing and the availability of green space, land and soils for recreation. Measurements which would allow assessment and quantification of their social value are necessary on both a local and national scale. Mental health consequences, as a result of environmental disasters and perception of risk are an area that is often overlooked. There may be benefit in increased observations linked to research in the social and behavioural sciences. Although previously out of scope for the UK-EOF, socio-economic observation requirements is an area that the UK-EOF will be looking at in 2010.

Understanding, avoiding and mitigating the effects of <u>Extreme Events</u> and <u>Disasters</u>

For the lithosphere, the requirements for observations fall into 4 main categories:

- Monitoring of long term environmental change e.g. climate and its impact on extreme event frequency, intensity and impact.
- Monitoring of day to day 'background' processes to identify signals, trends or triggers that may indicate an imminent event.
- Monitoring of the events themselves to observe processes and impacts and contribute to emergency responses and mitigation of aftermath and long term impacts.
- Rapid response capability to follow up events and gather new observations to support ongoing research on prediction, pre-emption and mitigation strategies.

If monitoring systems are coupled to baseline information on lithosphere properties, (which themselves provide spatial knowledge of hazard distribution and susceptibility), they could be used to inform risk assessment, contingency and mitigation strategies. For example, when considering landslides and subsidence, information on the types of soil, rocks and structures most prone to landslides are provided by baseline surveys and are used to map the distribution of, and susceptibility to, hazards to life, property and infrastructure. Real time monitoring will help to model and predict timing and/or impacts of individual events and by coupling the information with models of climate change, could be used to develop scenarios of how vulnerability and impacts will change in the future.

By increasing our understanding of which rocks, sediments or landforms are most prone to erosion, we can determine which geographic regions will be at most risk to coastal or soil erosion. Periodic monitoring/mapping could be undertaken using remote sensing techniques and surveys linked to time series information on erosion rates and how this could be impacted by temperature, rainfall and storminess. This information could be fed into relevant planning cycles for future management.

Flooding incidents are becoming more common both within the UK and in some regions of the globe. There is a need to understand the risk and identify which areas are most prone. Measurements need to relate to the water storage capacity of soils and water infiltration. Further information is also required to predict areas prone to groundwater flooding and whether events will increase with a changing climate. Conversely measurements to help us to understand how droughts could impact on soil biodiversity and how we can best manage soils under drought conditions are also needed.

In order to make contingency plans and predict the environmental impacts of a nuclear disaster, further knowledge on how soils respond to radionuclides is needed. This would include soil attenuation, buffering and resilience to the effects. Post event monitoring would determine the extent of the effects and recovery.

Identification of the locations most suitable for burial of carcasses in the event of pandemics requires extant knowledge of soil and lithology to avoid issues such as groundwater pollution. Post-burial would also require site monitoring to confirm that pollution was not occurring.

Some extreme events may not be directly relevant to the UK itself but will have relevance to UK overseas territories; this includes secondary seismic hazards (such as tsunamis) and volcanic activity. Post event observations to determine the damage and monitor further impacts are necessary along with relevant measurements to predict and respond to events.

Understanding and reducing the impacts of environmental change on marine and terrestrial biological diversity, ecosystems & services

Participants unanimously noted that ecosystems and ecosystem services are intrinsic to the lithosphere and pedosphere and would therefore be covered under all of the fundamental issues. Ecosystem functioning is a broad and complex subject requiring many measurements to understand the relationships that are occurring within the system. Continuous measurements are required to understand how change impacts function and how resilient the system is to cope with change. For management purposes periodic measurements would suffice.

As well as functioning of soils, there is a need to understand the biodiversity status within the soils - whether this is changing (both taxonomically and functionally) and the significance of these changes. Some relevant work has been done in this area including the Countryside Survey, SNIFFER LQ09, National Soil Inventory and the Environmental Change Biodiversity Network. Defra are also developing a series of biological soil quality indicators. When these are prescribed, baseline data will be a fundamental requirement. Information on the variability of ecosystems between soils and also the importance of these soil ecosystems for terrestrial biodiversity are also required.

High resolution baseline surveys of seabed substrate conditions and mobility are required to model impacts of new marine infrastructure (e.g. renewable energy installations, carbon capture and storage pipelines/ repositories) on marine benthic communities.

Understanding climate variability and climate change within Earth System Science.

Both the direct and indirect effects of climate change have impact upon the lithosphere and pedosphere. Several issues link to those under extreme events such as ground stability and erosion.

Coastal change is linked to erosion and landslides, as well as cross cutting issues such as hazard management. Along with measurements to map erosion rates, there are requirements to measure the seaward processes such as sediment distribution, properties and transport. Current observations are adequate for local areas however these are not coordinated and there is no national picture.

Climate impacts such as temperature on the biodiversity of soils and water content are considered to be important issues as both affect the function and services of soils. Water content and the risk of drought affect land management for arable land. Measurements, for which there is some local but no national coverage, will help to identify areas at risk. Climate change could also affect groundwater quality and quantity for which real time measurements of key sites are needed, with lower frequencies for wider areas.

Scientific and Technological Advancement/Innovation

There is a need for more reliable measurements which can provide real time, *in situ* data acquisition. Within the lithosphere and pedosphere there is large spatial variability; soils vary widely across the country which makes up- or down-scaling and extrapolation of measurements difficult. Monitoring networks should be integrated and information intelligently processed. This can be enhanced by the sharing of techniques across disciplines.

Many technological advancements developed in other areas of science are applicable to soil science and geology. Out of the box thinking, to apply these to the lithosphere or pedosphere, should be encouraged to stimulate new ideas.

Models for groundwater are relatively advanced however there is often a lack of empirical data for verification, there is therefore a need to determine what observations are required to test unified models.

Other Requirements and General Comments

As found with other environmental domains some of the issues are peripheral to actual requirements for observations. Comparison of field methods across programmes such as the National Soil Inventory and the Countryside Survey would be beneficial to determine the comparability of results and drawing of conclusions. Important issues surrounding data interoperability and re-purposing such as the use of common standards, formats and information are valid and will be addressed by the UK-EOF Data Initiative.

If we are to be resilient in terms of 'expecting the unexpected' and dealing with unforeseen events or priorities that may arise then monitoring data that is not of immediate and obvious utility is required. In order to be able to deal we need a balanced suite of observations, and along with the collection, stringent, secure archiving. Crucially such archiving does not only apply to data, but also to physical samples. These need to be preserved appropriately and accordingly.

When considering the general use of soils, measurements to answer questions over trade offs of soil functions and exploitation with minimal damage, would be complex and would vary greatly with the specific questions being asked. However this is a likely requirement for the future.

Within the requirements tables themselves, the primary use for the observation data is dependent on who is asking the questions (i.e. scientist or policy maker); this is also reflected on the frequency required for observations – often research will require high frequency, whereas longer term monitoring may for various reasons including cost, demand lower frequencies.

In terms of soil observations, there is a generic requirement for an accurate and comprehensive monitoring of a range of soil physical, chemical and biological properties in space and time. Biological data is currently extremely poorly represented at a national scale. We have a strong appreciation of what the properties should be for different contexts (i.e. the headline issues in the tables below), and an increasing – but not yet adequate - understanding of what the spatial and temporal scales should be. Existing soil surveys and inventories can be used to inform this

process, but there is a requirement to duly understand what the caveats are to any interpretations of such data. The challenge is that there can be no one monitoring structure suited to all purposes, and soil monitoring is inherently expensive. Thus the priority questions have to defined – with some urgency – and monitoring systems implemented, otherwise there is a danger of delaying any action using the excuse of "awaiting more understanding". There is no doubt that the higher the spatial resolution of such data, the potential effectiveness of applications increases markedly, and data sets that can aid the prescription of the appropriate scale are in existence.

Lithosphere and Pedosphere Observation Requirement Table

Information captured in the table will help to articulate what the UK's requirements are for observing the natural environment, what the questions are that we need to answer and how close we are to being able to provide that evidence via a balanced suite of environmental observations.

For each environmental domain information has been collected on the specific issues or sub issues that are of importance for the headline issues identified in the UK-EOF Statement of Need.

Consultation with the community has led to the population and validation of the following table. The tables are currently 'work in progress' and will continue to be revised as requirements and priorities change. The requirements captured have not been prioritised in any way.

Table 1 Fundamental Issues (one table for every environmental domain**) LITHOSPHERE PEDOSPHERE Version 2**						
Specific/Sub Issue	**What are the key questions that require answering in order to address the specific/sub issue?**	**Measurement Type** (variables that would need to be measured to provide evidence to address the specific issues)	**Frequency of collection** e.g. A continuous measurement for 1 week in Spring, repeated every 2 years. Or A spot measurement, once a week, every week throughout the year. Or Irregular measurements as required i.e. extreme event monitoring.	**What geographic coverage do we need?** A) UK B) England C) N. Ireland D) Scotland E) Wales F) Localised UK (e.g. part of Wales) G) Europe (non UK) H) Global I) Other (please specify) J) Ocean/Sea (please specify	**What is the primary use for the data?** A) Basic Science B) characterising environmental issues/solutions (influencing policy) C) Direct env. Management D) Modelling & Prediction E) Complying with Legislation F) Development & Growth	**Are the current actions / measurements sufficient to provide the evidence needed to address the issue?** If known, please list the current programmes/sensors which are capable of providing the evidence (e.g. for Sea Surface Temperature AATSR, SLSTR. AVHRR, AMSR and Modis satellites are capable of measuring SST).
GENERIC POINTS	Generic question is soil suitability for particular land-use so that least damage is done to the soil resource (i.e. sustainable use), and that given not all soils can	Generically, detailed soil inventory / auditing of the resource – spatial scale will vary according to question as will the properties				This needs reviewing in context of extant data when it is collated. Almost universally, the answer is going to be 'partly', i.e. spatial or temporal resolution is often going to be compromised, but ultimately depends

	provide all functions simultaneously, trade-offs are optimised at (local and ?) and national levels Cost-effective survey, inventory and observation programmes needed that balance multiplicity of user needs at local to national resolutions	needed … many properties = complex ! Temporal scale explicitly covered by next column… Getting the resolution right to balance cost against diversity of application. Evaluating and communicating uncertainty in observations and models derived from them. *Prioritisation is needed given that it will certainly be impractical to realise the 'ideal' scenario – but may wish to consider different levels of pragmatism, e.g. an 'imperative', 'important/ necessary' and 'desirable' grading of scenarios*				on resolution of answer required to the questions…. SNIFFER study (LQ09) provides good summary of soils data as of 2006 DEFRA Soil Indicators Consortium (UK-SIC) has been working on defining pertinent soil indicators, less so on optimised sampling and frequencies (as noted, this is rather case-contingent). Extent of development, vegetation etc compromises value of remote sensing observation of lithosphere at high resolution in UK. Airborne geophysics a highly valuable tool for many applications but national coverage is currently at too low resolution for environmental applications. In the future, this may change with technological developments.
Population Growth (Pressure on all environments in the light of population growth and associated pollution)						
Effects and Pressures on Soil	Which soils are most suited to providing a platform function?	Habitable land - colonisation of land surface	Irregular	A-G(H) given migration context	A, B, C, D, E	Need a better mechanism for measuring loss of land to development – Cite EEA report. GMES Priority Service
		Soil 'Strength'				Much data held by geotechnical community

		Geological Functions				Soil parent material map available, much data in private sector on soil physical properties
		Likelihood of Flooding				Susceptibility to groundwater flooding available for parts of Thames valley, no wider dataset
		Rates of Degradation/Recovery				
		Soil Sealing percentage (see also economic growth & Sustainability)	5 yearly			
	What are the future requirements – related to population growth & projections?					
	What pressures will soils be under with respect to pollution given population growth / intensification of industry?	Pollutants, baseline geochemistry	5 yearly	A, F		Soil baseline geochemistry (inorganic) available for central England and NI, stream sediment geochemistry for all UK except area to south of M4 (approx). Lower resolution dataset based on NSRI dataset available 2010?
	How will increasing population affect demands for food production and national food security ?	Population – spatially explicit demography		A-F (G,H if modelling includes global patterns which will affect UK)		See also Agriculture table
Impacts on resources	How will urbanisation and changing demographics/socio-political factors impact on mineral/energy/groundwater	Spatial distribution of resources	Irregular for baseline geoscience surveys, ongoing near real time	A, F & J for baselines	A, B, C, D, E	Information can be used for 3D modelling. BGS Capability – need to expand to improve superficial geology.
		Character of resources				Ongoing need to monitor resource usage against demand

	resources and sterilisation/pollution?	Aquifers, recharge rates, baseflow	requirement for monitoring aquifer response to urbanisation and increasing demand			Funding 'ring-fenced' until the next CSR, but there is a danger of cuts and loosing a data collection season. Much data in water industry, EA, BGS, requires synthesis and modelling
		Geology (including superficial)				Ongoing and enlarging survey. Baseline geology OK onshore, higher resolution needed offshore for spatial planning (offshore renewables, infrastructure, benthic habitats.
		Geochemistry				Baselines deficient in Scotland and Southern England (see above)
		Geophysical mapping				Higher resolution airborne EM and radiometric data (equivalent to NI TELLUS survey) required for rest of UK
		Groundwater levels				Some data held in private sector (but there are accessibility issues) BGS holds national well records database, EA has data, much data retained in private sector (accessibility issues),
		Temperature				Groundwater temperature collected and monitored by water companies, need to investigate accessibility
		Mines/Quarry Surveys				Directory produced by BGS, every 2 years
		Minerals				Much data held in private sector (accessibility issues). Need to involve industry organisations. Funding 'ring-fenced' until the next CSR, but there is a danger of cuts and losing a data collection season. BGS data on Mineral Statistics and commodities available through Minerals UK website

		Chemistry	5 yearly re-sampling for pervasive pollutants, proxies			Stream sediment chemistry available, except southern England (see above), hydrochemistry data in BGS, EA and private sector, gaps need to be investigated
		estuarine/marine sediment chemistry		J (UK Continental Shelf)		Low resolution marine geochemistry data available for continental shelf, high- resolution data available for Clyde estuary and parts of Thames
	Are sufficient resources available? (Related to energy requirement to use resources)	Requires estimation of reserves, forecasts of demand	Demands change, so at least every five years			Information on commodities prices, usage statistics on minerals available from BGS
Infrastructure	Are there sufficient raw materials for infrastructure development?	Materials audit	1- 5 years	A, G, H		There is a need for improved auditing (1-5 years) of consented minerals with demand and availability. What are the imports from overseas – Global context?
	Will there be a need for using underground space?	Engineering properties and processes in the subsurface needed to inform spatial planning decisions				Geological maps available, but critical information gap in shallow subsurface zone (0-40m) requires 3D datasets
Water Cycle/Supply	How will changing population growth affect the availability of water?	Water Capacity	Seasonal	A, F, G, H	A, B, C, D, E	Much data is in the private sector, synthesised by EA
		Water Demand				
Access/Recreational demand	What are the conflicts between access and recreational use?	Demand and impacts	5 yearly	A, F	A, B, C, D, E	National Trust and National Parks have data??

Waste Disposal/Pollution	How can the soil be best used when considering waste disposal/ recycling?	Contaminants	5 yearly	A, F	A, B, C, D, E	See above? Monitoring of test sites would be useful to assess effectiveness of bio-remediation methods
		Impacts				
Economic Growth & Sustainability (Allowing Economic Growth and sustainable use of natural resources such as aggregates, minerals and energy).						
Condition of Soils	Are soils 'fit for purpose', to what extent can they deliver the panoply of ecosystem goods and services ?	Audit (monitoring) for status & processes	5 – 10 yearly	A, F: UK wide and regional	A, B, C, D (not E?)	Partly – see overarching section
Resources (geological, land, soils)	Where are geological resources? E.g. Coal, Oil, Water, minerals, geothermal?	Mapping, statistics extraction, reserves	Assessment of baseline capacity, ongoing need for stats on commodity usage and availability, 2-5 year intervals	A, J (UK and Continental shelf)	B, C, D, E	Information important for issues such as CCS storage potential, geothermal (see Carbon), minerals statistics available from BGS but ongoing need
	What is the vulnerability to the depletion/sterilisation of the following resources : • Minerals? • Energy? • Groundwater? • Oil? • Gas? • Water? • Coal? • Food? • Gas Hydrates?	Spatial distribution of resources (type and resolution dependent on economic priorities)	Irregular baseline surveys, 1-5yrs for mines/quarries inventories, 1-5yrs for minerals stats	A-F, J for baselines	A, B, C, D, E	Generally good baseline coverage of basic geological data available for the UK
		Available resources/reserves in context of usage trends and statistics				Impacts mainly economic, complex relationships between supply, demand and sustainability needs to be addressed (loss of one resource requires replacement by another). Foresight required to evaluate future strategic supply/demands for raw materials emerging from new technologies e.g. batteries for fuel cell powered vehicles

	Is land safe for development?	Engineering properties and processes, geohazards	Baseline surveys of properties and processes, ongoing monitoring of hazards by various means including remote sensing, geophysical sensors, integrated	A-F	A-E	3d properties data lacking in shallow subsurface, see above. Ongoing need for monitoring hazards and responding to individual events, ongoing monitoring of unstable land and built infrastructure to asses long term climate change impacts
	Is the full life cycle of resource use considered at the outset (e.g. after use options, waste storage)?	Requires integration and interoperability of diverse EO datasets to support decision-making and spatial planning		A-E	A-E	Requires integrated assessment of many environmental datasets
	What impact has the legacy of mining on land use and development?	Inventories of mines/ quarries	See above	See above	See above	Airborne infra-red good for mine workings, also see above
		Mineral usage stats to predict trends	See above	See above	See above	This is urgently required if the UK to avoid importing aggregates and armour stone (coastal erosion).
	Which minerals should the UK seek to renew	Mineral usage stats to predict trends	See above	See above	See above	
Foundation Conditions	What is the availability of infinitely suitable areas for built development?	Ground conditions, Engineering properties and behaviour of ground materials, geohazards	See above	See above	See above	3d properties data lacking in shallow subsurface, see above. Ongoing need for monitoring hazards and responding to individual events, ongoing monitoring of unstable land and built infrastructure to asses long term climate change impacts

Energy	Can we harness geothermal energy?	Ground water heat exchange capacity , geothermal potential, ground heat flow capacity				National GIS on ground source heat and geothermal energy being prepared by BGS; ground source heat not regulated yet, supporting data requirements for regulation not yet clear.
	What is the impact of alternative energy such as: • Biomass/biofuel production? • Harnessing Solar power • Wind energy • Tidal energy	Requires integration and interoperability of diverse EO datasets to support decision-making and spatial planning ***Is this question too general for specific response?***				
Radioactive waste storage	What is the level of radioactive waste contamination, and if so, what measures are required to reduce levels?	Radioactivity, baseline survey of background radiation	Real time, one off baseline surveys of potential sites	F	A, B, C, D, E	Airborne radiometrics desirable for new build sites (nuclear power stations, waste sites),
	Is the contamination bioavailable?	Spatial mapping of transport pathways, monitoring of contamination movement for individual sites	Process related	A, F	A, B, C, D, E	
CCS – See CO_2 Storage under Carbon						
Soil Sealing	What is the impact of soil sealing on water resources	Area lost to development	5 yearly	A	B	Remote sensing?

	& the reduction in soil resources? Can development mitigate the impacts of soil sealing?	Quality of area				
Global impacts (interactions)	How do overseas events impact the UK? (e.g. interconnections with food/water shortages) ***Is this question too general – are there more specific questions that need answering?***	Requires integration and interoperability of diverse EO datasets				
Geodiversity **Amenity**						
Carbon Cycle (Understanding future states of the earth, including element cycles, in particular the Carbon Cycle)						
Carbon/ GHG sources and sinks	Are soils acting as sources or sinks of C, and to what extent (budgets for C trading and targets) ?	Soil C content (all forms, incl. organic & DOC) with depth	3 – 10 per yr, i.e. at appropriate resolution to allow intervention. Long term monitoring.	A, UK Wide F Localised G Europe H Global	A, B, C, D, E	Need to consider marine sediments, including salt-marshes (presently enormous uncertainty of inventories). It is uncertain which is the best method to use. Should however consider loss of volume not just concentration.
		Bulk Density				
		Stock (depth x BD x density C x area).				
		Fluxes				
	Are soils acting as sources or sinks of other GHGs?	As above for: • Nitrous Oxide • Methane • Oil • Coal • Gas				

	What are the controls? ***Again is this too general and are there more specific questions that need answering?***	Requires integration and interoperability of diverse EO datasets				
	What can be done to mitigate/ reduce the effects? ***Again is this too general and are there more specific questions that need answering?***	Requires integration and interoperability of diverse EO datasets				
Condition of Permafrost (See also Cryosphere issues)	What is the extent of permafrost melt and CO_2/methane release? (Large policy implications)	Permafrost distribution	Initial baseline of permafrost distribution, annual to real time monitoring at specific sites	H(Arctic; Mainly Russia with some other global locations)	A, B, D, C	Little info on changes in permafrost thickness and linking permafrost retreat to methane release Satellite TM? Airborne sniffer Requires access to circumpolar territories for data acquisition
		Permafrost thickness (changes)	Annual to real time??			
		Boreholes				
		Ground and Airborne geophysics				
		Gas Sniffer???				
Marine Methane Hydrate	What are the impacts/gains/feedbacks of climate change on stability and methane hydrate	Spatial distribution of host sediments	Survey of spatial distribution.	H, J (continental slope and shelf, especially the Arctic)	A, B, D	Limited surveys of UK coastal margin in progress, past events being mapped (pock marks etc), seismicity being monitored, no systematic
		Quantity (of host sediments)				

	release? What are the links between releases and events? (e.g. seismicity, landslides, ocean temperature etc.)	Stability (of host sediments)	monitoring of landslide/seismic events			monitoring of events
		Methane release	Monitoring of events and triggers (temp, pressure, seismiciity			
		Ocean temperature				
		Pressure				
Condition of Peats, organo-mineral & mineral soils	How will the distribution, thickness and erosion rates of peat/mineral soils be impacted by climate change? (This equates to stock and baseline condition).	Spatial distribution (time series mapping)	Baseline survey of distribution	A, F, G, H (Regional and National UK, Europe & Global)	A, B, C, D	Do we need soil observatories in different agro-climatic zones across the UK?
		Erosion rates	5 year frequency? (via Remote sensing)?			Can we relate extreme erosion events e.g. bog bursts to carbon fluxes?
		Carbon content (all forms: DOC, POC, DIC, Total C Stock				
	Will methane and other GHG be released from peats and at what rate?	GHG Fluxes				
CO_2 Storage	What are the capacities and sites for safe geological storage of CO_2?	Spatial distribution	Baseline analysis of storage capacity, linked to assessment of capture needs, sources and sinks	A-F, J	A, B, C, D, E	Work in progress nationally but inventory of safe storage sites needs accelerating if power generation industry is to meet demands for emissions reduction
		Physical properties				
		Porosity permeability of reservoirs				
		Cap rock integrity				
	Are geological storage sites intact or is there leakage/contamination?	CO_2 leakage (gas/fluid escapes)	Real time	F		NB this is not just confined to carbon dioxide but also radioactive waste (see Other section). In SAR could be used for monitoring ground elevation changes resulting from gas storage

		Ground water displacement/ fluxes in saline aquifers used for storage				No systematic measurement yet at demonstration sites
	What are the capacities and sites for safe soil storage of carbon (e.g. biochar)?	As above for Soils		A, F		
	How do soils process carbon?	Wide range of biogeochemical measurements				Extant soil inventories provide modest precedent data but inadequate plans currently in place.
	Is carbon leaked from storage sites in a bioavailable form?	***To be developed?***	Process related	A, F		
	Can we estimate the level of carbonate precipitation?	To be developed for CCS reservoirs, seismic anisotropy may be solution	1 to 5 years for operational sites?			
Carbon and Nitrogen Flows	What direction and rate does carbon and nitrogen flow through the soil/rock?	Spatial Distribution	Process based	A, F, G, H (Local & National UK, Europe & Global)	A, B, C, D, E	
		Flow rate				
Agriculture, Food Security & Water Supply (The effects of environmental change on agriculture, food security and water supply)						
Soil Productivity/Quality/ Health	Which soils are most appropriate to deliver production function?	Soil inventory: (C and nutrients, pH, bulk density)	Annual	A, F (UK Wide and Localised	A, B, C, D, E	Partly – see overarching section
		Yield data (plant and livestock)				***Must exist – a National Statistic (ADAS ?) but where does this reside now and who has the current remit for tracking national yield data ?***
		Microbial diversity	5-10 y	A-F	A-D(E)	No

		Microbial function	??	A-F	A-D(E)	No
	Is the production capacity of soils being sustained?	As above	5 y (??)	A-F	A-D(E)	No
	What is the relationship between productivity/function and: a) water conservation b) pollutant buffering in different soils? (and how would pressures affect this relationship – see pressures below).					
Forestry	Storage? Or Loss?	Extent	Annual	A, F, G, H. (UK local and national, Europe and Global)	A, B, C, D, E	
Water Storage/ Flooding	What is propensity of soils to store water / mitigate flooding ?	Storage capacity	Event Based	A, F (UK Wide and localised)	A, B, C, D, E	
	How will ground instability impact on flooding e.g. coastal subsidence	Changes in ground level & sea level (integrated)	Monthly	A, F, G (UK wide and localised, Europe & Global)	A, B, C, D, E	PS –InSAR (Permanent Scatter, inferometric synthetic aperture radar) – observes crustal strain accumulation (technique used to reveal subsidence), GPS, Gravity, Tide gauges.
	Will Soils harvest rainwater and to what degree?	Storage Capacity				

Climate Buffering	How do soils buffer climate?	GHG fluxes	Continuous	A, F, G, H	A, B, C, D, E	Partly – national audits are occurring (e.g for ammonia, and others (?)) – ***Which ones are relevant here?***
Pressures	What is the impact of erosion on soil productivity/functioning for different soil types?	Erosion rates of soil types	5 years	A, F (All scales and resolutions)	A, B, C, D, E	
		Links to soil productivity/quality for specific soil type				Indicators of quality/structure/disturbance due to erosion required
	What is the impact of organic matter decline on soil productivity/ functioning for different soil types?	Soil productivity	5 years	A, F (All scales and resolutions)	A, B, C, D, E	
		Organic Matter content				Indicators of soil quality/structure required
	What is the impact of acidification on soil productivity/functioning for different soil types?	Soil Productivity	5 years	A, F (All scales and resolutions)	A, B, C, D, E	
		Soil Acidity				Indicators of soil quality/structure/acidity required
	What is the impact of salinisation on soil productivity/functioning for different soil types? (may become relevant with sea level rise)	Soil Productivity	5 years	A, F (All scales and resolutions)	A, B, C, D, E	
		Soil Salinity				Indicators of soil quality/structure/salinity required
	What is the impact of drought on soil productivity/functioning for different soil types?	Soil Productivity	5 years	A, F (All scales and resolutions)	A, B, C, D, E	
		Soil Water Content				Indicators of soil quality/structure/water content required
	How do the various pressures affect pollutant buffering within different soil types	Pollutant concentrations				

Land Management	What forms of land management are most destructive/restorative to different soil types?	Soil Quality of managed land (with known management techniques)		A UK Wide F Localised		
	Where can we learn from techniques developed elsewhere e.g. Conservation Agriculture	Desk studies		H Global		See FAO website.
Biomass/Biofuels – see Energy under Economic Growth						
Food sourcing	There is increasing pressure to source food locally, however some areas are nutrient deficient – what implications does this have for human health?					
Human Health (Consequences of environmental change for human health, wealth and well being)						
Pollution	Which soils are sources of pollutants?	Surface flow	Daily	A, F UK Wide, Catchment monitoring	C	
		Subsurface flow				
	What are pollutant loads in soils, and associated risks? (With respect to proximity to habitation ?)	Soil inventory - metal, POP	5 – 10 y	A, F UK Wide and Localised	A, B, C, D, E	Soil and stream sediment geochemistry inventory deficient in southern England (see above), organics information patchy
	What is the contribution of metals to air and water contamination in natural rock and superficials?	Baseline Geochemical mapping (continuation)	Baseline survey			NB Link to Atmosphere. Soils, rocks and superficials to dust – PM10s and nanoparticles. Loads vs. concentrations
		Air/water particulate composition and distribution, linked to forensic characterisation of superficials/soils,	Irregular, following up weather, flood and pollution events			

		Calibration of industrial/environmental change.				
Pathogens	What are pathogen loads in soils and what are the associated risks?	Soil Inventory – pathogen loads		A, F: UK Wide and Localised		
		Remote Sensors?				
	Are soil pathogens linked to the spread of animal disease (blue tongue or other vector borne diseases – malaria)	Pathogen genome/DNA.		A, F UK Wide and Localised		
		Pathogen spread/distribution in soil				
	How can we resolve conflicts with recycling and private/public water supplies?					
Hazardous Gas	Will climate driven changes in ventilation/air conditioning systems raise susceptibility to environmental radon and other hazardous gases?	Monitoring of individual properties, representative sample type	Real time	A, F UK wide and localised (representative sample types)	D, E	***Data may already be available? Where?***
		Remote Sensing?				
Extreme Events – (see specific section) e.g. Earth quakes, Volcanoes, Landslides, Tsunamis						
Recreation /Human Well being	What is status of soils for recreation ?					
	What is the importance of green spaces for human well being? (and therefore the social benefits of soil)?	Green space (area)				(Human Health data is out of scope for the UK-EOF however environmental data on the amount of greenspace is in scope).
		Social Aspects				

	What is the impact on health (including mental) and well being of soil/lithosphere events and changes in condition?					
Waste Disposal	What are the sources, and sinks of heavy metals and organics from sites / in ??	Geochemical monitoring	Daily	A, F UK Wide and regional.		Needs operation of source pathway receptor principle, and hence interoperable datasets
		Dust				
	Are there conflicts with recycling?					
Wind Erosion	To what extent is wind erosion linked to respiratory issues?	Wind erosion rates				
		Dust				
Extreme Events & Disasters						
Much of the monitoring for extreme events/disasters will be event driven sampling or for use in the development of pre-emptive infrastructure.						
Ground Instability e.g. Landslides and Subsidence	What soils, rock types and structures are most prone to landslides / bog bursts?	Soil inventory: • Structure & Sub Soil • Bulk Density • Sediment loads • Erosion rates	annual ?	A-F	C, B, D	Information can be used to determine the risk to life, property and infrastructure.
	Where and when do landslides occur?	As above and Mapping of landslides	Event based	A, F (high risk areas)	A, B, C, D	Remote Sensing – Lidar Monitoring (strain, groundwater levels, ground resistivity) available for some major landslides, more needed to assess risks
	How will Climate change affect Ground stability (and therefore landslides, subsidence, foundation stability)?	As above and meteorological conditions	Annual to real time & event based (survey changes, damage)	A, F (high risk areas)	A, B, C, D	InSAR, ground lidar measurements, ground resistivity
		Land movement				

	What will be the impacts of ground instability on Climate change impacts?	Saturation				
		Shrink Swell				
		Mineralogy				
		Ground Water Regime				
Erosion	Which geological areas (sediment types, landforms, physically distinct bodies) are most prone to coastal erosion?	Mapping	5 years (planning cycle?)	A	B, C	InSAR, ground lidar measurements. Current datasets adequate for insurance purposes not for development
		Insitu electrical resistivity				In situ electrical resistivity monitoring
		Cliff retreat monitoring				Remote sensing: lidar, AP, InSAR
		Rock physical properties data				
		Engineered embankments/dams, movement, stability				Very little monitoring of critical infrastructure. Much data in private sector.
	What are the rates and geographical extent of soil erosion?	Comprehensive Soil monitoring programme	5 years	A	A, B, C, D, E	
	What are the impacts of changes in temperature,	Soil Mass (depth)	3-10 years	A (UK Wide) F (Localised)	A, B, C, D, E	
		Bulk density				

	rainfall, hydrology and land use on soil stability?	Particulate export	High frequency			Relevant information is collected by the EA (for Water Quality until 2015). Although collected for a different reason this could be used. SEPA Could use river sediment concentrations.
Pollution incidents (groundwater)	What is the attenuation function of superficial deposits, aquitards?	Inventory of aquifer physical and chemical properties	Baseline, rapid response and follow on monitoring to contamination events			Available for major aquifers, limited for minor aquifers and non-aquifers
		Tracer tests	Irregular tracer tests	F (vulnerable aquifers)		
		Ground water chemistry	Baseline, rapid response and follow on monitoring to contamination events			
	What are the impacts of pollutants and risks of contamination?	Range of sensors/ tracer tests around incident sites				Capability exists to follow-up individual incidents with short term monitoring and assessments, long term monitoring of impacts also needed
Groundwater Flooding	Which areas are most prone to groundwater flooding?	Monitoring of events	Event based	F	A, B, C, D, E	Partially adequate in some flood prone areas, sensor networks need expanding in other risk zones
		Groundwater levels	Monthly??			
		Contribution of Run off				
		Baseflow				

		Spatial Distribution, topography				
		Post event Survey (extent and impact)	Event based			
	How long will inundation last?	As above				
	How will groundwater flooding change with climate change?	As Above				
Earthquakes	Can we predict timing of earthquakes? How can we learn from earthquakes and incorporate this knowledge into the built environment?	Earthquake monitoring	Real time	A, F, J	A, B, C, D, E	National network probably adequate
		Post event monitoring of aftershocks.	Post event damage surveys			
		Micro-seismic arrays on vulnerable infrastructure	Real time			Information could be displayed on a public website for community input.
Secondary Seismic hazard e.g. Tsunami	What areas will be most vulnerable?	Slope Stability		A, F, G, H, J	A, B, C, D, E	National risk assessment provided for DEFRA, probably adequate for level of risk
		Spatial distribution of potential hazard				
		Post event surveys of damage	Event based			
Space Weather	What are the impacts of geomagnetic storms? (e.g. effects to power generation, communications and navigation).	Update of global geomagnetic reference field	Real time	A, F, G, H	A, B, C, D	Current monitoring systems probably adequate
		Solar event monitoring,				
		Geomagnetic field monitoring				
Volcanic Hazards	What are primary and secondary risks from eruptions	(Individual) Volcano monitoring: • Gas • Uplift	Real time, rapid response to events	G, H, J	A, B, C, D, E	

		• Seismicity • Eruptions • Aftermath – ash, lava flows, tsunamis etc.				
Surface Water Flooding	What is the risk of flooding from surface water? (Related to the water storage capacity and infiltration)	Infiltration	Event response? Assessments to Calculate risk and identify high risk areas	A, F	A, B, C, D, E	
		Water Storage Capacity, topography				
		Pollutant transfer, spatial distribution of contaminants with respect to flood vulnerability	Baseline survey			Baselines of environmental contaminants distribution available including soil and stream sediment geochemistry. Little systematic data on organics
Nuclear (Chernobyl type) Events	What is the soil response to radionuclides?	Soil Attenuation capacity	Event based (effects and recovery)	A, F	B, C, D	
		Soil Buffering Capacity				
		Resilience				
Drought	How will soils respond to drought?	Soil Moisture			B, C, D	
	Howe can we manage soils under drought conditions?				C	
	What is the impact of droughts on soil biodiversity (and other biodiversity)?	Biodiversity changes (under drought conditions)			B, C, D	

Fire	What is the impact of wildfire on peat or managed heathland?					
Ozone, HFCs, etc	What is the relative importance and impacts of Ozone and HFCs to soil/rocks?	Mean and peak events	Real time	A, F, G, H	A, B, C, D, E	
Biological Diversity (Impacts of environmental change on biological diversity. N.B. Ecosystems and Ecosystem services are covered in other questions)						
Biodiversity	What is biodiversity status of soils and how is it changing (taxonomically & functionally)?	Inventory of biotic status: genotype	5-10 Yrs (different scales of temporal dynamics)	A, F; UK wide and regional.	A, B, C, D, E	(c.f. DEFRA Soil Quality Indicators) Require Baseline Data, however need *a priori* data to be able to determine frequency of collection for such data. Population abundance is important if it impacts on the ability of the organisms to perform functions & resilience ECBN Linked to ECN. Countryside survey (2007 data available, new survey underway) SNIFFER LQO9 NSIS2 (completes 2010)
		phenotype				
		function				
	What are the significance of the changes (and what do they mean)?	As above				Resistance to change.
	How variable are soil ecosystems (re. genes, species & communities) in space and over time?	Microbiology	Seasonal/Annual/ Decadal	A, F: UK wide and regional	A, B, C, D, E	
		Invertebrates (in Soil)				

	How important is soil biodiversity for above-ground biodiversity?	Link with terrestrial monitoring				
	How do field sampling methods compare?	Comparison of methods				
Ecosystem functioning (N.B. this is a broad and complex category, and	What are the functional consequences of the changes & therefore what is the resilience of the system? (c.f. the delivery of EGS)	Multiple measurements to understand and manage relationships	Continuous (understanding) Periodic (management)	A-J	A, B, C, D, E	
Climate Change (Understanding climate variability and climate change within earth system science)						
Carbon and nitrogen content	What role do soils play in Carbon and nitrogen cycling now and in the future?	Inventory of C, N and process in context of NPP – c.f. climate change model requirements (existing and new)…. (i.e. other properties likely needed)	3 - 10 y (frequent for intervention management)	A (UK Wide) & F Localised.	A, B, C, D, E	

		Broad suite of biogeochemical measurements including P, S etc.				
		Biological Measurements?				
Predicting future changes (for Climatologists)	Can we predict future climate changes and their impacts using geological records?	Isotopic analysis of climate proxies in geological record (observation of past events) & characterisation of the Anthropocene	Irregular	A, F, G, H, J	A, B, C, D, E	Inventory of geological/geoarcheoleogical data needed, much exists but not synthesised/interpreted from palaeoclimates standpoint
	Can we predict future climatic changes and their impacts (directly via climatic factors and indirectly via changes in land use and land management, cropping etc)?	Monitoring of Soil Structure		A, F, G, H, J	A, B, C, D, E	
		Soil biogeochemistry				
Land Management (Particularly Arable Systems)	Increased drought risk, workability and trafficability	Moisture holding capacity	Every 5 years	A (UK Wide) F (Localised)	C, D	Good local coverage, not national
Ground Stability – See Ground Instablity under Extreme Events and Disasters						
Soil Erosion – See Erosion under Extreme Events and Disasters						
Soil Biology	What are the impacts of changes in temperature, rainfall, hydrology and land use on macro & micro flora and fauna?	Microbiology	Annual to sub-annual	A (UK Wide) F (Localised)	A, B, C, D, E	
		Soil invertebrates				
Coastal Change	What will be the changes associated with Climate Change?	Sediment distribution	Annual to sub-annual, irregular follow up to storm	A (UK Wide) F (Localised)	A, B, C, D, E	BFS, CEFAS, UKHO, MCA, Private Sector. Good local coverage but not National.

		Sediment properties	events			BGS, Private Sector. Good Local coverage but not National.
		Sediment transport				NERC, Private Sector. Good local coverage but not National.
		Coastal Change including coastal retreat				Needs offshore systems in place to monitor impacts of extreme events
Groundwater	How will climate change impact groundwater quality/quantity?	Ground water levels	Real time for key sites coupled to lower frequency for wider areas	A (UK wide), F (Localised)	A, B, C, D, E	Access to private sector data an issue, opportunities for citizen science observations (springs etc)
		Chemistry				
		Storage				
		Recharge				
		Baseflow/ Springflow				
		Temperature				
Scientific & technological advancement/innovation						
Attaining Reliable measurements (pedosphere)	How to appropriately measure and assess a particularly variable (spatio-temporally) resource	In situ systems		A, F (localised insitu), G (EU), H (Global – measurements from space) (Coverage should allow scaling).	A, B, C, D, E	These measurements will help to fulfil all applications on the other sheets. For in situ and remote systems – there is a need for networks, integration and intelligent processing. In situ systems should be linked to auto alert communications Remote systems need to be connected/integrated
		Remote systems (space, aircraft and on/in ground)				
		Digital Soil Mapping systems	Automated			
		New Detectors				
Attaining Reliable measurements	How to appropriately measure and assess a	In situ systems		A, F (localised in situ), G (EU), H	A, B, C, D, E	These measurements will help to fulfil all applications on the other sheets.

(Lithosphere)	particularly variable (spatio-temporally) resource	Remote systems (space, aircraft and on/in ground)		(Global – measurements from space) (Coverage should allow scaling).		For in situ and remote systems – there is a need for networks, integration and intelligent processing. Insitu systems should be linked to auto alert communications Remote systems need to be connected/integrated.
		Digital Soil Mapping systems	Automated			
		New Detectors				
		Real time measurements				
Sharing of techniques across disciplines	How can sharing of techniques across disciplines be encouraged?					Aspirations are there but funding models remain essentially divisive and myopic.
Stimulating ideas (fewer constraints)	How can new ideas be stimulated? How can disasters stimulate ideas?					as above Disasters provide imperatives which must be reacted to, rather than instigating proactive or pre-emptive activity.
Developing/Testing Models	What new observations do we need to test Unified models? How do we ensure data integration/interoperability					
Others						
Others: Comparison of Field Sampling methods	How do field sampling methods compare?	Comparison of methods				A comparison of field sampling methods would be useful: NSIS2, CS, SHS, NSI, NSIS.

Soils (general use)	Can soil suitability for a particular land use be 'exploited' so that the least damage is done to the soil resource (sustainable use).	Generic, detailed soil inventory (audit of resource).		(spatial scale will vary with Questions being asked)		Very complex. The properties needed will vary with questions being asked. But this links back to the top-level questions at the start of this chart. Much of what is here would be / needs to be underpinned by an appropriate-resolution auditing and monitoring programme feeding into a spatially and temporally explicit biophysical model of the UK land resources.
	Not all soils can provide all functions simultaneously, therefore can trade offs be optimised at local, regional and national levels?					
	Can cost effective, inventory and observation programmes be developed that balance the multiplicity of user needs at local to national resolutions?					Essential to get the correct resolution to balance cost against diversity of application. Evaluating and communicating uncertainty in observations and models derived from them. Determining the priorities is key!
Capacity to respond to currently unforeseen questions	What is the resilience of the system to change?	Long term collection and archiving of samples, monitoring data	5 yearly	A, F, G, H	A, B, C, D, E	This is linked to the question of how can security and longevity of archives be secured? (Data and samples)
Data knowledge/ interoperability	Can we use common standards, formats and information systems to enhance data knowledge and interoperability?					