InformaTec Soils

Report to NERC: InformaTec Soils

Report for the InformaTec-Soils meeting at Defra, Nobel House, March 14th 2011

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Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

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Executive Summary:

InformaTec is a 2-year, NERC-funded project that seeks to identify how to manage the increasing wealth of environmental data and information so that it can be transmitted, distributed, stored, archived, analysed and visualised, and in so doing, aims to recognise and develop opportunities for knowledge and technology transfer, both nationally and internationally. As such, InformaTec addresses a major objective of the NERC science strategy, namely, the "exploitation of technological advances to develop improved methods of monitoring environmental change." **InformaTec-Soils** is one component of InformaTec; other aspects of the project focus on environmental monitoring, data standards, interoperability, and distributed computing.

The specific aim of **InformaTec-Soils** is to draw together key players having interest in the collection and synthesis of large-scale soil data sets with a view to identifying what needs to be done to improve understanding of soil and environmental change. As part of the **InformaTec-Soils** initiative, a meeting of 24 experts from across the UK was convened at Defra, in London, on 14 March 2011. Through presentations, roundtable discussions and breakout groups, the meeting explored, current informatics, methodological and cultural challenges, and constraints, to the synthesis of UK and European soils data for understanding soil and environmental change.

This report presents a vision for an ecosystems approach to soils and summarizes the conclusions and recommendations of the meeting held in London. As well as identifying opportunities for the soils community generally, the report will be presented to NERC to inform decisions on future funding. The authors of the report extend their gratitude to all who contributed to the meeting and the production of this report.

The report identifies the following important research topics for soils:

Key areas for research:

1) Framework development
2) Quantifying the soil resource, stocks, fluxes, transformations and identifying indicators
3) Valuing the soil resource for its ecosystem services and natural capital
4) Developing management strategies and decision support tools

Within these 4 key areas for research we identify the following 5 major challenges that the NERC technologies theme should address:

Major research challenges:

1. Ecosystem approach to national soil monitoring; how we measure and model at a range of scales.

2. Exploit new technologies for airborne, ground based sensor networks, and molecular biology techniques to link from structure through to function and on to service.

3. Develop data accessibility (via cloud), and integration by exploiting new data IT tools (eg Open MI) to support projects building exemplar or baseline data/models eg EVOp project (Community)

4. Decision support tools, simple, practical tools for people trying to utilize and visualise data for a range of common purposes (e.g. planning).

5. Pathways to 'valuation'. How do you link users perceptions of value to the parameters created by the data and models? (e.g developing techniques from social–science research in terms of perceptions and value judgements)

Some of the challenges and opportunities to arise from the meeting with regard to '**Data Handling**' and '**Measurement Methods and Technologies**' are identified in two appendices to the report.

1) InformaTec

InformaTec is a 2-year, NERC-funded project that seeks to identify how to manage the increasing wealth of environmental data and information so that it can be transmitted, distributed, stored, archived, analysed and visualised, and in so doing, aims to recognise and develop opportunities for knowledge and technology transfer, both nationally and internationally. As such, InformaTec addresses a major objective of the NERC science strategy, namely, the “exploitation of technological advances to develop improved methods of monitoring environmental change.” **InformaTec-Soils** is one component of InformaTec; other aspects of the project focus on environmental monitoring, data standards, interoperability, and distributed computing.

Overview of informaTec aims:

- Informatics challenges: UKPLC needs data for improved decision making, especially in regard to the developing EU soils directive, which will require the need to integrate large and complex data sets to understand soil threats.
- To overcome people challenges such as: there is limited cohesion across disciplines, limited understanding of common issues, and limited sharing of information and techniques.
- Data challenges: data is collected and held in discipline / institute silos, need to be easily available, allow translation / integration, interoperable, technologies need to be shared worldwide.

The main InformaTec objectives are to:

- set technical agenda, agree community proprieties and to inform NERC council (via Technology strategic science theme), UK govt, industry, and academia.
- build lasting multi-disciplinary and multi-institutional partnerships to take forward joint initiatives and to respond collectively to future calls
- enable knowledge exchange within the community e.g. to share best practice / tools.

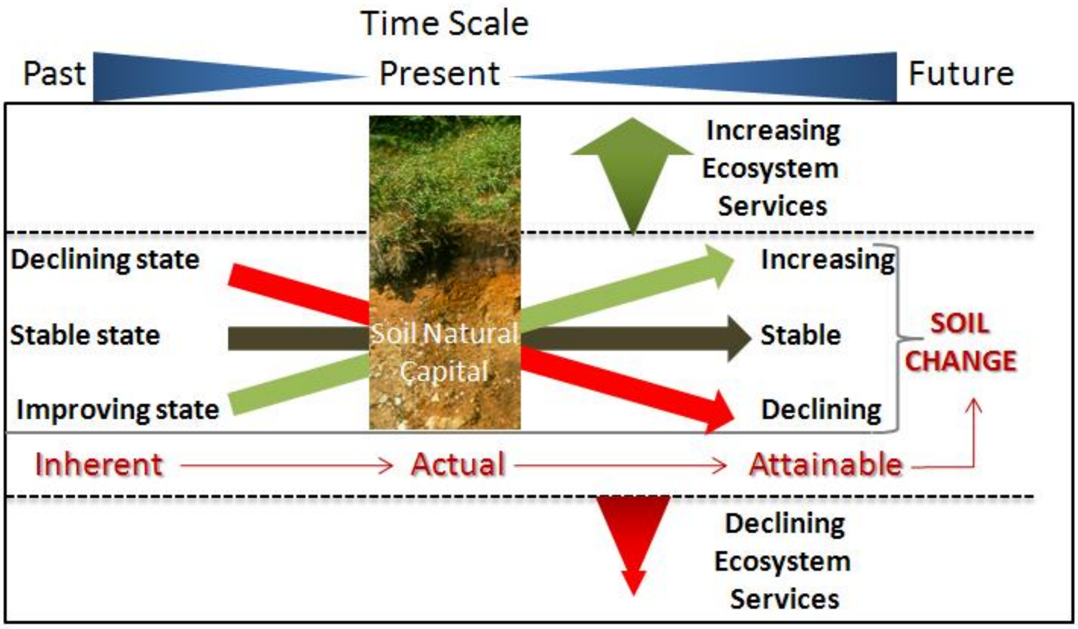
InformaTec has four working groups, the other three are technical; InformaTec soils will act as a use case for how InformaTec can work to build a community and deliver outputs.

2) Building an Ecosystems Approach to Soils

Soil functions as part of the Earths' life support system, but how do we describe this in a functional way and value our soils appropriately? In this section we provide a vision to address this question, based on recent work using an ecosystems approach to soil (Robinson et al., 2011a). Consideration of the ecosystem services and natural capital of soils offers a framework going far beyond performance indicators of soil health and quality, and recognizes the broad value that soil contributes to human wellbeing. It provides links and synergies between soil science and other disciplines such as ecology, hydrology and economics, recognizing the importance of soils alongside other natural resources in sustaining the functioning of the earth system. In the case of soils considering both ecosystem services and soil natural capital is important, above ground ecosystem services often tend to deemphasize natural capital, but this is important for soils which have important existence values characterized by the stock.

The addition and synthesis with the ideas of soil change, which recognise the continual evolution and transformation of soils on anthropogenic time scales primarily as a result of land use, land use change and climate change, builds a conceptual framework for understanding the dynamics of soils in response to current anthropogenic and earth-system drivers of change. Figure 1 demonstrates how these concepts fit together, with the current soil stocks determining our soil natural capital base Robinson et al., (2011b); from these stocks many ecosystem services are derived. Soil change concepts provide a temporal aspect identifying that the current state is derived from an inherent state and that in the future soils have an attainable state. No soil change with time leads to a stable state, where as soil change resulting in an improving state often enhances the ecosystem services we derive from the soil, whilst degradation, and a declining state tend to reduce the ecosystem services derived from the soil.

Figure 1. Illustration of the temporal balance between soil natural capital and ecosystem goods and services supporting the concept of 'soil change'. The inclined pale green arrow through soil natural capital indicates capital improvement, whereas the descending red arrow is capital degradation. In time, ecosystem services will diminish if capital is degraded; conversely, building capital may increase soil capacity to deliver goods and services. This is a broad generalization as building capital may also result in disservices. The end goal is a sustainable balance of capital in addition to ecosystem services.



Soils Data in the Context of Natural Capital

There is substantial interest from both Government, especially from its recent white paper (Defra, 2011), and industry to obtain the distribution and valuation of soil function through the ecosystems approach. A step towards this is identifying soil stocks which form natural capital (Defra, 2011); these stocks may be transformed, or increase or decrease through fluxes. It is the stocks, their transforms and fluxes from them, which constitute the basis for determining many soil ecosystem services. Table 1 is an attempt to identify major soil stocks, at national scale, and determine the availability of data sets for the stock and/or change. The table does not seek to provide an exhaustive list, but more act as a guide to help identify obvious data gaps. The table does not include flux data, but to our knowledge there is no national monitoring program for fluxes such as GHG's, CO_2, CH_4, NOx, or soil moisture, opportunities may exist to identify *insitu* and remote sensing technologies that might provide such data.

Table 1. Attempt to provide a summary table of soil natural capital data according to the framework of Robinson et al. (2009); with regard to stock and change, Yes, indicates at least one national level data set available. The table does not provide an exhaustive list but seeks to identify obvious gaps.

NATURAL CAPITAL	**SOIL STOCK**	**Parameters**		
MASS			stock	change
Solid	Inorganic material			
	I) Mineral stock	Mineralogy	some	N
		Texture	Y	N
	II) Nutrient stock	Nitrogen	Y	Y
		Nitrate	Y	N
		Olsen P	Y	Y
		Potassium	N	N
		Micronutrients	N	N
	Organic material			
	I) OM/Carbon stock	Carbon	Y	Y
	II) Organisms	Invertebrates	Y	Y
		Microbes	Y	N
Liquid	Soil water content	Volume	N	N
		soil pH	Y	Y
Gas	Soil air	O_2	N	N
		CO_2	N	N
		CH_4	N	N
		NOx	N	N
ENERGY				
Thermal Energy	Soil temperature		Y	Y
Biomass Energy	Soil biomass	Carbon	Y	Y
ORGANIZATION / ENTROPY				
Physico-chemical Structure	Soil physico-chemical organization, soil structure	Aggregates? Porosity	N Y	N N
Biotic Structure	Biological population organization, food webs and biodiversity	Biodiversity Food webs	Y N	N N
Spatio-temporal Structure	Connectivity, patches and gradients	National scale soil map		

Soils Data and Ecosystem Services

Daily et al. (1997) presented perhaps the first attempt to identify distinct soil ecosystem services (Table 2) that have been expanded by others (Wall, 2004; Andrews et al., 2004; Weber, 2007; Clothier et al., 2008; Haygarth and Ritz, 2009; Dominati et al., 2010; Dominati 2011), but to date, no accepted ecosystems approach for soils. More broadly, there is still much discussion and refinement of the ecosystem services framework in general. Fisher et al. (2009) provide a recent overview of how ecosystem services are defined, showing that the literature has no commonly accepted consistent definition, something that they, and others (Boyd and Banzhof, 2007; Wallace, 2007), argue is required to turn a conceptual framework into an operational system of accounting. There is developing agreement on the use of 'intermediate' and 'final' services, but soils need to be examined in this context to determine how they best fit. This represents a challenge for soil science, but also an opportunity to engage at this stage to shape the broader framework.

Table 2 Soil ecosystem services identified by Daily et al. (1997). And categorised according to the MEA (MEA, 2005) classification of ecosystem services.

SUPPORTING
Renewal, retention and delivery of nutrients for plants
Habitat and gene pool
REGULATING
Regulation of major elemental cycles
Buffering, filtering and moderation of the hydrological cycle
Disposal of wastes and dead organic matter
PROVISIONING
Building material
Physical stability and support for plants
CULTURAL
Heritage sites, archeological preserver of artifacts
Spiritual value, religious sites and burial grounds

Soil Change and the Ecosystems Approach

Anthropogenic activities are causing increasing environmental impact, which will increase with the projected increases in population growth. Humanity is substantially altering the Earth's erosion cycle (Hooke, 2000; Wilkinson, 2005), the carbon cycle (Houghton 2007), nitrogen cycle (Johnson and Lindberg, 1992; Vitousek et al., 1997), phosphorus cycle (Filippelli 2008; Richardson 2008), climate system (Robertson et al., 2000), and hydrology and water quality (Postel et al. 1996), all changes that significantly involve Earth's soil. The rate of soil change directly affects both our natural capital stocks and the ecosystem services we derive from them. It is this rapid alteration of soils that forms the focus of the concept of soil change on anthropogenic time scales (Tugel et al., 2005; Richter et al., 2011).

Given the important role that soils play in the functioning and regulation of the earth system, it is paramount that we understand the soil change in parallel to research on land-use and climate change, how to identify and monitor it, and how best to predict the consequences of impacts through decision making with regard to soil management.

The UK has played a leading role in understanding soil change with long-term plots, such as the Rothamsted classic experiments such as Broadbalk, Alternate Wheat and Fallow and Park Grass,(Johnston et al., 2009; Rothamsted Classical Experiments, 2011) and more recently with the national scale surveys (RSSS) and Countryside Survey (Emmett et al., 2010). However, there remain substantial challenges both nationally and internationally to integrating data, making the right observations, understanding processes, and determining how to translate our observations into useful products of soil function, natural capital and ecosystem services that can be used in a decision making process for environmental management by industry and government alike.

The European Commission has a 'Soil Thematic Strategy' regarding soil protection (COM(2006) 231). The Communication (COM(2006) 231) sets the context and framework, which identifies 8 major threats to soils, for which annual costs to the EU economy have been estimated, 1) erosion: €0.7 – 14.0 billion; 2) organic matter decline: €3.4 – 5.6 billion; 3) compaction: no estimate possible; 4) salinisation: €158 – 321 million; 5) landslides: up to €1.2 billion per event; 6) contamination: €2.4 – 17.3 billion; 7) sealing: no estimate possible; and 8) biodiversity decline: no estimate possible. The estimated economic losses to the EU come from the Impact Assessment (SEC(2006) 620). The EC Soil Thematic Strategy is already impacting research across the EU, and is likely to do more so, should it become a legal framework for implementation. Chapter 1 of the EC Soil Thematic Strategy identifies the threats outlined above. Chapter 2 of the EC Soil Thematic Strategy describes the procedure to be followed in the implementation of the Soil Framework Directive (SFD) by member states, and includes

1) Identification of risk / priority areas.
2) Establishment of risk reduction targets / risk acceptability.
3) Decisions on measures / action programmes to reach the identified risk reduction targets.

Key areas for Research:

Given the importance of developing a coordinated ecosystems approach to soil science there are significant key areas for research that can be identified in order to combine these concepts to a useful framework to improve our understanding of the environment and better inform decision making. Robinson et al., (2001b) identifies four areas that require research, development or synthesis to develop tools for bridging the science / policy divide:

1) Framework development
2) Quantifying the soil resource, stocks, fluxes, transformations and identifying indicators
3) Valuing the soil resource for its ecosystem services and natural capital
4) Developing management strategies and decision support tools

1) Framework Development: One aspect of framework development which is of particular importance for soil science is the treatment of soil natural capital (Robinson et al, 2009), especially linking it better with ecosystem services. Key to sustainability is ensuring that ecosystem services are not derived at the expense of soil natural capital and soil system degradation (e.g., strip mining without restoration), and perhaps some of the biggest challenges we face in soil science are preventing soil degradation and erosion in an increasingly populous world. To date, natural capital has been under-emphasized in the ecosystem approach, where the focus has been more on flows of ecosystem services without much thought as to how this impacts our natural capital stocks. Soil often has a high existence value which is often overlooked or omitted in many ecosystem services assessments as it's hard to value. Soil plays important roles in ecosystem services by virtue of its existence for instance in flood regulation. The existence of soil across the landscape, and its porosity, controls the partitioning of precipitation between infiltration and runoff; no flows of soil occur or changes in form.

2) Quantifying the soil resource, stocks, fluxes, transformations and identifying indicators: The next challenge is to identify the appropriate indicators and metrics for evaluating natural capital and ecosystem goods and services. Based on the natural capital framework, one approach is to evaluate soil stocks and determine how they change with time (Bellamy et al., 2005; Emmett et al., 2010). This is one challenge for profile scale soil architecture since soil structural change may not be explained by a reductionist approach (de Jonge et al., 2009). Further, measuring the change of soil stocks through time is not trivial due to dynamics caused by changes in soil bulk density (Lee et al., 2009). Perhaps the only way to truly estimate changes in stocks is to measure entire soil profiles using soil cores to either lithic or paralithic contacts. Other opportunities that may exist: methods to evaluate soil depth across landscapes, and determining the depth-distribution of soil properties, particularly bulk density/porosity, i.e. do they transition smoothly or is there an abrupt change due to horizonation?

An alternative approach to quantifying stocks is to measure the fluxes into and out of the soil as a means to estimate change in the magnitude of the stock; this still requires a one-time estimate of stock to determine a baseline for natural capital. This approach is also not trivial as closing the mass balance is challenging, though some would argue that all that is needed is to know the relative changes. This approach may be more suitable for certain properties under specific boundary conditions, e.g. for determining carbon fluxes from peatlands, and to look at the impacts of different land-uses on soil natural capital stocks. Another potential approach is to measure proxy parameters when a stock or flux is hard to quantify (Dominati, 2011), e.g. using workable days as an indicator for susceptibility to soil compaction. An important contribution is therefore to determine how to best assess 'soil change' with regard to soil stocks, fluxes or transformations. Much of the existing monitoring at national scales tends to emphasize direct measurement of soil stocks, e.g. the UK's Countryside Survey (Emmett et al., 2010).

3) Valuation and tradeoffs: There are virtually always tradeoffs among ecosystem services, manufactured goods and other sources of human wellbeing. We implicitly ascribe relative values to them whenever we choose between alternative actions such as deciding whether to use land for production agriculture or a wildlife reserve. In order to better understand and inform these decisions, it can be helpful to render these values explicit, and this is what environmental valuation seeks to do. By valuing ecosystem services in common units (usually monetary), it is anticipated that the contribution of ecosystems, including soils, to human wellbeing will be recognized by society (Pearce et al., 2006), which may otherwise tend to consider only those goods and services which are currently traded in markets (Edwards-Jones et al 2000).

As well as assisting with specific decisions, it is anticipated that environmental valuation will lead to the "greening" of existing economic indicators such as GDP, which at present only incorporates goods and services traded in markets or supplied by governments, ignoring other sources of human wellbeing such as flood control and carbon sequestration which are incompletely valued by markets. In addition, GDP, which is a measure of the flow of goods and services, does not take into account the depreciation of capital stocks. While depreciation of manufactured capital is integrated into other national accounting measures (such as Net Domestic Product), the depreciation of natural capital is generally ignored. Developing a coherent ecosystem services - natural capital framework is essential for the proper valuation of soils and the environment, and it is imperative that soil scientists participate in this important process.

4) Decision support tools: While the methods of environmental valuation are well-established and case studies abound, the practical challenge of valuing soil ecosystem services and the natural capital which produces them is formidable. As a result, the feasibility of systematically incorporating environmental values into existing economic decision making tools (e.g. cost-benefit analysis) and accounting systems (e.g. GDP) has yet to be fully realized, and may pose a substantial challenge to approaches by which society currently makes decisions. Development of economic tools for decision making may not be seen as the remit of soil science, but soil scientists should engage in this process. One reason is that these decision based tools need strong input from a soil management perspective, especially with regard to land-use. A prerequisite, and current research challenge, is to understand the interaction between land management / use and soil change. Already, soil science has made important contributions by developing decision support tools for land management (Andrews et al., 2004; Tugel et al., 2008). The challenge here is to evolve many of these tools or decision support methods so that they can be used by many sectors of society for wider policy decisions, and be applied to different types of ecosystems, rather than solely for production agriculture. Attempts to develop such tools for ecology are now emerging, e.g. Invest (Nelson et al., 2009), and integration of soil science is essential. As a community, soil scientists must develop information, e.g. **soil spatial data and soil function data** that is readily integrated into other decision support tools by other communities such as ecology, hydrology and the social sciences at a range of scales.

3) Legacy Data, Data Access Landscape, Current Reporting.

UK Soils Data

The UK is rich in soils data from a legacy of soil surveys conducted over the last 50yrs; these are identified in Table 1 and 2 with unpublished data sets in Table 3. Where possible, making these available in a user friendly format is a first step in building a knowledge base for soil change. It is important to recognize that there are large quantities of legacy data within the UK, with a range of accessibility arrangements; negotiating these can be complex, and they can constrain what individual organizations can do. Soils data has been collected for many years in the UK, under different institutional ownership arrangements over the years. This is an important consideration in dealing with legacy data, and one that may be less of an issue in the future as data availability policies are moving toward open access for new data gathering that is commissioned. In addition, it is important to recognize that the institutions involved with gathering and maintaining soil related data sets range from Government research centres, through universities, to private companies. All these organizations view data in different ways with regard to its value as a commercial product.

The Sniffer report LQ09 (Emmett et al., 2006) provides a helpful starting point to gaining and overview of the UK's legacy soil data; they identified data sets for soil monitoring up to 2005 (Table 1.). The purpose of this report was not to identify all soil information but only monitoring which means data like the national soil inventory was not included, but it acts as a starting point.

Table 1 Major soil data sets identified in the Sniffer LQ09 soil monitoring network report (Emmett et al., 2006).

Data set	Project	Custodian
ITE/NCC 'Bunce 1971' woodland survey	NCC woods	CEH
Countryside survey	CS	CEH
Representative Soil Sampling Scheme	RSSS	Cranfield, NSRI
Rothamsted Classical and other Long-Term Experiments	RothRes LTEs	Rothamsted
National Soil Inventory	NSI	Cranfield, NSRI
Soil structural conditions in England & Wales	Soil struct.	Cranfield, NSRI
AFBI 5K PITS 1995	AFBI 5K 1995	AFBI Northern Ireland
AFBI 5K 2005	AFBI 5K 2005	AFBI Northern Ireland
AFBI 1K 1995	AFBI 1K 1995	AFBI Northern Ireland
AFBI RSSS	RSSS(NI)	AFBI Northern Ireland
GSNI TELLUS 2004-06 (= BGS's G-BASE scheme in the rest of the UK).	TELLUS	Geol. Surv. NI
National Soil Inventory of Scotland	NSIS + NipAqua	James Hutton Institute
Representative Soil Profiles of Scotland	RSPS	James Hutton Institute
Soil map unit transect study	SSMUTS	James Hutton Institute
Trends in pollution of Scottish Soils	TIPSS	James Hutton Institute
Grid Surveys in Scotland	Grids_Scot	James Hutton Institute
Geochemical Baseline Survey of the Environment	G-BASE	BGS
Geochemical Survey of Urban Environments	GSUE	BGS
Forum of European Geological Surveys European Geochemical Atlas	FOREGS	GTK Finland /BGS
Environmental Change Network - soil solution chemistry	n/a	Consortium/CEH
Environmental Change Network - soil	ECN	Consortium/CEH
BioSoil	BioSoil	Forest Research
Level I Forest Conditions survey	Level I	Forest Research
Level II Intensive Monitoring of Forest Ecosystems	Level II	Forest Research
Level II Intensive Monitoring of Forest Ecosystems - soil solution	n/a	Forest Research
Effects of sewage sludge applications to agricultural soils on soil microbial activity and the implications for agricultural productivity and long term soil fertility.	Sludge	ADAS

Effects of organic carbon inputs on soil quality	SOIL-QC	ADAS
NSRI representative soil profiles	NSRI_RSP	Cranfield, NSRI
UK Soil and Herbage Survey	EA_Soils	Environment Agency

Table 2. National soil data sets that don't feature in LQ09 (Emmett et al., 2006).

Data set	Custodian
NATMAP, National soil map, UK	Cranfield, NSRI
County and regional soil mapping	Cranfield, NSRI
Soil temperature, GB	Met office
HOST, Hydrology of soil types, GB	CEH / Cranfield, NSRI

Table 3. UK Legacy soils data that may be held by institutions but is not currently available

Data set	Custodian
Engineering soil depth, GB	BGS
Landslides, GB	BGS
Farm scale soil maps and nutrient information	Cranfield, NSRI
Field-based soil auger records (extensive, but paper-only)	Cranfield, NSRI
Rabbit Squares (some 450 square km surveys)	Cranfield, NSRI
Miscellaneous Farm soil surveys (across England and Wales)	Cranfield, NSRI
Various thematic soil-based mapping (regional/national)	Cranfield, NSRI
MORECS neutron probe soil moisture	CEH

Access to Key National Soil Data Sets

Within the Sniffer report LQ09 (Emmett et al., 2006) information is provided on accessibility of the soils data. These range from, no access; outright purchase; licence; free; variable according to need, together with contact details of data or IP holder:

http://www.sniffer.org.uk/Resources/LQ09/Layout_Default/0.aspx?backurl=http%3a%2f%2fwww.sniffer.org.uk%3a80%2fproject-search-results.aspx%3fsearchterm%3dlq09&selectedtab=completed

With respect to major national soil data sets more information is provided below with respect to current soils collection, archiving of past surveys and methods for accessing the data. Currently there are no secured funds for any national (including devolved administration) soils monitoring programme to carry out repeat survey work beyond that already commissioned.

i) National Soil Resources Institute, Cranfield University. (http://www.cranfield.ac.uk/sas/nsri/index.html)

NSRI welcomes the InformaTec-Soil initiative and is keen to play a part. The basis of engagement going forward has yet to be established. The National Soil Resources Institute encourages the widest use of its LandIS (Land Information System) GIS soils data by other organisations. Bonafide research projects and Crown Users are eligible for royalty-free access to the majority of the soils data, which covers all of England and Wales.

With support from Defra, NSRI has also developed a series of free and low cost tools for accessing LandIS soils data by non-GIS users. Further to this NSRI has developed (with Defra's support), and maintains freely accessible soil education websites.

GIS Soils Data

Arrangements for access to Cranfield, NSRI's soil data are governed by an agreement between NSRI and Defra acting on behalf of the Crown. Under this Agreement:

- Data are only ever licensed (i.e. not sold) for use over a specified period;
- Departments of the Crown and their contractors are entitled to royalty-free data for specified applications, and therefore only pay a nominal administrative fee to cover the cost of extraction and administration;
- Bona fide researchers are entitled to royalty-free data, and only pay a nominal administrative fee to cover the cost of extraction and administration;
- NSRI is entitled to charge all other individuals and groups, including the Executive Agencies, an additional royalty fee to reflect the value of the information. Royalty fees are calculated using a set of standardised charging formulae that apply progressive discounts on base rates for larger volumes of data.

Free Soilscapes Viewer and Soil-net

The Cranfield NSRI Soils Portal hosts the web based Soilscapes Viewer (www.landis.org.uk/soilscapes) which provides the public with easy access to NSRI's popular Soilscapes dataset. This service is freely available for use for non-commercial purposes.

A simplified version of the Soilscapes Viewer is also embedded within our parallel free educational website Soil-net.com (www.soil-net.com)

Free and Low Cost Soils Site Reporter

The Cranfield NSRI Soils Portal also hosts the Soils Site Reporter service (www.landis.org.uk/reports) which provides access to detailed soils reports for a specific area, specified by Postcode or grid reference. This information is provided in a pdf format.

Access to the Soils site reporter is free for undergraduate students. For all other users, nominal fees (depending on area size and detail required), are chargeable.

ii) NERC soils data, CEH and BGS (http://www.bgs.ac.uk/nercsoilportal/home.html)

The NERC Soil Portal provides a gateway to discover, view and download large-scale soils property datasets from across NERC research centres. It aims to bring together resources to improve our understanding of soils and to help answer key, policy led questions. The data management and access landscape in the UK is changing, recently NERC published its new 'Data Policy' (NERC, 2011), providing key principles:

"*The environmental data produced by the activities funded by NERC are considered a public good and they will be made openly available for others to use. NERC is committed to supporting long-term environmental data management to enable continuing access to these data.*

NERC will supply the environmental data it holds for free, apart from a few special cases as detailed in the policy.

NERC requires that all environmental data of long-term value generated through NERC-funded activities must be submitted to NERC for long-term management and dissemination."

This will impact future projects funded by NERC.

The British Geological Survey (BGS) and Centre for Ecology & Hydrology (CEH) hold various datasets for soil samples collected across the UK; these include physical, chemical and biological data.

Countryside Survey

Soil data has been collected by the Countryside Survey in three surveys from 1978-2007 and is representative of the topsoil to 15 cm depth. Samples are collected from 591 (1 km × 1 km) squares across the UK. Data are available on the total stock and inter-survey change of a wide range of soil attributes including soil carbon, nutrients, heavy metals and invertebrates. Both summary and raw data by country, broad habitat, vegetation type, and soil organic matter category can be downloaded from Countryside Survey data access. You will need to become a registered user to access their data. A caveat with the use of this data is that the sample location data cannot be released, which has been the source of some disappointment and frustration at time. However, it is worth noting that what is not available is the exact site location; it is possible to have some coarser scale location information, such as the details of the Watsonian Vice Counties, or of Joint Character Areas in which the squares lie. As stated on the Countryside Survey website, in circumstances where the approximate locations of survey squares is valuable to users of the data, four-digit grid references can be released under licence allowing users to identify in which 10x10km grid square each square is located. Further information on the reasons for this, and the data policy are explained at: http://www.countrysidesurvey.org.uk/square-access-policy.

G-BASE

The Geochemical Baseline Survey of the Environment (G-BASE) project has collected samples at a density of one sample per 2 km^2; from mostly agricultural fields, across part of Great Britain. Each sample site has a surface (5–20 cm) and a profile (35–50 cm) sample. Inorganic analytical data are available for over 50 determinants.

Major and trace element analysis of the NSI database

The National Soil Inventory (NSI) project collected soil samples at a density of 1 sample per 25 km2 during the 1980's and 1990's from agricultural soils across England and Wales. In a joint project between BGS and Rothamsted Research, some 5500 surface soil samples (0–15 cm), were reanalysed for 53 major and trace elements (e.g. Al, Ca, Rb, La, Se etc.). A new atlas of interpolated maps for these elements is in production.

GEMAS

The Geochemical Mapping of Agricultural soils in Europe (GEMAS) project collected soil samples during 2008 at a density of 1 site per 2500 km2 from grazing and arable fields across the UK. Further information can be obtained from BGS enquiries; data will not be available until 2013.

iii) James Hutton Institute
http://www.hutton.ac.uk/

The James Hutton Institute is actively engaged in developing new technologies for soil research, whether laboratory analyses (from gene to soil particle), rapid field assessments (e.g. FTIR, XRD) or computational approaches (e.g. modelling, statistical analyses). We are committed to maintaining soil science expertise with the experience and knowledge to interpret this new soils information alongside existing soils data and knowledge and improve our capacity to predict, manage and restore the functional capacity of soils. The strategic and applied application of soils knowledge will continue to require soil scientists with practical skills. To meet this end we have an on-going programme to rejuvenate pedological / field based soil science alongside the development and uptake of new technologies. We are hoping in time to be able to develop a soils portal for Scottish data that will allow us to more easily and widely disseminate the data we hold.

National Soil Inventory of Scotland (NSIS)

The NSIS (NSIS_1) is a subset of the National Soils Database of Scotland. The sample framework is a 5km grid based on the National Grid of GB. The data comprise a site and soil profile description at each 5km intersect of the National Grid. Soil horizon samples, to a depth of 75-80 cms where conditions allowed were collected at the 10 km intersects and at some 5km intersects. The bulk of the profiles were collected during field work for the 1:250 000 soil survey of Scotland (1978-1981). The remainder were collected in three subsequent years from areas which had previously been surveyed. Some 3100 sites were visited in total, with 721 at the 10 km intersects having soil samples taken and analysed. The analyses are primarily chemical in nature including that of a suite of heavy metals for all mineral surface horizons.

A subset of the 10 km sites were revisited between 2007-2009 (NSIS_2). Similar procedures were used for describing and sampling the profile but a number of other sample types were also taken to test different sampling techniques, investigate short range variability and for specific objectives. A much wider range of analyses have also been undertaken, notably for bulk density and a suite of biological and molecular methods.

Representative Soil Profiles of Scotland (RSPS)

The RSPS is a subset of the National Soils Database of Scotland. These profiles were selected at the time of mapping by soil surveyors to characterise the soils currently being mapped. The data comprise morphological descriptions of soil profiles to a metre's depth where conditions permit and constituent horizons and systematic analytical data from soil horizon samples. The information was collected during field work for the 1:63 360 and 1:50 000 scale soil survey of Scotland.

iv) Agri-Food & Biosciences Institute, Soils Datasets, Northern Ireland

http://www.afbini.gov.uk/index/services/services-specialist-advice/soils-environment.htm

In Northern Ireland, the Agri-Food & Biosciences Institute (AFBI) is responsible for soil survey and soil quality monitoring of the Province. As a result, AFBI has built up an archive of soil maps and their associated soil attributes. The AFBI soil classification maps are at 1:50,000 and 1:250,000 scales and are available in both paper and digital formats. AFBI have also created a Soil Geochemical Atlas for Northern Ireland for 15 key elements based on data from over 6000 A-horizon samples. Details of the AFBI soil products for Northern Ireland are available at our website.

The AFBI 1:50K soil vector dataset is currently licensed free to those government departments in Northern Ireland with whom AFBI have a service level agreement. Other requests for data access are dealt with on a case-by-case basis. In general, we try to accommodate all requests from UK government departments and non-commercial researchers for access to the AFBI soil data either by licensing extracts of the data to them (at no cost) or by providing the summary information they require. Commercial companies are leased the 50K soil map together with limited attribute data; soil attributes are charged separately.

The AFBI 1:250K soil vector dataset is currently being made available under licence, but at no cost, to all users including the general public. It is a generalised version of the 1:50K soil map.

Access to the vector soil maps will be available soon through the GeoHubNI portal, a web based platform to facilitate sharing, using and developing Geographic Information for Northern Ireland, and hosted by our government partner Land and Property Services (incorporating the Ordnance Survey of Northern Ireland) – see http://www.geohubni.gov.uk/ ; currently only soil metadata is available online; see
http://www.geohubni.gov.uk/index/geohubni_datasets/geohub_ni_datasets_geoscientific_information/geohub_ni_datasets_geoscientific_information_afbi_50k_soil_map-2.htm .

Other major data sets:

Environment agency was responsible for the UK soils and herbage survey which was conducted to 'provide robust estimates of contaminant concentrations in soil and herbage at background (rural), urban and industrial locations. The data are not suitable for interrogation at individual sites; their real power is to provide a national picture.' Analytical data for each site is available on CD. A summary of the data, reports and findings can be found at http://publications.environment-agency.gov.uk/PDF/SCHO0607BMTE-E-E.pdf; and directs inquiries to: enquiries@environment-agency.gov.uk.

Forest research has conducted the level I forest condition survey (http://icp-forests.net/) and the level II intensive monitoring of forest ecosystems. All validated datasets from FE land are freely available to third parties (there are currently debates within the EC on the legality of sharing data from private forests and we may have to reduce the level of precision of the location perhaps to one tenth of one degree latitude and longitude, rather than quote more precisely). More information can be found on the Forest research website:
http://www.forestresearch.gov.uk/website/forestresearch.nsf/ByUnique/INFD-62VASW

Addressing the Challenges: What Might be Missing for an Ecosystems Approach?

Based on Table 1 soil biogeochemical stocks are relatively well represented by monitoring, especially through the work of NSRI and the Countryside Survey. Soil biology in terms of microbial diversity is emerging, but we lack detailed information on soil macrofauna such as earthworms which are important ecosystem engineers; this is true for the whole of Europe (Morvan et al., 2008). Soil physical properties are perhaps the least well represented; we don't know static physical properties like soil depth across the UK for instance, which is important for determining definitive stocks. Dynamic soil physical properties are poorly represented including soil moisture, which is important for drought, flood and weather prediction, and which is increasingly linked to human health via heatwave exacerbation (Seneviratne et al., 2006). Soil gas flux data for major GHG's and for soil oxygen levels is also limited. It is often these more dynamic stocks which are important for assessing soil function and performance and where developments in technology, particularly unmanned sensor and monitoring networks, could advance our understanding.

Anthropogenic activity can lead to dramatic soil change, on short time scales measured in months to years. Measuring and monitoring this is important for decision making. Rates of soil formation, vs rates of loss are not well understood or monitored and this links to the question of whether the depth and mass of soil is changing across the UK due to erosion? Developments in technology may allow us to further engage in more citizen science. For instance, exploring the possibilities of using smart phones to photograph and give the GPS position of soil erosion, backed by a suitable campaign to engage the public, could help update some form of satellite based erosion monitoring program which could be valuable.

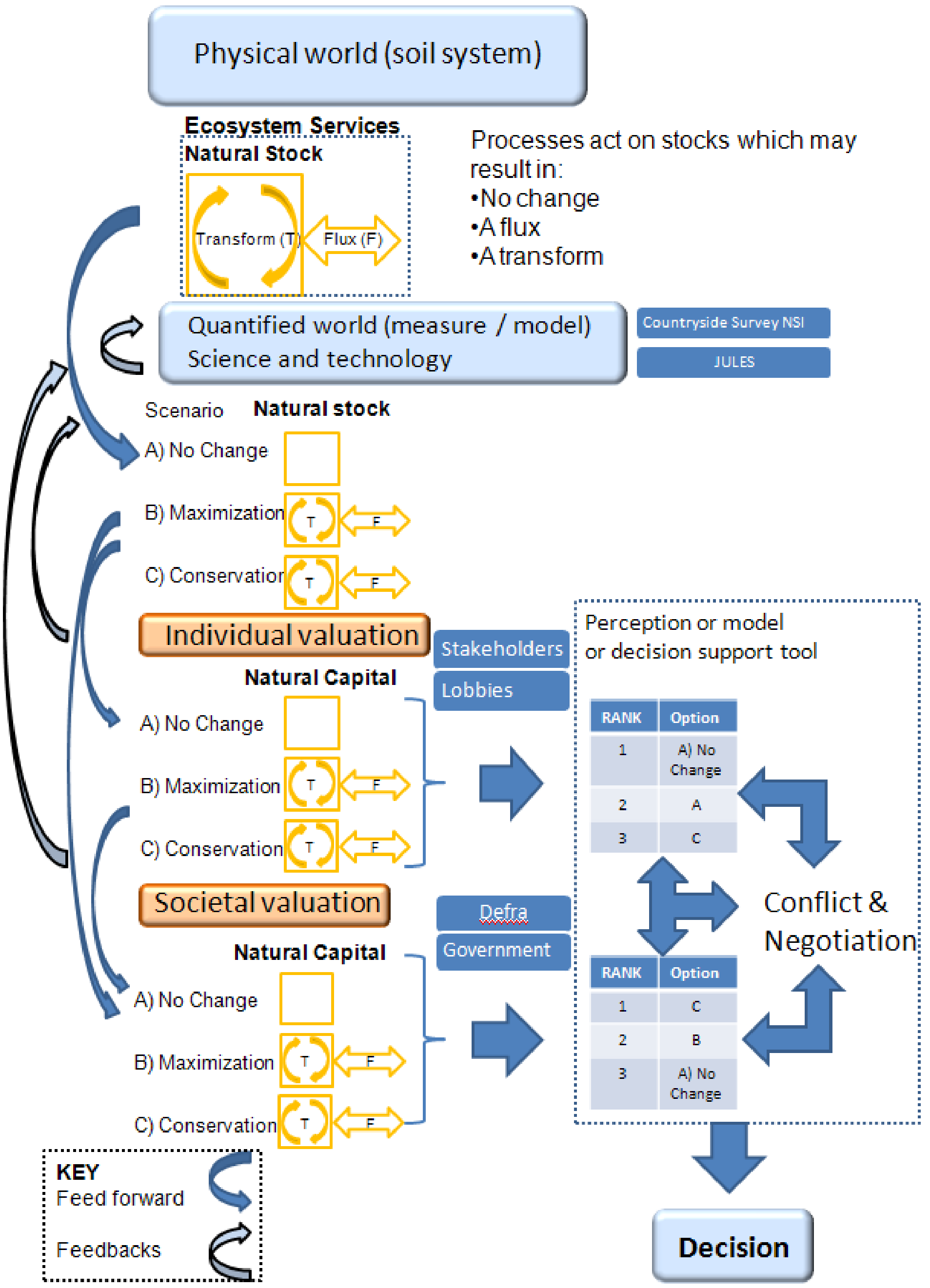
Any national scale approach must take the opportunity to link monitoring programs and technologies with modelling approaches in an iterative way. For instance, at present, CEH and BGS conduct monitoring programs such as the Countryside Survey and G-BASE. They are also involved with community modelling such as the Joint UK Land Environment Simulator (JULES) which is used by the Met Office for weather forecasting. Opportunities exist for synergies, using monitoring data to help validate model predictions but also using model predictions to identify how spatial and temporal monitoring could be improved.

This report began by using the natural capital / ecosystem services (NC/ES) concept for soils. In Figure 2 we present a conceptual framework indicating how the components of a comprehensive ecosystems approach to soils could look. This framework recognises soil natural stocks that become soil natural capital when they acquire a value; the natural stocks are the fundamental resource; processes act on the stocks resulting in, no change, a flux, or a transformation. The *status quo* results in no-change in the stock, as can a transformation (depending on how it is measured), whereas a flux will result in an increase or decrease of the stock. The ES and disservices based on this division result from all of the stock, its transforms and fluxes; all of these can be measured or modelled using physical units. In the next step a biophysical model or measurement/monitoring program is used to assess, or describe, the stock and its flows and transforms. These will be monitoring programs like the National Soil Survey and Countryside Survey, which could be better linked to community modelling efforts such as JULES.

Given a description of the stocks, valuation can be added which may be monetary or some other valuation system. The valuation is divided into two components, individual valuation, which may be individuals or stakeholder groups; and societal valuation which is an aggregate of stakeholder values and may include a value put on things like earth system function. There are different ways a system can be valued, e.g. monetised or assigned a relative value, and these values have an objective and subjective component. Where the objective component might be considered the utility of the item which is a constant, e.g. the number of kcal obtained from a kg of wheat, and can be determined by the labour that went in to the production of the item, whilst the subjective component would be how much someone is prepared to pay. The values assigned to a system by stakeholders and societal bodies then feed into the decision making process. This is where decision support tools would be used to try and reconcile the different perceived values of a system, often through a process of negotiation and conflict, ultimately leading to a decision.

This whole process also contains feedbacks that inform the process. For instance, advances in science and technology inform the process of measurement and modelling by determining what is known, what can be measured and modelled. In the same way stakeholders view different aspects of a system as important and create bias toward measuring certain parameters that they feel are important; this may be at the expense of other parameters. This also occurs through societal valuation and priorities, recent examples include the increased monitoring of carbon, which 30 yrs ago was perceived as being of much lower importance. Ultimately the decision leads to a change in the system, from which we learn something; this again ultimately feeds back into out quantification of the physical world.

Figure 2 The decision making process based on the physical world, our measurement or model of this, and how it's valued by individuals and society. Ecosystem services defined as the natural stocks, fluxes and transforms. Stocks become capital following valuation.



Challenges and Opportunities

In order to address these issues there are a range of challenges and opportunities that exist, many of which were identified and discussed, for both data handling and with measurement methods and technologies, during the Informatec soils workshop. A summary of these are given in **Appendix 1**, **Challenges and Opportunities with Data Handling**; and **Appendix 2**, **Challenges and Opportunities with Measurement Methods and Technologies**.

The emerging concept from this report (Fig 2) sets forth the need for a measurement / modelling framework for soil natural stock assessment and or ES assessment, and for soil protection and management within the ecosystems approach. In order to become operational, this framework will need the development of appropriate measurement/monitoring methods and biophysical models as well as trade-off models and decision support tools, the technology program in NERC has an important role to play in supporting both IT and monitoring technologies in regard to such an effort. In the case of soils, biophysical process models that incorporate impacts of vegetation type on soils would likely be an eventual goal. There also needs to be serious thought given to trade-off approaches and how to develop this in an effective way, tools like inVEST (Nelson et al., 2009) perhaps indicate the way forward for developing trade-offs and decision support approaches. In the following sections the different aspects are explored in more detail.

Monitoring

Developing the biophysical modelling approach requires both data for modelling input and data to act as ground truth for prediction; this prediction data should feedback in an iterative way to help improve and update models, and possibly help optimize sampling. This process is not a foreign concept to environmental scientists working to understand the environment. Many concepts have been developed, however, data resources may not be in the correct format as required by models, or offer adequate temporal and spatial resolution to provide needed inputs. The National Soil Inventory contains important soil stocks that would be used in modelling, but lacks others, perhaps the more dynamic soil state variables like moisture and temperature. Monitoring frameworks such as Countryside Survey (Emmett et al., 2010) address the issue of monitoring change in soil stocks such as SOM, soil biota, pH and heavy metals and repeat surveys every ~8 years but don't capture data to depth or more dynamic variables. An issue emerging in the literature is the need to measure both bulk density and soil depth for monitoring purposes to obtain realistic stock and change assessment; difficulties with fixed length topsoil measurements for change determination are discussed in Lee et al. (2009) and subsequent literature. A comprehensive monitoring programme tailored to the needs of soil protection biophysical modelling might best be developed given a modelling framework. This would require identifying a modelling approach, determining the required inputs, and using the model to help design an optimal monitoring scheme to reduce uncertainty.

Monitoring programmes specifically address the issue of how land-use and climate change are impacting certain stocks and provide an important temporal snapshot for national scales. Data from the National Soil Inventory may provide other inputs. However, low cost, sensor technology should offer the opportunity to augment this with a soil monitoring network capable of capturing changes in the more 'dynamic' soil stocks, such as soil moisture, temperature, and some gases, (currently O_2 and CO_2 sensors are available) on a daily basis. In the USA, the soil climate analysis network (SCAN stations) has been deployed across America by NRCS to obtain spatio-temporal data to provide evidence of climate change at the land atmosphere boundary (http://www.wcc.nrcs.usda.gov/scan/). It provides a valuable way of determining actual soil response to a changing climate that can help interpret and improve model prediction. The ECN sites in the UK are the closest equivalent but only 12 exist and data on soils is limited to temperature, some moisture and some chemistry. Expanding this to incorporate more stand alone sensor technology for soil moisture and gas, and to collect measurements for biology could provide an important data set that supports modelling applications like JULES. In addition, current measurements tend to be limited to sensor measurements at the soil profile scale (<1m^3 of soil), or to estimates from remote sensing that has footprints of km's. There is an intermediate scale gap, and a need to develop a multi-scale observational network that crosses scales, which hopefully emerging technologies will address, and perhaps citizen science could help with?

Modelling

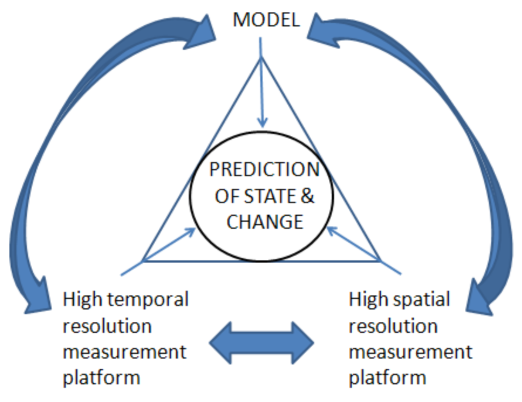
Advances in low-cost computational power have dramatically improved our ability to model complex environmental processes at a range of scales. Biophysical soil/ecosystem models to address local, regional, and national scales are in need of development. These models must focus on integration of processes and the understanding of emergent behaviour through complex interaction. The models must integrate across physical, chemical and biological processes, in order to help us understand changes in NC and ES that occur through complex drivers; they should also incorporate drivers such as vegetation type which are important predictors of soil behaviour.

Modelling in the context of management generally includes two components: a description of the processes of concern (biophysical model); and management optimisation (trade-off algorithm) based on some quantification of the utility of outcomes. In conceptual terms, a management driver is routed through a biophysical model to provide a simulated outcome. Both the management option and the outcome have a utility, and a full modelling approach seeks to optimise that utility. This is a control optimisation problem which in principle can be tackled using well-established techniques. The appropriate integration of process modelling with control optimisation in practice should be a key area for model development. While full industrial-style process control is likely to be inappropriate in soil management, there is scope for a technology transfer of some of the principles and practices. One of the key recognised difficulties lies in assigning quantified preferences to a range of outcomes, and to a large extent this is outside the realms of science, relying on input from stakeholders.

Optimisation with respect to management options is a function of the sensitivity of processes to these options, with respect to desired outcomes. This sensitivity is unlikely to be obvious for complex processes and their models. Automated, fully computerised, optimisation searches out this sensitivity and uses it to select good management options. This generally requires very large numbers of model runs (~10^3-10^4), which may not be practicable for large models. A simple rough-and-ready alternative is to use "scenario" management options to drive individual model runs, which is the approach taken with InVest, (Nelson et al., 2009). This may fail to give a full optimum where different management options have correlated effects, but is likely to give a good general indication of the best management options and the extent to which they are applied.

For the national scale a key process model under development as a community model in the UK is JULES; though there are other models in other countries, researchers in the UK are focused on the development of JULES. It operates in one dimension vertically through the land surface including the vegetation cover and the soil. The model simulates the energy, water, carbon and nitrogen budgets. As a 1-d model it is defined at a point on the land surface, but typically, in application, the point is taken to be a grid square, and large areas are modelled as comprising contiguous grid squares. The key drivers for JULES are atmospheric, and the model includes a soil parameterisation, based for England and Wales applications, on the NSRI LandIS database, with vegetation cover derived from the CEH Land Cover Map 2000 (to be succeeded by land cover map 2007). Management options can be identified with particular changes in the vegetation or soil parameterisation. Changes in the atmospheric drivers may be due to climate change, or, for example in the case of irrigation, by management options. JULES is under continual development to improve parameterisation, and the most appropriate parameterisation may depend on the use to which the model is put. The needs of soil protection are likely to stimulate improvements to the soil process component of the model, and to improved representation within the model of particular management options. One option would be to link ECN style platforms with comprehensive soil measurement to feed into JULES and provide data, against which modellers could test and improve prediction. It is important to remember that the models tend to handle changes in dynamic, environment driven processes, but do not account easily for manmade change such as point source pollution.

Figure 3 The three pronged approach to measure the state and change of UK soils to help protect them from soil threats.



Within JULES climate change influences model drivers, the key variables are temperature, precipitation and radiation. Projected values of these, derived from downscaled general circulation model simulations, were used at a 1km grid scale to drive a range of soil threat models at a mixture of time steps in SP0571. Some of these models were unable to respond directly to atmospheric drivers, but could respond to outputs from JULES, which provided, for example, soil moisture estimates for use in a compaction model (“Workable Days”; WD).

In work conducted for Defra, the projected influence of a change on recognised soil threats within England and Wales has already been addressed through modelling (SP0571). Which examined, soil erosion, salinity through inundation, contamination via acidification, carbon, and sealing through workable days. At present there is no model for biodiversity as our understanding at the national scale is weak. Using the same basic approaches some of the soil stocks, and changes in them, could be estimated. For instance, changes in soil moisture stock could be estimated and temperature used, as could changes in nitrogen stock. Comparison with long-term monitoring could be used as a check of model predictive capability and ultimately a combined measurement and modelling national assessment tool could be developed. This approach would be best to incorporate both measurement and modelling platforms into an integrated approach to determine soil state and change (Figure 3). In a similar way to weather forecasting, predicting soil change in response to drivers could be developed as a long term vision, where models are continually updated by new measurements, understanding and discovery. A soil monitoring approach could combine high temporal resolution measurements from sensor networks, with data obtained from sporadic surveys, that are required to tell us how land use change is impacting the soil system. All of this requires integration and the implementation in new technologies to assist in moving this forward.

4) Overview of Areas for Research and Major Research Challenges

This report identifies 4 key areas for research and development with regard to developing the ecosystem approach for soils based on work by Robinson et al. (2011b):

Key areas for research:

1) Framework development
2) Quantifying the soil resource, stocks, fluxes, transformations and identifying indicators
3) Valuing the soil resource for its ecosystem services and natural capital
4) Developing management strategies and decision support tools

Within these 4 key areas for research we identify the following 5 major challenges that the NERC technologies theme should address:

Major research challenges:

1. There is a need to develop an Ecosystem Approach to national soil monitoring:

   This would be a regional to UK-wide, soil-ecosystem service assessment tool that combined modelling and monitoring for integrating, upscaling and assessing spatio-temporal tradeoffs for ecosystem services at regional to national levels to link to policy and decision making.

2. Exploitation of new technologies for airborne, ground based sensor networks, and molecular biology techniques to link from soil structure through to function and on to service.

   This requires data creation and integration from sensors to establish baseline and change parameters for key national datasets. (e.g. landcover information, or soil moisture and temperature for JULES etc.)

3. Develop data accessibility (via cloud), and integration by exploiting new data IT tools (e.g. Open MI) to support projects building exemplar or baseline data/models e.g. EVOp project.

4. Decision support tools, simple, practical tools for people trying to exploit data for research and planning.(Dash boards, portals and web/app interfaces).

5. Pathways to ‘valuation’. How do you link users perceptions of value to the parameters created by the data and models.

The initial meetings and report development have clarified the challenges for the soils national capability research community, which require the following steps to help address them:

5) Next Steps

The soils community presents an important case study for informatec given the challenges of data owned by companies, universities and research organizations. An important part of improving data availability is developing common ground for future projects and data sharing, this requires developing a **Community Common Data Strategy**. Concurrent to this activity it is important to determine the technicalities of bringing data sets and models together to address the vision set out in this document. This could be achieved by an exemplar to develop a soil and ecosystem service planning tool. An **Exemplar Study** should be run with core data sets from NERC, and with any volunteered data sets from the community so that actual challenges of linking different types of data can be investigated. This would give both NERC and the wider community the opportunity to test data and model synthesis on a practical problem of developing an ecosystem service planning tool. The proposed next steps comprise two parallel work streams:

Stream 1 **Community Common Data Strategy**	**Stream 2** **Exemplar study**
1) Initial high level strategy meeting between primary data stakeholders: (CEH, BGS, Cranfield, TJHI, Forest Research....) to determine interest in joint community based project for soils.	2) The Plynlimon catchment could provide the focus for an exemplar given its long-term data sets held by CEH and BGS that can be augmented with any other available data from the wider community.
Step 1 Key institutions to agree principal aims (Is there an integrated data output that stakeholders can agree to create: eg an iphone app for soils/critical zone).	CEH to coordinate gathering of relevant data and models within NERC for an exemplar based on the Plynlimon Critical Zone Observatory.
Step2 Bring on board other stakeholders (TJHI, Forestry Commission, AFBI) The stakeholder should be aiming to establish a spatial database that encompasses the needs of soil research in the UK with a clear focus on the impact of soils on society e.g. for planning.	Subject to funding support, organize a data manager and model development meeting with wider community to confirm data sources, models and techniques that are relevant to the aims of the consortium (eg establish core inputs) Countryside Survey, Landis, GBASE, Landcover, Jules, Grid2Grid, Polyscape etc.
	Subject to funding support, organize technical meeting to establish how data and models can be interfaced to deliver the required outputs. E.g. (appropriate data handling, model adaptation) • Data synthesis • Open MI • Semantic mapping

Conclusions

This report presents a vision for an ecosystems approach to soils and summarizes the conclusions and recommendations of the meeting held in London. As well as identifying opportunities for the soils community generally, the report will be presented to NERC to inform decisions on future funding.

The report identifies the following important research topics for soils:

Key areas for research:

1) Framework development
2) Quantifying the soil resource, stocks, fluxes, transformations and identifying indicators
3) Valuing the soil resource for its ecosystem services and natural capital
4) Developing management strategies and decision support tools

Within these 4 key areas for research we identify the following 5 major challenges that the NERC technologies theme should address:

Major research challenges:

1. Ecosystem approach to national soil monitoring; how we measure and model at a range of scales.

2. Exploit new technologies for airborne, ground based sensor networks, and molecular biology techniques to link from structure through to function and on to service.

3. Develop data accessibility (via cloud), and integration by exploiting new data IT tools (eg Open MI) to support projects building exemplar or baseline data/models eg EVOp project (Community)

4. Decision support tools, simple, practical tools for people trying to utilize and visualise data for a range of common purposes (e.g. planning).

5. Pathways to 'valuation'. How do you link users perceptions of value to the parameters created by the data and models? (e.g developing techniques from social–science research in terms of perceptions and value judgements)

The meeting in London demonstrated a high level of commitment by soils researchers to work together, whilst at the same time highlighting the practical difficulties in dealing with data sets that are the property of different owners, ranging from private entities to universities and research centres, with different IP agreements. Easing access to soils data to a wider community can only be of benefit to both the soils research community and the wider society.

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Appendix 1. Challenges and Opportunities with Data Handling.

What are the Informatics challenges to national/ continental/ global interoperability:

Data Standards

- Can vary significantly, with noticeable variation nationally to globally (some constraint at European level with INSPIRE directive).Importantly, the draft specification for soil information has recently been announced (see: http://inspire.jrc.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_SO_v2.0.pdf). This document describes the "INSPIRE data specification on SOIL – Guidelines" version 2.0 as developed by the Thematic Working Group (TWG) Soil using both natural and a conceptual schema and provides guidelines for the implementation of the provisions laid down in the draft Implementing Rule for spatial data sets and services of the INSPIRE Directive.
- Legacy data (archived data, rather than active research-datasets) is prone to local variability in standards of capture, storage and availability. Most significant challenge for legacy data is the quality and quantity of published information about the datasets and the ever-decreasing corporate knowledge about the data within the supplying organisations.

Metadata

- Metadata standards are improving for active datasets, but there is still a significant variation nationally to globally. The INSPIRE framework for metadata standards is simplifying and standardising these across Europe. All soils data will conform to these standards for metadata in the future with compliance becoming a legal requirement in 2011.
- Legacy datasets (archived data/ not actively-supported datasets) are subject to wide variation in metadata capture and publication.

Modelling platforms

- A wide range of modelling platforms exist, with potentially some duplication/overlap of methods for certain parameters (e.g. terrain analyses, erosion models).
- Legacy modelling platforms may no longer be supported/obtainable (what impact does this have on model comparison? Does this limit the value of the models for future work, how do we share a defunct model? Emulators? Conversions to new platforms?).
- Cultural/corporate/financial issues with regard to platform 'choice'
- Balancing priorities of process vs spatial modelling needs for researchers vs policy makers
- Balancing scope and scale of models for researchers vs policymakers
- Fledgling Open-Modelling systems still seen as developmental

Harmonization of Legacy data

- Obtaining legacy data (physical/IPR/cost constraints)
- Classification criteria and cross-correlation issues
- Measurement techniques
- Error propagation
- Resolving changing (fluctuating) demands for 'scope vs scale' and balancing these
- Cultural issues with regard to data
- Loss of corporate (database) knowledge with changing research culture in 'soil-science'
- Different revenue streams
- Different funding structures/culture

Capacity to deal with informatics challenges / people and training

- Restricted growth of soil science in UK academia (Europe? Globally?)
- Rapid expansion of data availability but high volume/uncertain quality issues = cost
- Stovepiping of research and funding streams
- Fragmented nature (national scope) of traditional soil-science

New opportunities

- Soils communities (policymakers, researchers, 'users') can more readily interact allowing more 'fluid' mix of skills, opinion and experience AND communities can more readily agree technical/policy agendas for future work packages
- Public awareness (improving public awareness directly affects potential income stream and research priorities. Encourages non soil-research collaborations)
- Links to industry and commerce (monetising value of soil as a resource/hazard. Monetising soil-research by its impact of everyday lives)
- Links in science (Impacts of climate change, Social science collaborations for health/resources)
- Public data corporation

What are the new and emerging IT technologies

Primary growth areas cover open innovation, open modelling, web 'apps'/user interactions, progression of web 2.0 into web 3.0 and development of the semantic web, better ontologies and linked data.

- **Open innovation** is essentially an 'open' collaborative framework in which organisations utilise/licence each others ideas/solutions/workforce to test/develop new products/information from their data for end users that they would otherwise be unable to deliver on their own or through formal arrangements with their usual collaborators.

- **Crowdsourcing** works at many levels (but can require intensive management). Engages with public and active 'interested' parties. Structured sampling/ observation/ is possible but can be limited by error/clustering. 'Popular' topics are likely to create high volume and high quality data (soil colour, worm counts etc).

- **Data dashboards (and data 'skimming')** are a growing area whereby thirdparty providers create web-applications to preprocess datasets ('skimming data' by filters/ statistics/ correlations) and also provide graphic/reporting outputs (dashboards). The tools can be tailored for expert to public user skills and resolve much of the back-office work that prevents users processing extensive or complete datasets. Such tools are expected to become commonplace (and indeed necessary) as the semantic web evolves and computer-to-computer creation of data becomes more commonplace.

- **Applications** ('Apps') are typically very customised data skimmers and dashboards. Their success lies in the popularity/flexibility of the platforms they are designed for. The primary growth area for app development (in terms of accessing environmental data/information) is live, spatially enabled content with scaleable 'in-app' purchasing (i.e. localised licensing) or value-added content (educational/ commercial advertisement). Apps can play vital roles in crowdsourcing.

- **Open Modelling** techniques will enable research areas to more fluidly share modelled information by defining the outputs in such a way that differing spatial and temporal parameters are resolved automatically within the modelling environment.

- **Web 3.0** is the progression from Web 2.0 (user content sharing) to machine content sharing (computers autonomously creating and sharing data).

- **Semantics and ontologies** are the development of systems and definitions where information is more fluidly self-defining so that users (human/machine) can identify the information.

- **Data linking is** the automated collation of data (a data record knows what it is, how it relates to other data, who it is relevant to, how it should be used) with the result that users (human/machine) can fully establish facts about the data and any other data that may be related to it.

New opportunities

- Open innovation provides Industry and commerce with a broader range of R & D sources. As well as facilitating test benches for new methods and prototypes. It also provides researchers with more opportunity to show direct application/impact of their science as Industry development cycles may be more responsive than typical ‘research’ organisations, moreover, policymakers and end users can see impacts and commercial trends more clearly. Develops wider skill set between soil research and industry/commerce. Opens up commercial funding streams and practices.
  .
- Links to public/users (accesses the skills and resources available beyond the traditional soil community, which can be creative or negative depending upon how it is managed). Public engagement is more hands on. Novelty aspect of some interactions may be ‘frivolous’ but widening appeal of subject area is generally positive.

- Semantic web and data linking, should(!) add significant value to data/information making it more visible and relevant to users.

Appendix 2. Challenges and Opportunities with Measurement Methods and Technologies.

What are major challenges with regard to methods of soil data collection

- **Scientific**

Bulk density, no agreed upon standard method to be used to understand change.
Linking remote sensing to ground data, often and intermediate scale measurement gap.
How do we link proximal data or soft data like geophysics into soil evaluation?
Translating derived data into functional data
Do we have a community vision, grand challenges, are they understood, what is the role of the professional societies in this, are societies engaged with other national societies?
Do we have agreed upon standards for regional/national scale measurement
Still no agreed on method of description!

- **Policy**

Funding, especially the funding structure which tends not to have a specific home for soils research
Community coordination
Scoping and vision, where do we want to be in 20 yrs, what will be the issues, how are we preparing? Are we collecting the right data for future needs?
IPR issues, not always clarity and understanding of these
Linking up data into required products
Mechanisms for resolving issues with conflicting data and interpretation

- **New opportunities**

Development of efficient sampling designs, perhaps using models or response surfaces to aid design?
Community data collection coordination groups

How do we overcome methodological / monitoring / data collection challenges?

- **Science:**

Better coordination network for major data holders/gatherers
Need to collect soils data in conjunction with other environmental data so it fully integrates
Ensuring soil scientists understand how their data fits to wide/pressing environmental issues
Perception that soil change is slow and unimportant / need to understand soil change can be rapid
Need for vision, what's interesting, exciting, what are the new discoveries?

- **Policy**

Funding – structure - internal barriers
Funding focus – science, translational science, holistic data analysis.
Fractured soils research community
Need for a global food security network, soils research outside the UK impacts the UK as much of our provision is from external sources.

- **New opportunities**

Links to industry
Links in science

What new and emerging methods and technologies

Age determination methods and technologies improving
Rapid field techniques and insitu sensors (which work, which don't) / loss of soil survey/description skills (insitu soil chemical sensors needed, biological?)

Technology can replace description, but we must not lose pedological/soil process understanding and synthesis capability.
Remote sensing methods, especially for GHG, but there is a need to link to ground based observation.
Geostatistics and data fusion methods

In situ soil sensing
Proximal sensing
Remote sensing

New opportunities

Dealing with soft data, data fusion techniques
Intermediate measurement gap. Many point measurements are incommensurate with the grid scale of models. There is a need to develop/deploy sensor measurement capability at intermediate scales to test climate models.

Links to industry, sensors
Links in science, better links with remote sensing, space science