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A Gap Analysis on the Future Requirements of Soil & Water Management in England

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RASE Gap Analysis – executive summary

Soil and water management is fundamental to agriculture and will become more important over the coming decades. As concerns rise for future natural resource use within the context of climate change and population growth, England's soils must be managed sustainably in order to meet future demands for multi-functional goods and services. A number of recent reports have highlighted food security as being one of the twenty-first century's key challenges. Food production is, therefore, now increasingly important and efficient resource management (e.g. of soil, water and nutrients) has a critical role in enabling farming to be both highly productive and effective in meeting multiple societal objectives.

As the global area of productive land decreases and global population expands, yields must be increased and the environmental impact of land management reduced. This new paradigm of 'sustainable intensification' of agriculture will ask a great deal from our natural resources, in particular of our soils, and it is therefore essential that we manage our soil and water appropriately. It also raises questions about whether relevant research, education and information are available and sufficient to meet future requirements; if there are enough specialists to deliver advice and training; and whether a robust knowledge network exists to support innovation and development.

Today, many participants operate in a dynamic soil and water knowledge network. Broadly these participants can be categorised as communities of farmers, advisors, developers and researchers, although, other participants also have an influence over the knowledge network, such as stakeholder groups and education. These communities require different types of knowledge and play different roles in knowledge generation and its communication both within and between communities. The analysis in this report is made from the perspective of the farm and therefore what is required by farmers and land managers to maintain appropriate soil and water management now and in the future. The analysis considers requirements for research, initial and continuing education, access to appropriate advice and support for the adoption of innovative technology, to support farm level decisions.

The existing soil and water management knowledge network is driven primarily by market demand. The network has both a demand side, which for the purposes of this report is considered to be generated by the farming sector, and a supply side, supported directly or indirectly by researchers, developers and advisors. Knowledge based decisions on the farm are either ongoing and operational or strategic. A detailed fundamental understanding of the soil system is not always essential but a basic understanding is desirable, combined with experiential knowledge, especially when strategic decisions are being made about choice of farm system. The soil and water knowledge requirements for a productive agricultural system can be broadly divided into two categories - systems and technology – both need to be deployed together, for example when choosing the optimal crop system for a particular soil.

Advances in agricultural production and environmental protection ultimately depend on fundamental research on soil-water-plant systems and its experimental development into practical application. Future requirements for a farm management that integrates food production together with delivering other ecosystem goods and services, requires a strong research and development base: one that has the facilities and financial support needed to respond to a range of questions from different communities and stakeholders, with sometimes opposing interests, needs and timescales. A deterioration of this research and development base would be detrimental to the future ability of England to maintain sustainable ecosystems goods and services. Therefore, a priority of this report is to understand the current state of England's research and development into soil and water management, and its capability to meet future requirements. Increasingly, it will be important for soil and water research and development to be better integrated with innovation in farming systems, which requires a well defined mechanism to adapt research into practical advice or application, for example centred on experimental farms. We suggest a strategic initiative for soil and water research and development, jointly-owned by the industry, the Research Councils and Government, with input from other stakeholder groups (e.g. water companies, retailers, not-for-profit and non-governmental organisations), to secure a step change in the pace of research supporting future industry performance and more emphasis on technological development. At present there appears to be a lack of the shared vision and governance needed to ensure soil research underpins future industry performance. Unless this problem is addressed there is a danger that the rationale for future soil research will not be appreciated and current funding will decline, leading to a lack of industry competitiveness as well as a strategic gap in UK capabilities.

Current numbers of soil and water specialists are considered to be adequate but these may well decline because of a number of factors, including: the closure of some agricultural colleges, a lack of practical application at all levels of agricultural and environmental education, poor uptake by UK candidates into higher level education in soil science and land engineering, lack of perceived job opportunities and a weak emphasis on the importance of soils throughout education. The apparent deficiency of agricultural experience, particularly of some advisors, is of serious concern and at present there seems to be no focus or mechanisms to improve the situation. Only a concerted effort now to promote the importance of soil and water management education and establish clear and rewarding career paths will ensure that the human resources are in place to meet future challenges.

Farmers receive advice from many sources but the primary one is advisors. Advisors acquire knowledge either through education, contact with developers or from research outputs. Researchers consider more fundamental knowledge while developers translate fundamental knowledge into tools and management systems that directly benefit production and environmental performance. As there is no formal structural organisation of the current knowledge network, the flow of information can be non-systematic and inefficient. Of particular concern is an apparent lack of connectivity between the research community and other communities, including developers. Effective applied research choices depend on a clear identification of the strategic knowledge gaps that need to be filled. For example, there are significant opportunities for exploiting advances in soil informatics and biology but no strategic programme to support and encourage this exploitation by the developer community.

Responses from a project advisory group formed of representatives from key communities within the knowledge exchange network (i.e. farmers/land managers, advisors, developers, researchers and educationalists) suggest that while there is perceived to be a lot of existing and relevant information on soil and water management, accessing it is problematic because of time, cost or formatting. There is a need to collate and present up-to-date information about soil and water status, trends and performance, in the context of specific production systems, in ways that are readily accessible and understandable to farmers. Moreover, the direct value of research outputs and information to the farmer is often obscure, with information about the value of enhanced soil and water management to gross margins scarce. The economic advantage to farmers of optimum soil and water management has to be made explicit to justify them paying for necessary professional advice. There is also evidence of a lack of trusted independent advice, suggesting a requirement for more professional accreditation.

Education plays an important strategic role by populating the knowledge infrastructure with educated participants. It also may determine how favourable farmers and land managers are to adopting new ideas and technology. The knowledge base of individual farmers is critical to good ongoing operational decision-making about soil and water management. For new-entrant farmers, our findings indicate that the current education on soil and water management is inadequate with little time being spent teaching soil and water science within agriculture programmes at further education (FE) and higher education (HE) levels.

Educational opportunities for advisors, developers and researchers dictate the ability of the knowledge network to function efficiently e.g. advisors need a sound understanding of soil and water management and of farming systems to enable them to give sound and trusted advice to farmers and land managers, and to assimilate and pass back observations to developers and researchers. The quality and availability of education is pivotal to meeting future demands on the industry.

Finally, while a functional knowledge exchange network does exist for soil and water management its present structure is sometimes difficult to define and not all agricultural sectors (arable, horticulture etc.) receive the same level of interaction with other key communities. The complexity of soil and water management within different agricultural sectors requires specialist knowledge within each sector. As technology and methodology changes to meet future demands, the importance of farmers having a strong education in, and access to, up-to-date information on soil and water management will become ever more essential. Present gaps identified include the need for advisors to have practical agricultural experience, better governance of research to ensure it delivers relevant outputs and is better valued, a formal route to interpret research findings into practical agricultural knowledge, and an easily accessible mechanism for storage and retrieval of information by all interested parties. Weaknesses include a lack of independent advice, undervalued knowledge and a generally insufficient emphasis on the importance of soil and water management.

We are currently at a cross roads because of the re-evaluation of priorities, economic challenges and concerns over the number and quality of farmers, advisors, developers and researchers. The decisions we make now will have long-term implications for future food production and food security in England and the competitiveness of the country's agricultural industry. However, farming and land management is not only about food production – delivery of other ecosystems goods and services is also critical and this may well require significant changes to present farming practice. The growing complexity of integrated farming systems requires that we invest now to ensure that a strong knowledge infrastructure is in place and aligned to strategic priorities. This is essential to underpin the future economic and environmental sustainability of farming and land management in England.

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1. Introduction

Farming is a dynamic industry in England that responds to changes driven by market forces and government policies. After 1945, the demand for greater self-sufficiency in production saw a long period of public and industry investment in English agricultural research, education and extension that created a foundation for steadily increasing productivity (Bowers, 1985). Farmers were encouraged to focus on production, sustained by agrochemicals, advances in mechanisation and government support. However, in recent years the rate of productivity increase has slowed along with investment in agricultural development (Thirtle and Holding, 2003; Thirtle *et al.,* 2004; Leaver, 2010), including investment in soil and water management (NFU, 2009; Leaver, 2010). Mounting overproduction across Europe during the 1980s led to less emphasis on productivity. While, growing concerns about damage to the environment from intensive production methods, led to new agricultural policies and increasing environmental regulation. For England, arguably the most significant change was the decoupling of financial support from production in 2005, with the introduction of the Single Payment Scheme (SPS) and Cross Compliance requirements in relation to soil management. Meanwhile the UK has seen a steady reduction in food self-sufficiency since the 1980s and is currently 60% self-sufficient in all foods (Cabinet Office, 2008; Defra, 2008).

The economic condition of the agriculture sector continues to be challenging which affects its potential to invest in better soil management. Although agriculture contributed £5.3 billion to the UK economy in 2007, its share of the overall UK economy has declined by about a third over the last 10 years, diluted by growth in the rest of the economy. Investment returns have also fallen: there was a 48% increase in farmland prices between 2001 and 2007 but since a peak in 1995 farm incomes have fallen by 44%, although they have rallied in recent years (UK Agriculture – statistics accessed on line).

Farm income is volatile to exchange rates and commodity markets and also to unexpected events that affect food availability, such as extreme weather events and disease outbreaks, but the underlying trend has been negative. Fifty one percent of English farmers no longer rely on agricultural production as a sole source of income, but have diversified to include other sources of income (Defra, 2007/2008). According to Turner *et al*. (2003) nearly a quarter of diversified holdings contain some form of equine enterprise, and other activities include: recreation, accommodation (B&B, self-catering, camping and caravanning), direct marketing (e.g. pick your own), processing (e.g. cheese, cider and preserves) and environmental schemes. Second jobs, which may or may not be related to agriculture, also seem to be an alternative mechanism to support some farm systems. These factors have contributed to changes in the scale of farming in England, both in economic terms and in the physical size of farm holdings. In the last two decades, increases have been seen in both the >100 ha and <10 ha categories, reflecting adaptation to economies of scale on the one hand and on the other an increase in part-time farmers (House of Commons, 2002; Blackstock *et al*., 2009). Thus the industry is now characterised by a divergence between larger and fewer units focused on production employing fewer people and a large number of smaller diversified enterprises. The former present better opportunities for technological innovation that relies on capital investment, but a general concern for innovation, including in soil management, is the increasing average age of farm holders which in 2007 was 59, even if this may be somewhat lower for all farm workers (RuSource; Arthur Rank Centre).

Farming is a dominant activity in the UK occupying 70% of the land area and almost all of the rural landscape (Defra, 2002). As there is little scope to bring new land in to production and greenfield land in England is being progressively lost to urban development at the rate of about 5,000 hectares per annum based on the period between 2000 and 2005[1] (Bibby, 2009; Foresight Land Use Futures Project, 2010), increased production depends on higher productivity, which in turn requires more intensive management of natural resources such as soil, potentially posing a risk to its continuing capacity to provide ecosystem goods and services (Defra, 2007; 2009b). The challenge laid down by the 'Food 2030 Strategy' is to produce more food without damaging the natural resources that we depend on (Defra, 2010), coined 'Sustainable Intensification' by the Royal Society (2009). With the UK population estimated to increase at an average annual rate of 0.7% between 2008 and 2018, provision will need to be made for more than 4 million more people (Office for National Statistics, 2009) without any opportunity for increased soil resources. And the UK may, in the future, also be called upon to provide food for other countries (Defra, 2010). The current level of UK food self sufficiency is around 60%. If population increases by 10% over the next four decades, as is projected, then to maintain a similar level of self sufficiency by 2050, the UK would have to increase production by around 10%, assuming no change in diet, level of food waste or per capita consumption. To increase self sufficiency beyond current levels would require further increases in production (see for example the Royal Society, 2009; Leaver, 2010) although it is possible that increases could, in part, be offset by dietary changes and reduction in food waste.

Others go further than the Food 2030 Strategy and suggest that farming should focus on being environmentally responsible, delivering attractive landscapes, historic features and cultural values, diversity of wildlife and habitats, public access – while still producing affordable wholesome food (the National Trust's vision for a sustainable future for farming; UK Agriculture). Several strategic challenges lie ahead in order to support the need to increase productivity as a priority, notably (NFU, 2009):

- a growing global demand for food as domestic and world populations increase;
- increasing wealth in developing nations pushing up demand for food;
- declining global land availability for agriculture, due to competing demands of urban expansion, desertification and diversification in rural areas;

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[1] Sixteen percent of Greenfield developments occur in villages or deep rural areas (Foresight Land Use Futures Project, 2010)

- the current diminishing rate of increase in productivity due to a decline in relative research, development and investment ;
- the increasing scarcity and price of oil and also increasing demand for energy crops[2]; and
- growing challenges from climate change, such as an altering climate, increasing extreme weather events and an unavoidable requirement to reduce the agricultural carbon footprint.

It is certain that the future demands on farmers will continue to rise as a balance is found to both optimize production as well as environmental protection (NFU, 2009). And at the heart of the solutions required will be the management of soil and water as the basic resources underpinning agriculture.

The central role of soil in sustainable agriculture has been long appreciated by policy makers as well as farmers. The Strutt Report (MAFF, 1970) drew attention to the potential long term damage to soil resources by inappropriate intensive production. The Royal Commission on Environmental Pollution report on the sustainable use of soil (RCEP, 1996) encouraged the development of explicit policies for soil protection. Subsequently, the First England Soil Action Plan (Defra, 2004) underpinned a quite rapid development of soil protection measures in England, and also complemented the concerns of the European Thematic Strategy for Soil Protection (European Commission, 2006). But while these advances in soil protection have undoubtedly slowed the degradation of soil resources, there are continuing concerns, particularly about erosion, declining soil organic matter, compaction and also diffuse contamination (Defra, 2009b).

The recent Foresight project on land use futures (The Government Office for Science, 2010) has highlighted a requirement to maintain high quality land resources not just for agriculture but also for non-priced 'public goods' including carbon sequestration, flood risk management and protection of biodiversity. Ensuring a sustainable farming system for the future will require further development of an integrated approach to soil and water management in which the value of services such as provision of drinking water, climate regulation, biodiversity, flood protection and pollution filtering is considered alongside food, fibre and energy crop production. The 'Soil Strategy for England, Safeguarding our Soils' published by Defra September in 2009, highlights the need to protect agricultural soils (to provide ecosystem good and services) as one of its priority areas for action. All farmers who receive payments under the Single Payment Scheme (SPS) must now comply with an updated series of Good Agricultural and Environmental Conditions standards (GAECs). One of these is the Soil Protection Review (SPR2010) which aims to give farmers greater flexibility and responsibility in identifying risks to their soils, remedying any damage that has occurred (through erosion, compaction or loss of soil organic matter) and taking preventative measures to reduce the risk of future soil degradation.

[2] UK Governments renewable transport fuel obligation (2008) requires and increase in biofuels from 2.5%in 2008 to 5% in 2013

It is critical that farming is economically viable, and environmental protection needs to support the farm's bottom line, not take away from it. Improved environmental protection supported by soil management can reduce on-farm expenditure, for example on fertilisers and pesticides, and over the last two decades, farmers in the UK have succeeded in increasing yields while reducing the use of fertiliser (Defra, 2010). Other off-farm benefits such as carbon sequestration and flood protection also need to be valued by society. Payments such as the Single Payment Scheme (SPS), which acknowledge environmentally friendly farming practices, will still be needed in the future but will need to be adapted to reflect society's demand for non-traded goods and services.

Approximately 66% of agricultural land in England receives some form of agri-environment scheme payment (Natural England, 2009) and farmers in these schemes are made aware of the soil and water management best-practices. The type of soil and water management practices that are needed is varied because of the different soils and diverse land uses that are found in the English landscape, from low intensity upland systems through to intensive arable and grassland systems. Consideration needs to be given to alternative activities that have developed through farm diversification and that also impact on soil and water resources, such as equine and recreational uses. Within the farm itself, different areas may require different soil and water management practices. For example, a farm may have areas where the aim is to maximise production but also areas where other objectives are prioritised such as biodiversity, flood control, landscape or historic environment protection.

Clearly, good management of soil and water is fundamental to meeting increased demand for food, fuel and fibre. The soils of England need to be made even more productive but managed sustainably. More effective water management is essential given both the growth in competition for water and the effects of climate change. The threats to England's soil and water resources are highlighted in Table 1. If England is to meet the challenge of increased productivity and adapt to climate change, soil and water management must become and remain a high priority.

In their recent report, Godwin *et al.* (2008) concluded that there is an urgent need for increased investment, both to sustain existing effective soil and water management practices and to support innovation to deliver higher yields and a reduced environmental footprint. The aim of this report is to explore and report on the evidence-base for the need for this investment.

Table 1: Potential threats to soil and water from increased production and climate change

		Potential threats to:	
		Soil	**Water**
Threat from:	**Increased production**	• Increased erosion • Decline in organic matter content of soil • Reduced fertility • Damage to soil structure	• Reduced storage water capacity • Increased demand for water supplies • Potential for increased diffuse contamination of supplies
	Climate change	• Increased erosivity by wind and rain • Shifting patterns of food production increasing pressure in certain areas • Increased survival of pests and diseases • Loss or change due to sea level rise • Potential for loss of organic matter	• Reduced water reserves • Potential for increased diffuse pollution • Increased demand for irrigation • Periods of excess water • Fluctuations in demand and supply • Saline intrusion

2. Terms of reference[3]

British farmers and land managers face a situation where they will in future be asked, by government and society, to increase yields whilst at the same time reducing inputs, improving soil health and generally enhancing the environment. It is necessary to ascertain whether they will be able to meet the demand for enhanced soil and water management required to deliver these diverse outcomes.

This report aims to address three key areas: research, education and information and answer some fundamental questions, namely:

1. Are appropriate data and research in the pipeline to help sustain effective soil and water management in the future?
2. Will there be enough specialists to help?
3. Is new and relevant information for our future requirements reaching farmers quickly and effectively?

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[3] The terms of reference were agreed by the project commissioners (Royal Agricultural Society of England) and project funders (Defra, the Environment Agency and Natural England).

3. General approach and methodology

Over recent decades the agricultural knowledge infrastructure in England has become market-led, following the privatisation of advisory services. The result is a more complex knowledge infrastructure than existed before the 1990s when the state supported a comprehensive advisory service (the Agricultural Development and Advisory Service) with experimental centres linked to national research centres. Today there are many participants operating in a dynamic market who require different types of knowledge about soil and water management in order to support agricultural productivity and/or delivery of ecosystem goods and services; these play different roles in knowledge generation and communication to farmers and others. Within this report these participants are identified by their communities (see Section 4.1.). A description of this market-led infrastructure is required to frame an assessment of current and potential gaps in soil and water management research, information resources and education provision.

Current and anticipated gaps in the knowledge infrastructure can limit industry performance e.g. if supplies of artificial fertilisers become limited and more expensive, can this be countered by increased efficiency in their use? Closing gaps like these will require innovation to maintain productivity while delivering the other environmental outcomes expected by society, however, it is as yet uncertain as to how equipped farmers are to meet these challenges. Investment in soil and water management needs to be justified by and targeted towards these gaps. A gap analysis should cover the breadth of the knowledge infrastructure including:

- demand-side dimensions, such as sectors (arable, livestock and horticultural; lowland and upland) and enterprise scale and scope; and
- supply-side dimensions, such as education, scientific research, technology innovation and advisory services.

To address this relative complexity, a conceptual model is required to identify the critical demand–supply interactions that should be included in an analytical framework for identifying present and future soil and water management requirements and then assessing existing and required capacities to meet these requirements.

Godwin *et al.* (2008) identified a range of key technical issues relevant to both increasing productivity and environmental performance (e.g. soil-water-machine interactions; drainage and irrigation practices). Others that should be covered are water quality (in line with the Water Framework Directive); soil and water management in grassland and the uplands; emerging digital technology (e.g. for real-time field measurements, informatics[4], control and interventions); areas of strong progress in soil

[4] Informatics is the practice of information acquisition, processing, storage, management, utilisation and dissemination through computer science, computational, statistical and visualisation techniques

science (such as pedometrics[5], soil biology and soil carbon dynamics); and integrated farm management advice, guidance, support and research that would enable farmers to deliver a balanced range of environmental products, including food, biodiversity, carbon storage, water, access, landscape and greenhouse gas flux reduction.

As farmers and land managers are the custodians of 70% of the UK countryside and have operational control over soil and water management, we chose to make our desk-based analysis from the viewing point of the farm, covering requirements for initial and continuing education of farmers, access to appropriate advice and extension services and adoption of innovative technology. We looked out from the farm through the various knowledge exchange relationships, taking account of the human and other resources needed to service different parts of the knowledge infrastructure, from fundamental research to practical on-farm decision-making. As explored later (see Section 4.2), knowledge is required on-farm to support ongoing operational decisions and also strategic decisions about the types of farming systems deployed. Thus an on-farm perspective is likely to be more focused towards the availability of tools and processes to optimise system choices and performance to meet market and regulatory demands, than on the science of soil and water *per se* or land management at scales beyond that of the farm.

The proposed knowledge infrastructure and the conclusions drawn from its analysis were tested and extended through a structured interaction with five communities (defined in Section 4.1.2.), namely:

- leading farmers and land managers,
- advisors,
- developers,
- researchers and
- educationalists.

This was carried out in three phases:

Phase 1: the analytical framework for the knowledge infrastructure that had been developed from a desk-based analysis was tested, using feedback from leading members of each community formed into a 'Project Advisory Group' (PAG). PAG members were selected by approaching a range of organisations and asking them to recommend potential members. These included the British Society of Soil Science, the Institution of Agricultural Engineers, the Institute of Professional Soil Scientists, the Chartered Institute of Water and Environmental Management, the Royal Agricultural Society of England, the England Catchment Sensitive Farming Delivery Initiative (ECSFDI) and recommendations from PAG members or people approached to be PAG members. A selection was made to provide as even coverage as possible of different groups namely producer types (arable, livestock etc) and roles (farmers, advisors, developers and researchers and educationalists). A list

[5] Pedometrics is the application of mathematical and statistical methods for the study of the distribution and genesis of soils (Pedometrics commission, www.pedometrics.org)

of PAG members and their affiliations is given in Appendix A. Two meetings were attended by 10 out of 26 members. This group consisted of one farmer, two advisors, four developers, 1 researcher (excluding the authors of this report) and two representatives from the educational sector (excluding the authors of this report).

Phase 2: desk-based research and semi structured telephone interviews with 24 PAG (including members who had attended the two meetings) member representatives provided information to populate the framework (see Appendix B and C for details of the questionnaire employed and responses). Telephone questionnaires were conducted with 4 farmers/land managers, 5 advisors, 5 developers, 5 researchers and 5 educationalists. Participants answered questions related to how/why they were involved with soil and water management e.g. occupation, agricultural sector and education. They were also asked their opinions on knowledge transfer, knowledge gaps and education.

Phase 3: the initially-populated frameworks were presented to the PAG to corroborate findings and identify items that might have been overlooked.

This report brings together the findings of the desk-based study and the opinions of the PAG members, considering both the demand-side and supply-side frameworks, to identify strategic gaps relating to soil and water management with respect to:

1. Likely future land management requirements
2. Research capabilities, resources and capacities
3. Numbers of soil and water management professionals and their training and development
4. Training of and support for advisory staff in soil and water management
5. Provision of initial and ongoing advice and training (extension) for farmers on soil and water management
6. Understanding of relevant issues by, and support for, regulators and policy-makers
7. Knowledge transfer to the farming community.

4. The knowledge infrastructure for soil and water management

4.1 Description

4.1.1 Conceptual model

The starting point for describing a conceptual model to support the framework for knowledge transfer of soil and water management to farmers and land managers was the model described by Klerkx and Leeuis (2008)[6]. The model proposed here is modified from Klerkx and Leeuis' original concept in that researchers and developers are considered to undertake explicitly different roles from one another. We regard as critical this separation of the researcher community (that develops fundamental and strategic knowledge) from the developers' one (that conducts experimental work to transform knowledge in to innovative tools and processes of practical benefit). Both are essential but their roles and skill requirements are different. From an on-farm perspective, as employed in this study, there may be an active research community that is well-judged by peer-review but its outputs will not be exploited optimally without the transformational capacity afforded by a well-directed developer community. Some researchers are also effective developers and vice versa but this is not universal and the issue here is a separation of distinctive roles rather than categorization of individuals. Therefore our model has four main communities:

(1) farmers and land managers who are the end-users of knowledge;

(2) advisors who act as intermediaries between the end-users and suppliers of knowledge[7];

(3) developers with specialist knowledge who transform research into practical solutions for end-users; and

(4) researchers, who generate new knowledge.

A fifth community is that of educators, but their role and relationship to the other groups is distinct – it is to supply the other groups with individuals who have the necessary education to allow them to be effective participants in the infrastructure. While these communities comprise the main providers of knowledge exchange this does not occur in isolation. External influences from stakeholders in the form of suppliers, purchasers, government and regulators also act to influence the knowledge network.

In its simplest form this conceptual model might be seen as a simple linear flow of knowledge from its conception by research through development of knowledge for end user and delivery of knowledge by advisors to farmers and land managers. However, it represents a far more

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[6] Klerkx and Leeuis (2008) identify the main groups of actors in the infrastructure as being (1) demand-side end-users (farmers and land managers) (2) supply-side providers of research and development and 'knowledge-intensive business services' (KIBS) and (3) knowledge intermediaries who connect the demand for and supply of knowledge services to support innovation.

[7] Although professional individuals are the main advisory actors, web-based services are also important 'virtual' advisors.

complex flow of knowledge. Instead of being uni-directional the flow of knowledge is multi-directional. Figure 1 illustrates how the main communities and stakeholders described above relate to each other. Educationalists do not appear in Figure 1 but their role should be viewed as impacting on all aspects of the knowledge exchange infrastructure by providing human capital. The arrows indicate the direction of knowledge flow and the size of the arrows illustrates the strength of that knowledge transfer i.e. the larger the arrow the more dominant the knowledge pathway. Figure 1 represents the refined model based on PAG group feedback on how they viewed, from their respective communities, the current direction and strength of knowledge flow. Generally there was good agreement between communities with regard to the direction and strength of knowledge transfer. The most notable difference occurred between what researchers thought they were delivering to other communities and how other communities saw their contribution, which is discussed in more detail below (Section 5).

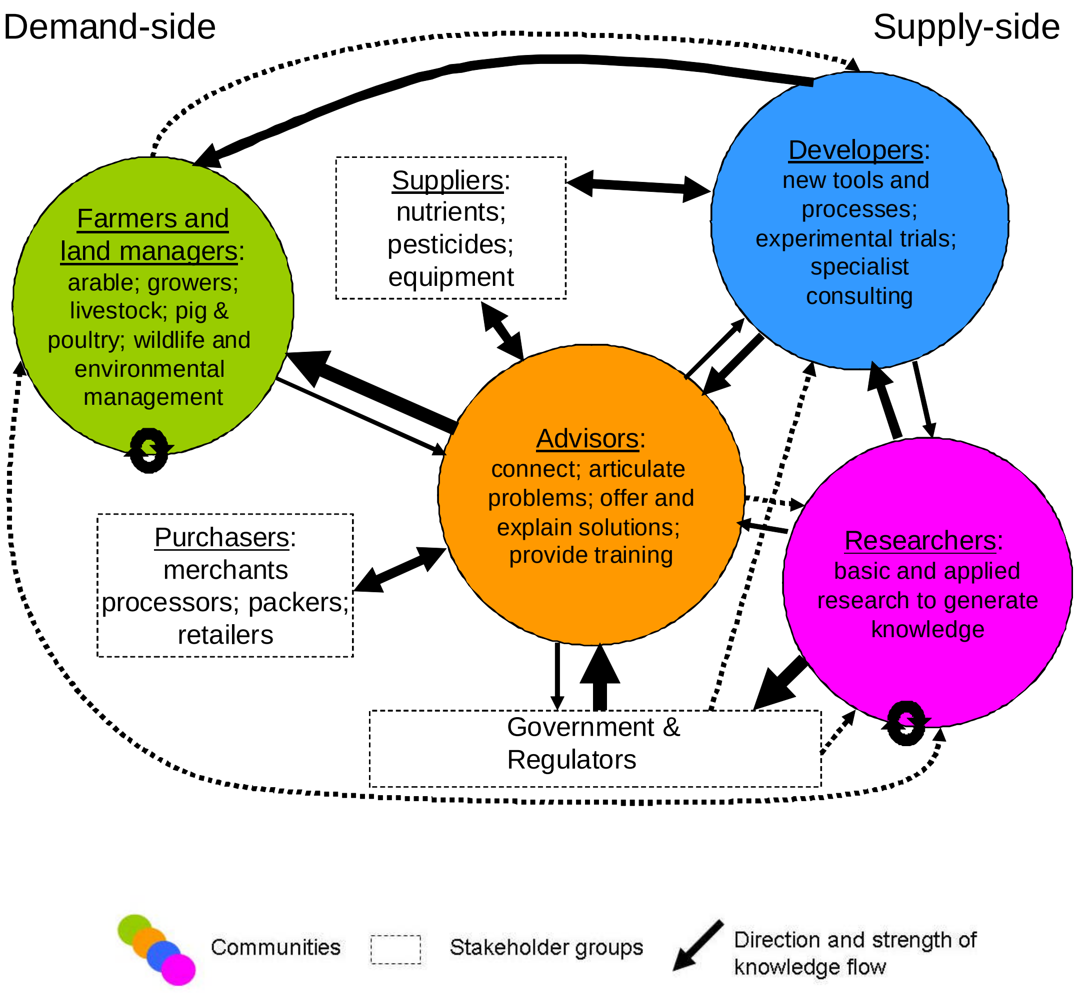

Figure 1: Model of the agricultural knowledge infrastructure, drawn from the ideas of Klerkx and Leeuis (2008).

4.1.2 Key communities within the knowledge infrastructure

The four identified key communities within the knowledge exchange network are farmers and land managers; advisors; developers and researchers. Each of these communities has a distinct role to play even though the array of participants within each community is variable. It is therefore important to understand the makeup and role of each community.

Farmers and land managers

There are many types of farmers and land managers in England, some full time others part-time. The enterprises they operate vary hugely in scale and scope, from large capital-intensive operations to small ones with low capital inputs. Nonetheless there is a commonality of soil and water knowledge requirements within different enterprises engaged in the same kind of production, so a useful classification of farmers and land managers is according to types of output. The agricultural statistics classification (Defra, 2009a) recognises the following types of produce: cereals, arable crops other than cereals, potatoes, horticulture, dairy cows, beef cows, breeding sheep, breeding pigs and fowls. For this study the following classes of producer are defined, based on a commonality of soil and water management issues: (1) arable farmers; (2) potato and vegetable growers; (3) dairy, beef and sheep farmers; (4) pig and poultry producers; and (5) wildlife habitat managers. However, often individual farmers fall within more than one category, for example by being both livestock and arable farmers, and all farmers may be considered as habitat managers.

A further important division of farmer and land manager types in the context of knowledge infrastructure relates to differences in their behavioural attitudes towards innovation. They may be grouped (Rogers, 2003) as: (1) innovators who are actively engaged in development of technology; (2) early adopters of technology; (3) late adopters of mature technology; or (4) traditionalists who generally fail to adopt new technology[8]. Innovation adoption relies on a flow of technology into trials by innovators, through to early adoption by industry leaders and then by later adopters. The depth and breadth of knowledge of soil and water management needed by a successful innovator or early adopter is greater than that for later adopters, because the former need to evaluate as yet untried and untested relative benefits and risks of different technology options. Later adopters are able to observe and assess outcomes experienced by others. However, there can be considerable conservatism within the farming sector driven by historic practices passed down from one generation to the next. According to Dwyer *et al*. (2007) there is also much evidence that opportunities to change farmer behaviour may be limited to occasions when the farmer is changing or adapting systems.

[8] A study of farmers in the Netherlands (Diederen *et al*., 2003) estimated the percentages of innovators, early adopters, late adopters and traditionalists (referred to as laggards) to be 3%, 10%, 24% and 63% respectively.

However, informal networks developed between groups of farmers can help 'break the mould' as farmers seem more willing to adopt new methods where other farmers are advocating their use.

Within the present knowledge infrastructure farmers and land managers tend to be recipients of knowledge from other communities. Some self-developed knowledge within the farming community is passed on to other farmers, but based on the opinion of the PAG group not much knowledge generated from the farming community is passed back to other communities within the knowledge infrastructure.

General advisors and advisory services

There is an array of advisors with a range of skills and expertise, some offering specialist advice while others provide generic support. Advisors may be independent consultants but are often employed by or linked to marketing cooperatives, suppliers' product support teams, farming trusts or movements (e.g. the Soil Association and Linking Environment and Farming (LEAF)), farming charities (e.g. the Farming and Wildlife Advisory Group) and initiatives that are sponsored by retailers, statutory bodies (e.g. agri-environment scheme advisors, catchment sensitive farming projects and the Environment Agency (EA)) and levy boards (e.g. Agriculture and Horticulture Development Board). In addition to individuals who act as advisors, there are 'virtual' advisors, such as the Agriculture and Horticulture Research Forum's Soil Information Gateway, the Environment Agency's web-based Net-Regs, ADAS's PLANET and MANNER, and the Country Land and Business Association's CALM, that provide information and interactive query and advice functions. The opinion of the PAG was that the majority of individual advisors are not specialists in soil and water management; they have expertise in the farm business as a whole or elements of it. They should have a sound knowledge of soil and water management topics. Following the diagnosis of on-farm issues, advisors may offer standard prescribed solutions to soil and water management problems and need to be able to contextualise the choices they advise.

The main function of advisors[9] is to help farmers to enhance their performance. Importantly, they are part of an informal network between farmers and land managers through which innovation can be exchanged between enterprises. However, they also play a pivotal role in the overall knowledge infrastructure. First, they should be listening to farmers and land managers, in the context of the markets they are servicing and the regulations they must meet, and articulating practical problems to developers, creating connectivity between the demand and supply-sides of the knowledge infrastructure. Second, they should be communicating innovative solutions provided by the developers (see below) back to farmers and land managers.

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[9] In the model proposed here, advisors correspond to 'innovation intermediaries' as described for example by Howells (2006)

Developers

Soil and water management developers work in technical consulting firms or other organisations that have product development capacities (e.g. ADAS, TAG and Soyl Ltd), equipment and chemical suppliers and in centres doing field-based experimental research (e.g. Rothamsted Research, East Malling Research and some universities). Government agencies (e.g. Natural England, the Environment Agency and Defra) also act as developers, turning scientific research into practical schemes.

Analysis of the PAG responses suggests that presently the role of the developers is under-developed and somewhat obscured, but is critical to the performance of the farming industry. Development is generally grouped with research, and there is overlap with individuals involved with both roles, but its specific role is distinctly different. The primary role of the developers[10] is to translate knowledge into tools and management systems that directly benefit production and environmental performance. In addition they provide a source of specialist soil and water management knowledge for advisors. These advisors may work for the same company but have a distinct role or they may be external contacts. Their focus is on seeking practical solutions to end-users problems using knowledge generated especially, but not exclusively, by researchers. They are engaged directly in experimental research to improve practice, conducting trials to qualify new approaches and products and demonstrate their effectiveness.

To support experimental development they may interact directly with innovators and early-adopters in the farmer and land management community, but their key knowledge exchange is with advisors. The most important role of the developers is to both pull new knowledge from fundamental and applied researchers into improved practice and report strategic knowledge gaps to these researchers. However, there is an implicit concern that developers have not been supported adequately in recent years to effectively perform this role.

Researchers

Research is commonly classed as basic, applied or experimental (OECD, 2003):

- **Basic research** cultivates and develops new ideas, principles and theories that often have no immediately identifiable benefit or application wider than the research community, however, it is essential in providing the foundation upon which applied research is built and for stimulating new fundamental knowledge;
- **Applied research** is carried out in order to develop knowledge for an identified general application;

[10] Some but not all of the organisations in which the developers work may be classed as ‘Knowledge Intensive Business Services’ or ‘KIBS’ which are characterised by having state-of-art technical knowledge and a focus on product or service development but not on manufacturing or end-user service delivery.

- **Experimental research** takes applied knowledge and translates it into products and management systems that deliver economic and other benefits – this category of soil and water research is delivered mainly by developers (see above) rather than researchers as defined here.

Both basic and applied researchers mainly work in Research Councils and other institutes and university departments. Their effective connectivity to developers and experimental research is critical to innovation in soil and water management.

Basic research outputs on soil and water management in agricultural systems are provided by a global network of scientists. In England the majority of basic research is funded by the Research Councils (e.g. BBSRC, NERC) with priorities mainly set by committees of researchers on the basis of scientific opportunity and excellence within a broad strategic framework agreed with government[11]. An important function of the basic researchers, as well as doing their own research, is to observe, interpret and report new international science to developers. Therefore, in order to enable future sustainable and productive farming practice in England there is a strategic requirement to maintain a healthy cohort of researchers covering the breadth and depth of soil and water science topics. This will ensure the development of the most appropriate techniques and technology for the English farming industry.

Applied research is problem-oriented but the problem is normally defined broadly. Effective applied research choices depend on a clear identification of the strategic knowledge gaps that need to be filled. For example, more efficient uptake of applied nitrogen by crops based on new knowledge of soil biology might be a strategic objective to increase crop yields and thus industry gross margins, as well as reducing emissions to the environment. From an economic perspective, the value of applied soil and water management research depends on its successful translation by developers into tools and processes that can be adopted by farmers and are seen to be effective.

4.1.3 Stakeholder groups influence on the knowledge infrastructure

The agricultural knowledge infrastructure does not exist in isolation but is closely connected to the industry supply chain as well as public institutions that determine and oversee the legal framework for the industry. Suppliers provide farmers with equipment and other resources and purchasers provide a market for farm produce; they both have an economic interest in producer performance and support advisors and in some cases developers. Government and its agencies aim to deliver policy objectives by supporting knowledge development and exchange, through

[11] The Haldane principle, as set out in the 1918 report which recommended establishing the Research Councils, says that researchers should decide on research priorities (i.e. which research proposals are funded) while Government should only set an over-arching research strategy.

their own research and advisors, such as the England Catchment Sensitive Farming Delivery Initiative (ECSFDI) and Natural England's Land Management Advisory Service, and Environment Agency staff working directly with farmers. Thus these groups not only strongly influence the agenda for soil and water management, they are actively engaged in the knowledge infrastructure, by providing advisors and developers and, most importantly, they fund research and development in this area. Defra and BBSRC are the main sources of funding for agriculturally-relevant soil and water related research in England.

4.1.4 The role of educationalists in the knowledge infrastructure

Education affects all aspects of the knowledge infrastructure for soil and water management. Primary provision comes from schools, colleges and universities. However the role of continuing professional development is also very important to soil and water management. Continuing professional development (such as BASIS, FACTS, NroSO and short courses) is provided by colleges and universities and also industry. While government also provide education through direct training courses and sponsored events.

Education determines the ability of people, in key communities and stakeholder groups, to identify, interpret, respond, communicate and take decisive action. The level and relevance of a participant's background education can considerably influence the effectiveness of knowledge transfer, both from and to them.

4.2 Knowledge requirements for soil and water management

The knowledge infrastructure for soil and water management requires different types and levels of knowledge.

4.2.1 Types of knowledge

Increasing production and reducing environmental impact depend both on knowledge of technologies and an understanding of soil systems and their responses to interventions. Therefore there is a need for knowledge about processes in the soil system; *system knowledge* (e.g. erosion by water and wind, the dynamics of soil organic matter and carbon cycling, biological transformation of nutrients and pollutant cycling, including greenhouse gas emissions) and also about technologies; *technology knowledge* (e.g. erosion control, water management , irrigation, tillage and traction, and grazing management). In order to maximise the efficiency of soil and water management within the farming system these two types of knowledge need to be integrated and applied at different levels of complexity within the knowledge chain, as in the schematic provided in Figure 2.

Figure 2 suggests the main providers and users of each complexity of knowledge. However, feedback from the PAG group suggests there is overlap between communities.

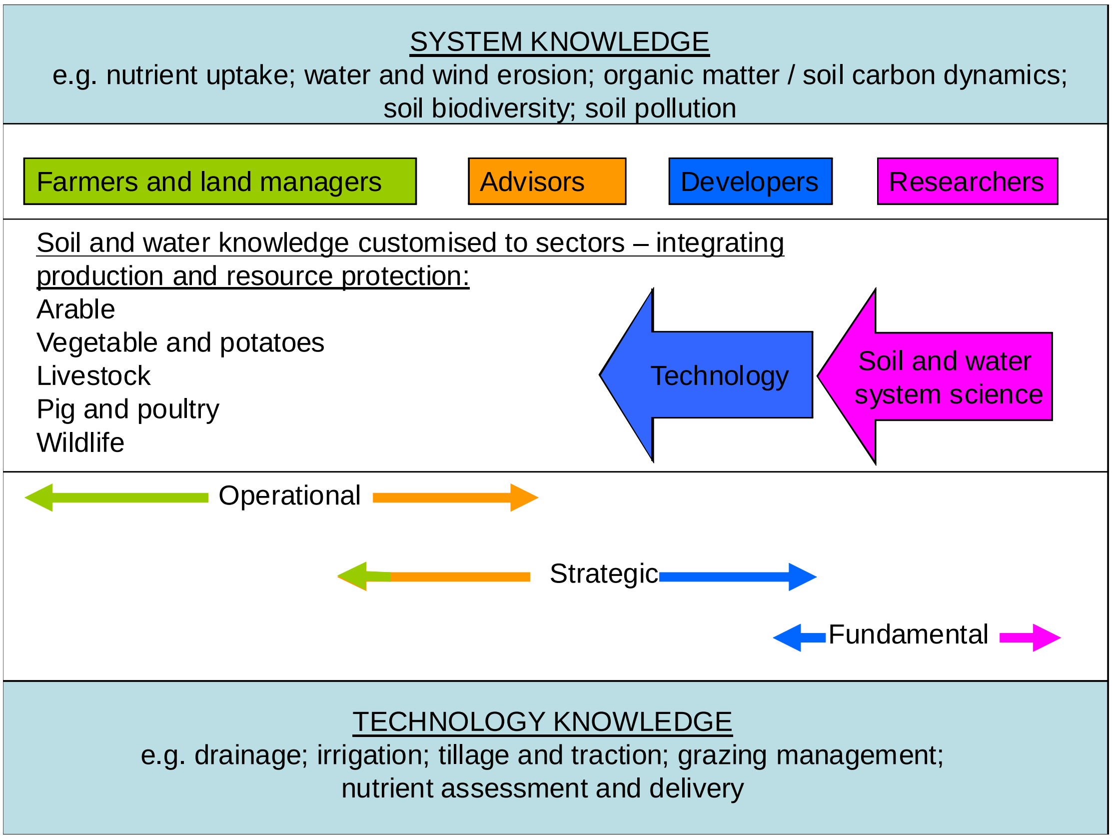

Figure 2: Knowledge requirements for soil and water management

Three levels of complexity can be defined in the knowledge chain relating to systems and technology knowledge: *fundamental*, *strategic* and *operational*:
Fundamental knowledge relates to understanding key processes i.e. the why and how things happen.
Strategic knowledge is about gathering and interpreting system and technology knowledge that can be used to set priorities and plan long term strategies.
Operational knowledge relates to putting knowledge to practical use e.g. knowing what to do and when.

4.2.2 Types of decisions

Responses from the questionnaire survey undertaken with the 24 members of the PAG suggest that operational, strategic and fundamental knowledge are important to all communities but not necessarily to each individual. For example the value placed on fundamental knowledge by farmers and land managers (n = 4) ranged between neutral to very important, whilst operational and strategic knowledge was considered to be important or very important (Table 13a, Appendix C).

Farmers and land managers have to make two types of decisions relating to soil and water management (see for example Table 2). First, there are *strategic* decisions that are made on two levels: the first level relates to a choice between different types of production and the second level considers the choice of a specific system of production (see Table 2). Strategic decisions are therefore about choosing a farming system that is capable of economic sustainability either through production or payment received for other goods and services. Decisions include considering the capability of soils and other resources on the farm and the consequences of any relevant legislation or compliance restrictions. Economics inevitably have a strong influence over strategic decision making e.g. predicted market prices for certain crops. Strategic decisions about what to produce and how to produce it may be updated annually but normally are linked to farm business plan reviews (in turn influenced by local and/or national policies and incentives) held at intervals of perhaps five years e.g. linked to Environmental Stewardship timescales. Therefore strategic decisions that influence soil and water management can have important long term implications.

Second, there are seasonal and daily *operational* decisions within an established agricultural system generally aimed at optimising yields, quality and environmental goals while avoiding soil conditions that may hinder farming operations and/or cause environmental damage. These types of operational decisions tend to only have short term consequences for soil and water management.

Ideally, both strategic and operational decision-making should be informed by a more fundamental knowledge of the soil and water system e.g. how a particular soil responds to wetting and drying cycles. New fundamental knowledge is fed in from researchers primarily to developers and advisors. Understanding soil system specific knowledge, e.g. nutrient uptake, water and wind erosion etc. developed by researchers, requires little or no translation before it can be used to direct soil and water management. However, the transformation of fundamental knowledge into technological advancements that will improve soil and water management within the industry requires the intervention of developers. In addition the extent to which knowledge about soil systems influences operational decisions is not always appreciated by technical experts since farmers often draw on extensive experiential knowledge about their particular soil systems (Verheijen, 2005).

There is no doubt that the knowledge requirements of an effective advisor are demanding: they include both up-to-date information about production systems and their performance, and a scientific appreciation of soil and water management that is able to inform local use and management accurately. Advisors therefore require operational, strategic and fundamental knowledge in order to offer best management advice tailored to individual farming systems. The PAG questionnaire responses from this community (n = 5) reflect this need with all respondents rating the three forms of knowledge as either important or very important to them.

Table 2: Examples of strategic and operational decision making - arable and pasture systems

	Strategic		Operational
	First level	**Second level**	
Arable	Choosing combinable crops because available soil resources will deliver optimal yields and gross margins without excessive soil degradation.	Deciding which crops to grow in which rotation, and whether to adopt zero, reduced or inversion tillage.	Considering timing of operations, ongoing nutrient and pesticide requirements, in-season water management and, potentially, the timing and rates of land spreading of organic materials.
Pasture	Deciding to continue in dairy production but to better exploit land resources by introducing maize silage to support increased herd size and milk volumes	Minimise losses of grazing and grass silage areas, by releasing land that will support good maize dry matter yields, while minimising the potential for compaction and erosion by avoiding excessively sloping land or vulnerable soil types.	Considering timing of operations, ongoing nutrient and pesticide requirements, the timing and rates of land spreading of organic materials.

4.2.3 Present and future requirements of soil and water management.

Soil and water management is not simply about increasing food production. There is a general realisation that appropriate soil and water management can offer a range of ecosystems goods and services, which can be summarised into four broad categories of *provision*, *regulating*, *cultural* and *supporting* (Defra, 2007; Table 3). Poor soil management threatens the provision of these goods and services. The Soil Strategy for England (Defra, 2009b) lists erosion, compaction and organic matter decline as the three main threats facing soils in England, as well as identifying threats such as contamination, sealing and acidification. Godwin *et al*. (2008), suggest threats linked to drainage, run-off control, tillage, waste management and irrigation. Whilst European policy discusses additional threats including salinisation, flooding and landslides, and loss of soil biodiversity (European Commission, 2006).

Table 3: Millennium Ecosystem Assessment categories of ecosystem services and examples relating to soil and water (adapted from a table in Defra, 2007)

Category	Examples of ecosystem services provided by soil
Provisioning services i.e. products obtained from ecosystems	• Food • Fibre and fuel • Genetic resources
Regulating services i.e. benefits obtained from the regulation of ecosystem processes	• Climate regulation • Water regulation • Water purification/detoxification • Bioremediation of waste
Cultural services i.e. non-material benefits that people obtain through spiritual enrichment, cognitive development, recreation etc.	• Spiritual and religious value • Inspiration for art, folklore, architecture etc • Social relations • Aesthetic values • Cultural heritage • Recreation and ecotourism
Supporting services, necessary for the production of all other ecosystem services	• Soil formation and retention • Nutrient cycling • Primary production • Water cycling • Provision of habitat

As we move further into the 21st century, appropriate soil and water management will also have to adapt to such things as competing demands on land area, climate change and food security. Table 4 lists the most important challenges facing the farming community now and in the future and the likely significance these changes will have on soil and water management. In managing land for different purposes (food, fuel, biodiversity etc) in a highly complex landscape where natural factors such as soil types, slopes, rainfall, temperature and aspect, vary, there is no 'one solution fits all' option.

Table 4: Future demands on agriculture and implications for soil and water management

Present and future demands on agriculture	Soil and water management
Increase production	• Maintain soil fertility • Reducing the risk of erosion from intensively used land • Meeting increased demand for water
Competing demands on agricultural land	• Dealing with increased land use pressures • Providing for different land options that may require different soil and water management techniques
Higher fertiliser prices and limited supplies	• Finding methods of optimising the nutrients that are available • Preventing loss of nutrients from the land
Lower carbon footprint	• Using methods that reduce fuel consumption • Producing alternative energy e.g. wind, solar and hydro • Find ways of increasing carbon sequestration in the soil • Minimise the loss of carbon and other greenhouse gasses through better land management
Extreme weather events including: drought, intensive rainfall, higher temperatures	• Managing the land appropriately to deal with extreme events • Meeting increased demand for water • Managing pests and diseases
Food security	• Understanding how to get the best from the available land without degrading it and the wider environment (sustainable production systems and technologies)
Restrictions on availability of herbicides and pesticides	• Changes to tillage practices e.g. conservative tillage techniques may no longer be practical because of weed infestation • Managing soil structural damage and erosion that may result from increased tillage • Changes to crop rotation cycles may be needed and spatial changes in crop types may occur leading to changing risks of soil erosion

Section 4: The knowledge infrastructure for soil and water management - Key points

- The agricultural knowledge infrastructure is complex.
- Knowledge flow is multi-directional but the strength of knowledge flow between communities and agricultural sectors varies.
- Four key communities form the knowledge infrastructure:
  - Farmers and land managers who apply soil and water management to the land;
  - Advisors who are pivotal to the overall knowledge infrastructure because they assimilate information from developers and researcher and communicate with farmers and land manager;
  - Developers who translate knowledge into tools and management systems that directly benefit production and environmental performance; and
  - Researchers who provide fundamental knowledge.
- The knowledge infrastructure is influenced by external stakeholders (suppliers, purchasers and government and regulators) who influence the knowledge infrastructure by providing advisors or developers; funding and sponsorship; their own agendas; or regulation.
- Importantly education has an overarching influence on the knowledge infrastructure because it determines the ability of participants to identify, interpret, respond, communicate and take decisive action.
- There are two types of knowledge that need to be understood: systems and technology.
- Knowledge can be applied fundamentally, strategically or operationally.
- Present and future soil and water management requirements will include the provision of a range of ecosystems goods and services: provision, regulation, cultural and supportive.
- Future pressures on soil and water management will come from population and climate driven changes.

5. Project advisory group opinion on the present state of the knowledge infrastructure

The PAG was used to test the conceptual model presented in Figure 1. As representatives of the four key knowledge network communities and education they were asked to give responses that both represented their communities and their own individual experiences. The following sections summarise their opinions on knowledge generation, knowledge exchange, barriers to accessing and providing information and improvements to knowledge. Other relevant research is also discussed where appropriate.

5.1 Knowledge generation

Knowledge is generated by each community within the soil and water management knowledge infrastructure illustrated in Figure 1 (farmers / land managers, advisors, developers and researchers). Farmers develop experiential knowledge from working their land year on year and from advice passed on between generations. Advisors generate new knowledge and understanding by assimilating information fed back from farmers and combining information gained from other advisors, developers and researchers. Developers transform fundamental knowledge into applied knowledge and adapt this knowledge based on feedback from farmers and advisors. Although the ultimate source of formal fundamental knowledge is mainly from researchers, some is derived elsewhere from field observation for example.

The generation of new knowledge has many drivers. At a community level demand for new knowledge is driven by economics, legislation and societal demand. For example, farmers may need to reduce costs in order to stay profitable; advisors may need to find solutions to meet new statutory commitments; developers may develop new technology in response to a demand to reduce pollution; and researchers respond to the priorities of funding bodies and to emergent scientific opportunities.

Based on questionnaire responses from the PAG, individuals are driven to acquire knowledge by personal curiosity and self-satisfaction, particularly a desire to be able to deliver within their community effectively (e.g. farmers want to get the best from their land, advisors want to give the most up-to-date advice, developers want to be innovative, and researchers want to extend knowledge). The PAG questionnaire respondents also suggest that the need to acquire new knowledge can be driven by external demand i.e. to resolve a problem, to comply with new policies/legislation/environmental schemes, or to meet contractual obligations. To help this acquisition of knowledge the PAG questionnaire respondents suggest knowledge needs to be easily accessible, be able to demonstrate a clear potential and provide a good investment return i.e. the knowledge will save time and/or money.

5.2 Knowledge exchange

Knowledge relating to soil and water management comes from a number of different sources and in a range of different formats. The sources identified in the PAG questionnaire included: one to one conversations, leaflets, workshops, internet, courses, group discussions, demonstrations, meetings, conferences and research papers. Responses from the PAG questionnaire suggest that all communities have some degree of interaction with the other key communities with respect to knowledge transfer (see Figure 1), although the amount of interaction can vary and can be related to individual preference and/or personal contacts. The primary routes through which information is received by each community is represented in Figure 3. Farmers, advisors and developers all receive some amount of information from each community. However, the dominant source of information for researchers is from within their own community.

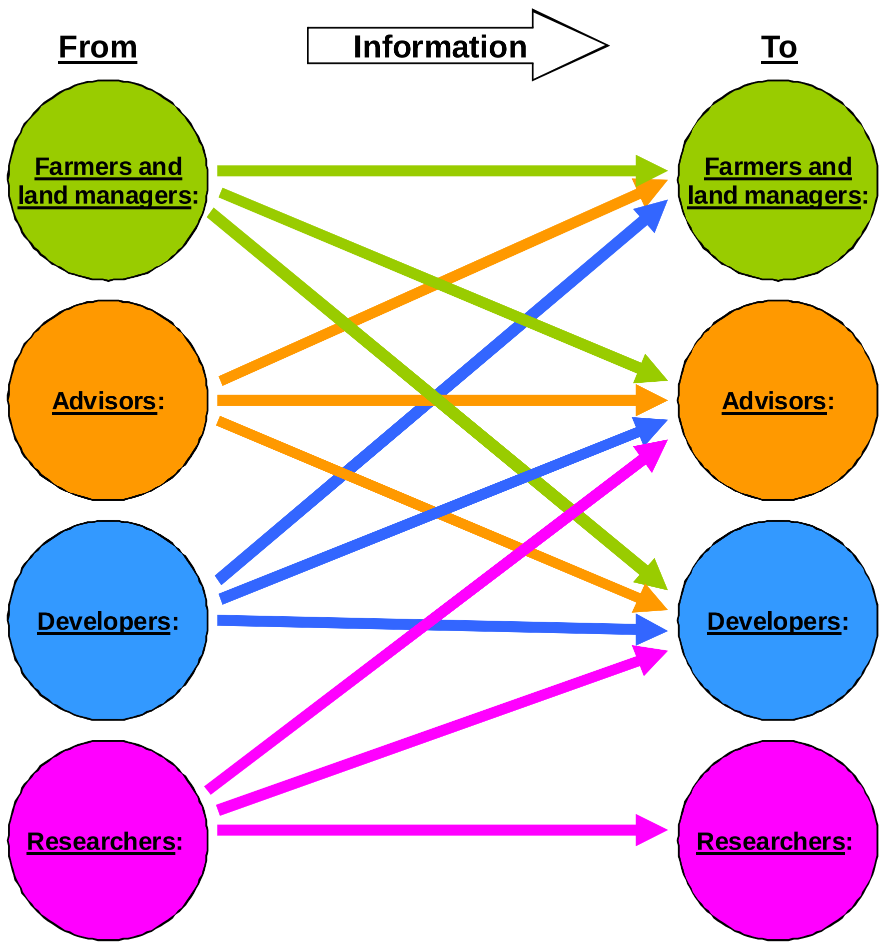

Figure 3: Primary routes of knowledge transfer from and to different communities. Based on results from the questionnaire and PAG discussions.

As providers of information, the PAG members suggest in their questionnaire responses that farmers are most likely to pass on their knowledge to other farmers/land managers; advisors were most likely to pass on their information to farmers/land managers; developers were most likely to pass their knowledge on to farmers/land managers as well as advisors and other developers; and researchers suggested that they passed their knowledge on to all communities. However, there are discrepancies between how communities think they interact with other communities and how those other communities suggest they interact, e.g. farmers/land managers, advisors and developers only reported minimal interaction with the research group yet the research group reported that they delivered information to these other communities in a number of formats (Tables 8a-e & 9a-e Appendix C). This discrepancy may be due to a number of reasons. It is possible that individuals do deliver information to a range of communities but because this is not typical of their community the general opinion of others is that this does not happen. It is also possible that a community does in fact deliver information to other communities but that the information is not understood and therefore not recognised as a transfer of knowledge, or that there are different views on whether individuals are developers or researchers. While this report identifies distinctive roles, individuals may fit into more than one classification and in some cases the difference between roles can become unclear.

According to the members of the PAG group, farmers and land managers prefer to receive information and knowledge through attending workshops, discussion groups, one to one conversations and practical demonstrations. This is supported by research carried out for Defra by Dwyer *et al*. (2007) who found that one to one farm visits were most liked and valued as they provide advice in the context of the particular farm. They also help to reach farmers who are otherwise relatively socially excluded. Supporting literature is welcomed but farmers often feel inundated by paper, so information in this format often gets overlooked. Dwyer *et al.* (2007) also reported that money spent on mailouts would be better invested in a network of advisors who would "sit down for half an hour and explain to the farmer what the environmental issues are rather than sending a leaflet that they didn't read". However, an evaluation of the England Catchment Sensitive Farming Initiative (ECSFDI) carried out in 2008 said the most useful types of support provided by the initiative were newsletters (71%) and advice visits (70%). This suggests that given constraints on time farmers may selectively choose to read literature from trusted and valued sources that they have prior knowledge of providing useful and relevant information e.g. from advice visits or demonstration events. Literature that arrives unsolicited may be given lower priority unless its design makes its value instantly recognisable, for example the Environment Agency's 'Best Farming Practices' was well received by farmers.

The farmer and land manager preferences highlighted in this report, match how advisors and demonstrators prefer to deliver information. However, researchers tend to favour using research papers and conferences to report their results as this provides scientific peer-review and is the main basis on which their performance is assessed by funders. This creates a continuing bias away from their reporting results to developers and the wider industry.

Advisors, according to PAG questionnaire responses, like to receive information through one to one conversations, small group discussions, workshops and demonstrations. This preference fits in with how farmers and developers prefer to deliver information but does not tie in with how most researchers present their results i.e. via research papers and conferences.

Developers within the PAG favour conferences, research papers and other publications (in particular good summaries in the technical farming press), technical events and using the internet. These preferences fit with how researchers like to deliver information but also correspond with the method of transferring information that farmers and advisors prefer.

Researchers within the PAG preferred to receive information through research papers and by attending conferences, which tied in partially with the developers but did not tie in with any of the other communities preferred method of knowledge transfer. However, there are exceptions to the general picture with some researchers recognising the importance of channels other than the scientific literature for communicating and acquiring knowledge. Differences in experience observed within the research group seem to relate to their personal contacts and opportunities.

5.3 Barriers to accessing and providing information

Five main barriers to accessing and providing information were considered: time, finance, understanding, mistrust, and format of information. Responses from PAG members suggest that time is the main barrier to both accessing and providing information to others (Table 16 & 17 Appendix C). The reason why time was a barrier in accessing information was put down to either too much information being available or inadequate time to sort and absorb information, ineffective search mechanisms and a lack of time to attend meetings e.g. whether farmers can get away from the farm to attend meetings, workshops and conferences.

Finance and understanding were also considered to be barriers to accessing information for all communities. Finance restricted which and how many meetings/conferences people could attend. Finance also restricted access to scientific publications for farmers, advisors and developers, as they have to pay for research papers up front that may or may not provide them with the information they are seeking.

Understanding and familiarity with processes of information collation and review appear to be a barrier in some cases; one individual reported they had no interest in learning how to use the internet although this particular issue will become increasingly rare as future generations brought up with computers become more prevalent. Other issues related to understanding were the form and language used (e.g. communities other than researchers thought the latter used a style that was awkward, not easy for them to understand, and has "too much jargon"). Some researchers reported that it was sometimes hard to understand what the farmers needs were because they (the researchers) lack mechanisms for acquiring this information. Of particular concern was a perceived lack of a formal mechanism for translating technical and scientific information into "farmer talk" and a feeling that only a relatively few researchers (and other non-farming individuals) are capable of doing this. Other recent reviews have highlighted poor mechanisms for connecting the research and farming communities e.g. Tatchell (2005); Dwyer *et al*. (2007). Although the Technology Strategy Board may help readdress this problem (see Section 7.3)

Mistrust was also reported by the PAG group as a barrier to accessing information. Advisors and developers, in particular those who had limited agricultural experience, were mistrusted by farmers - although trust could be gained once they had established a relationship.

The format of information was an issue to farmers, in particular the preference for agencies and other communities to put information on the internet. Some farmers disliked using computers, while others had no objection but only had restricted access e.g. no access to broadband. Developers found accessing scientific reports and papers was sometimes difficult because the data were of a pre-electronic age. Older research data were still considered to be of value but it was often difficult to locate these data or obtain copies.

Barriers to providing information were similar to those for acquiring information. Apart from limited time, finance was also a main barrier to providing information e.g. the cost of setting up courses or providing literature. One specific problem raised by the PAG was that people in general, as well as some farmers, did not see any financial benefit for acquiring knowledge of soil and water management, which raised the question of "why should farmers pay for this information"?

Researchers and developers reported that some farmers found it difficult to understand some of the concepts that they were trying to explain, making it difficult for advisors and developers to demonstrate the value of changes to farming systems. Palmer *et al*. (2006) also highlighted that 'the main blockage is not access to information, but rather farmer's adoption, understanding and integration of that knowledge into practice'.

5.4. Improvements to knowledge transfer

The opinion of the PAG members was that there was a vast amount of good information in existence but the mechanisms for transferring that information, both within and between key communities, were not as effective as they could be. The main points of discussion on how this could be improved included how to ease access to older data, how to speed up the process of acquiring information, and translating data into a form that could be understood by different communities and people within those communities.

The PAG members highlighted the problem of older research information and other relevant data being lost because it either pre-dated electronic data storage or it was held somewhere where others could not access it or it was lost when individuals moved on. There is therefore a perceived need to store and make accessible this type of information. There are currently some such archives that do this e.g. World Soil Survey Archive and Catalogue (WOSSAC), but they need to be more widely promoted as not all communities know that these facilities exist.

While some individuals do not favour the over reliance on electronic information transfer, this tends to be related to age. Older generations who grew up without computers have a tendency to be the group that favours computers least. However, future generations to whom computer use is second nature will be more receptive to electronic knowledge provision. How this knowledge is organised is critical to the success of knowledge transfer via this pathway. In the opinion of the PAG members a more centrally organised data repository is needed in order to reduce the time spent "hunting" for information i.e. a "one stop shop". Given the potentially vast repository this would generate, it would be crucial to have clear signposting within such a site that would guide different communities to relevant information.

Currently knowledge transfer is perceived to occur on an *ad hoc* basis driven mainly by market forces that mix communication of good practice and innovation with commercial priorities. Due to the complexity, environmental impact, educational requirements and national interest the PAG group felt that there was value in an independent group to whom all key communities had access (i.e. both receive and feed back information and advice). Importantly this group could be led by industry and take responsibility for the translation of information e.g. research findings into practical solutions for the farming system. Such a group could provide the missing linchpin that would ensure all key communities are linked up and that knowledge flows not just in one direction but in all directions e.g. knowledge exchange rather than knowledge transfer (Blackstock *et al*., 2009).

Section 5: Project advisory group opinion on the present state of the knowledge infrastructure – Key points

- Knowledge is generated by each community.
- Main drivers for new knowledge include economics, legislation and social demand.
- Individuals acquire knowledge for individual purposes e.g. self-satisfaction or external demand e.g. new policies/legislation/environment schemes.
- Knowledge must be easily accessible, be able to demonstrate a clear potential and provide a good investment return.
- Knowledge transfer by one-to-one conversations, discussion groups, workshops and demonstrations are favoured by farmers/land managers, advisors and developers, however, researchers favour scientific publications and conferences.
- Barriers to accessing and providing information include time; finance; understanding and trust; and format of information.
- There is a need for a centrally organised data repository to preserve data and allow greater freedom of access to the data for all communities.
- Currently knowledge transfer is perceived to occur on an *ad hoc* basis driven mainly by market forces that mix communication of good practice and innovation with commercial priorities.
- Due to the complexity, environmental impact, educational requirements and national interest it is felt that there would be value in an independent group who could help knowledge exchange by linking up all interested parties.

6. Gaps and weaknesses in the knowledge infrastructure

Figure 1 shows the direction and strength of knowledge flow through the knowledge infrastructure. The larger arrows show a high level of knowledge transfer and are the dominant methods of knowledge transfer in the present infrastructure. Smaller arrows with a dashed line represent areas of knowledge transfer that are presently weak. This weakness implies either fewer participants are involved and/or not all agricultural sectors experience the same level of participation. This section considers the fragility of parts of the present knowledge infrastructure.

6.1 Gaps and weaknesses in knowledge

Soil and water resources vary a lot within and between farms, with different soil resources, climatic regimes and markets supporting different types of production. Moreover, the soil and water knowledge requirements (both about soil systems and technology options) are quite specific to the type of production. This argues for channelling knowledge exchange between farmers-advisors-developers-researchers through production sectors. The knowledge requirements for arable farmers, vegetable and potato growers, livestock farmers, pig and poultry producers and wildlife managers appear to have some commonality but are distinct. They involve different types of equipment often deployed in landscapes where the soil types, topography and climates are not similar. At the industry level, improved soil and water management depends on widespread adoption of best practice that is continually enhanced through innovation. This will depend on strong research and development communities disseminating up-to-date knowledge about the performance of different systems and the novel options emerging for specific types of production. This information should be provided to advisors who in turn provide this to farmers.

Although a number of farmers and land managers will have some or all of the knowledge about soil and water management needed to make strategic decisions about product and production system choices, many will not and will require input from advisors. The effectiveness of the advice given depends on the advisor being able to:

i) gather and interpret information about the potential of available soil and water resources, and then
ii) identify and assess production options that are capable of using these resources to deliver optimal productivity and environmental performance.

It is also essential that advisors are capable of communicating this information effectively to farmers and land managers, and that their advice is trusted. Blackstock *et al*. (2009) stress the importance of contact from a trusted source for achieving behavioural change. In general, the higher the credibility of the source, the higher is the persuasion factor.

Results from a questionnaire survey by Ingram and Morris (2007) indicate that different types of advisors hold different forms of knowledge to varying degrees. Experiential knowledge is critical; Ingram and Morris

(2007) report how appreciative some farmers are of the length of time served as an advisor, and the breadth and range of knowledge accrued. Although some advisors come from a farming background, many have had few opportunities during their training and education to link scientific understanding to practical farming. This was not always the case; for example, graduates recruited by MAFF advisory services up to the 1980s served a postgraduate professional 'apprenticeship' in which practical skills were developed by shadowing front-line advisors and attending farm-oriented courses. While the industry has changed over subsequent decades, the need to understand the farming system and how productivity and environmental requirements can be sustainably incorporated into such a system still requires a holistic understanding of the industry.

Farmers' criticism of many advisors and developers for having limited practical agricultural experience appears justified, as without at least an appreciation of the practical requirements and limitations that farmers face, advice is likely to be less relevant and effective. However, there are few facilities and no formal structure for developing this knowledge base. Its re-introduction in one form or another would be constructive to building farmer confidence in advisors based on their increased effectiveness. Ingram and Morris (2007) identified the value of joint-learning to increase competencies across the sector through farmer-advisor interactions. The interactions that are based on trust, credibility, empathy and consultation can provide a more effective context for knowledge exchange, and more of these exchanges need to be fostered (Ingram, 2008).

Under the MAFF (ADAS) advisory service, advisors demonstrated consistently high levels of factual knowledge and understanding about soils (Ingram and Morris, 2007). Comments from the PAG suggest that despite demonstrating a high level of concern for soil conservation, some advisors now feel ill-equipped and unqualified to provide detailed soil management advice because they have had little or no formal training or experience in it. These thoughts agree with the results presented by Ingram and Morris (2007) who suggest that advisors still regard soil management as peripheral to their job specifications. In that paper, one advisor was quoted as saying "Personally I feel unqualified to provide detailed soil management advice. Most FWAG[12], RDS[13] and other advisors I believe are in the same position".

A similar scenario also exists for researchers. While effective scientific researchers are being produced, few of these have a strong appreciation of practical agriculture. This can lead to incompatibility between research outputs and farming needs. Also, there appear to be few mechanisms by which farmers and land managers can feed back information to influence new research towards solving problems that they have identified.

To support ongoing operational decisions about soil and water management, the farmer or land manager requires a level of knowledge

[12] Farming and Wildlife Advisory Group
[13] Rural Development Service (now part of Natural England)

that may be roughly equated with that in the Codes of Good Agricultural Practice. However, innovation, which is underpinned by science, to optimise yield and environmental performance requires additional knowledge, particularly about equipment operation and performance and the efficacy of different types of intervention depending on soil types and weather conditions. It is unclear how many farmers have sufficient technical understanding to support such innovation. Therefore operational knowledge (to support on-farm resource protection and production outcomes) needs to be integrated into structured decision tools customised to production types. The tools may be highly sophisticated (e.g. automated devices used within precision arable farming) or more basic (e.g. 'look-up' tables). In any case, there is a requirement for collating and presenting up-to-date information about soil and water status, trends and performance in the context of specific production systems, in ways that are readily accessible to farmers. Some good examples exist already (e.g. newsletters and advice sheets developed by the levy boards) but there is a need for a concerted approach with overall impact in place of scattered offerings.

6.2 Knowledge provision

6.2.1 Economic constraints

It is notable that some highly dynamic research topics (e.g. soil biology) appear to be hardly exploited by developers and largely unknown to advisors, while others (e.g. soil carbon) are known but have not led to substantial innovation in agricultural systems. For example, '*Profiting from soil organic matter*' (a guide produced by GYA, 2008) gives an assessment of the costs and benefits (in terms of improving soil organic matter) of good soil management practices from a wide range of farm case studies, but to date there is little evidence that developers are exploiting opportunities for innovative technology to manage soil organic carbon. This is also reflected by the equipment, chemical and other suppliers who have well-organised support for their products but generally soil and water management *per se* is a secondary priority, compared for example to work rates for machines or application timing for chemicals. In the livestock sector, soil and water management appears to be a very poor relation to animal health and nutrition, despite its importance to overall farm sustainability. This is because the economic value of soil and water management is obscured. Therefore, in most instances there is little economic incentive to encourage either developers to focus on these issues as a priority or for farmers and advisors to seek new techniques from developers. In order for this to happen a catalyst is required, such as a response to an external pressure (e.g. food shortages), increased pressures from stakeholders or evidence of value.

Information about the value of enhanced soil and water management to gross margins is scarce. Although the importance of understanding costs and benefits of mitigation measures is growing. Defra has recently commissioned studies on this including 'Soil functions, quality and degradation - studies in support of the implementation of Soil Policy'

(SP1601) and 'The total cost of soil degradation in England and Wales' (SP1606). While some values are quoted, such as those in the Soil Strategy for the total cost of degradation (£45 million per annum) these values are arrived at by making assumptions based on available data which is at present limited and therefore can not confidently be applied across different landscapes. GYA's 2008 guide shows through a wide range of farm case studies that improving SOM management can produce net benefits between £30 and £65/ha annually depending on the farming system, and that these benefits can be realised in as little as 2-5 years. Other mitigation measures such as reducing artificial fertiliser use by better monitoring of soil nutrient values and applying and valuing free resources (such as manure and slurry) also clearly have on-farm cost savings.

The economic advantage to farmers of optimum soil and water management has to be explicit to justify them paying for professional advice, unless they are subsidised to carry out soil and water management practices through incentives such as Environmental Stewardship or to meet more stringent legislative requirements. The value of altered practices will necessarily vary between sectors and associated production systems; a sector by sector economic justification for improved soil and water management is therefore essential in order to understand if management methods are economically sustainable within the farming system or whether supporting subsidies will be essential in order to achieve sustainability in an integrated farming system.

6.2.2 Knowledge transfer

National researchers are part of a global community and are critical both for the knowledge they create and to report global developments to developers. Their current connectivity to developers appears weak based on PAG responses, with a lack of knowledge exchanges both from the developers as well as from the research community. Dwyer *et al.* (2007) discuss the loss of extension and integration within the 'Agricultural Knowledge and Information System' in England and discuss recent reviews that highlight the poor mechanisms for connecting the research and farming communities (e.g. Tatchell, 2005). Blackstock *et al*. (2009) however, report that the relationship between farmers and scientific experts is beginning to shift from knowledge transfer to knowledge exchange, and that this has implications for how science will be conducted and communicated. Examples such as decision support tools for diffuse pollution (McIntosh *et al*., 2007) are responding to demands from stakeholders, including farmers to exchange knowledge in ways more suited to the end user's needs.

There appears to be a definite need for one or more national experimental and demonstration facilities to focus and support technological innovation in soil and water management. This would provide a much-needed focus for knowledge exchange between developers and with the researchers and advisors. It could also provide support to a continuing industry tradition of entrepreneurial innovation by isolated individuals who lack a supporting and connecting infrastructure. Such facilities are needed to provide developers and advisors with access to infrastructure for trials and demonstration where farmers can be shown new techniques and technology. Demonstrations were highly rated by farmers, developers and advisors in the PAG group as mechanisms of communication. Dwyer *et al*. (2007) also reported that demonstration farms are valued because they provide evidence of the suitability of new technology and they offer the opportunities to interact with other farmers.

Although research and development is often conducted successfully on working farms, research farms are important for long term trials that are often needed to prove the benefits of soil and water management. Over the last 20 years there has been a decline in the number of experimental research farms, including the closure of Seale-Hayne (University of Plymouth) and some ADAS facilities. These farms have a strong role in collating and disseminating information to all communities in the knowledge exchange infrastructure. This is important because at present information access and storage is considered by many to be scattered and poorly structured, for example, no open-access advisor-orientated (i.e. specialist) information source on soil and water management has been identified. This gap could be filled by a virtual information repository, with access to up-to-date information on advances in soil science, new technology options, farm-scale soil information and updates on environmental and other regulations.

PAG members also raised concerns over the lack of awareness of completed research, a point also raised by Palmer *et al.* (2006), and the lack of feedback mechanisms for farmers and land managers to discuss their needs with the research community. Martindale (2003) stated that 'engaging stakeholders in extension and research is essential' and discussed the fact that knowledge and information held by farmers and producers needs to be utilised in conjunction with research. The Audit of UK Soil Research (Defra, 2003) also raised the issue that 'single projects rarely produce results that are of practical value'. Results of research need to be interpreted and integrated for a particular user or user group before they are useful. But this raises the question of who is prepared to fund such an activity.

Many researchers also find it difficult to convey their research to farmers in a way that is easily accessible and understood. The Audit of UK Soil Research (Defra, 2003) highlighted the loss of the MAFF state advisory service, ADAS, and suggested that effective adoption of research based solutions will not be achieved without the contribution of a consultant who is experienced in both the particular aspect of research and the particular farming system, which in this report corresponds to a developer or higher-level advisor. This concern was also prevalent amongst PAG members in this study. It is possible that the Technology Strategy Board (see Section 7.3) will help to readdress this.

Closer connectivity with educators would also be beneficial, with better knowledge exchange between institutions (Further Education (FE) ↔

Higher Education (HE) ↔ researchers) to support state-of-the-art course content.

6.2.3 Fundamental knowledge

An audit of UK soil research (Defra 2003) noted that most soil research is conducted within projects that are not soil-specific and this observation is probably still valid since many recent and continuing projects that include soil and water management primarily address water and biodiversity issues. It concluded on the basis of a bibliometric analysis that UK soil research compared well with that within other developed countries and that total funding was fairly constant at about £30millions[14] per annum. At the time of the audit (2003), the authors held the overall view that it was 'a time of great opportunity and challenge for soil research, both in the sense of increasing fundamental knowledge of natural systems and of tackling some of the big contemporary environmental issues of climate change, pollution and remediation and sustainable land management.' They drew attention to important opportunities for 'marrying soil science and soil biology' and for 'the development of remote sensing and *in-situ* sensor techniques to enable the prediction of the soil behaviour at the catchment and national level.' A main concern was that the capacity for soil research might deteriorate due to a lack of soil science as a scientific discipline in UK universities, leading to a shortage of new researchers.

Since 2003 there has been some consolidation of research institutions: BBSRC closed its Silsoe Research Institute, but transferred most of its soil science capabilities to Rothamsted Research, which the North Wyke Research Station also joined to support a Cross-Institute programme with the potential to achieve economies of scale and scope. Both Cranfield University (incorporating the relocated Silsoe College, formerly the National College of Agricultural Engineering) and Harper Adams University College have made significant investments in land engineering research capabilities. Even so, the general situation in 2010 appears little changed since 2003, with major opportunities not being exploited effectively. In the intervening years, funding for soils research has probably remained fairly constant while the research has progressed, much of it within environmental rather than production-oriented projects. However, few 'breakthrough' outcomes for production have arisen from recent research, i.e. only a small proportion of research goes on to be adapted for practical on-farm application. Work has been done using molecular tools to explore soil biological systems without as yet providing a breakthrough development for agricultural production or environmental management. The work on the use of remote sensing techniques for crop and soil management that was completed prior to 2003 has been exploited (for example by Soyl Ltd) but little new work has been funded or reported in England.

Attempts to secure BBSRC funding for Masters level soil science training (for example at Cranfield) have not been successful, ironically due to a

[14] This includes all research including experimental research which we have identified as being done mainly by 'developers' rather than 'researchers'.

lack of BBSRC research grants in soil science. And although the results of the 2008 Research Assessment Exercise (as well as the continuing high esteem of UK research institutes) indicates that the number and quality of published outputs continues to match that of other developed countries, there is an apparent lack of innovation flowing from soil research to English agriculture. One possible reason may be a lack of industry demand and leadership (the total industry funding for soil science is estimated to be no more than £2millions a year or less than 10 percent of overall funding). The Technology Strategy Board research programme on crop protection includes some soil-related projects, although none that deal directly with soil and water management. Another factor may be a lower prioritisation of research targeting production outcomes by the Research Councils and other funders. Greater integration of production and environmental research could be helpful. The Soil Science Advisory Committee and others have tried hard (but unsuccessfully) to secure a targeted soils Research Council programme - those projects that are funded by BBSRC and others tend to lack focus on soil as a resource for production. Lastly, soil researchers have failed to deliver sufficiently convincing proposals to secure growth in their share of available funding, notwithstanding that the competition for this money is intense and a success rate of 20% or less is to be expected. In this study a further problem has been identified based on PAG feedback, namely a lack of connection between researchers and developers, and also advisors, suggesting that the researchers are less likely to appreciate the importance of their research to practical problems in the industry.

The current UK research capability in relation to soil and water management is portrayed in Table 5. The emphasis on environmentally oriented soil research noted in 2003 (Defra, 2003) has continued, with the result that research capabilities are generally stronger for this than for production oriented research. The importance of plant sciences and ecology to overall soil research capability arises from the fact that soil is predominantly regarded as a medium for plant growth.

The discussion above strongly suggests that there is a need for a strategic programme for soil research, jointly-owned by the agricultural industry, the Research Councils and Government, to secure a step change in research direction towards supporting future increased industry performance, including production as well as other ecosystems goods and services. At present there appears to be a lack of the shared vision and governance of research that is needed to ensure soil research underpins future sustainability within the industry. Unless this problem is addressed there is a danger that the rationale for soil research will not be appreciated and current funding will decline leading to a strategic gap in England's capabilities.

Table 5: Estimated stages of development of research capabilities related to the soil-plant system within selected UK institutions

	Production orientation			Environmental orientation		
	Soil Systems	Plant Sciences / Ecology	Land and Water Engineering	Soil Systems	Plant Sciences / Ecology	Land and Water Engineering
Universities						
Aberdeen	**	**		***	**	
Cranfield	**	**	***	***	**	***
Harper Adams	*	**	*	*	**	**
Newcastle	**	**		***	***	
Nottingham	*	***	*	*	***	*
Reading	**	***		***	***	
Lancaster	*	**	*	***	***	*
Institutes						
CEH				***	***	
Macaulay	**	***		***	***	
Rothamsted	***	***	*	***	***	
SCRI	***	***		***	***	
ADAS	***	***	**	**	**	**

Key: absent; * present; ** developed; *** mature

6.3. Understanding knowledge and educational provision

Education establishes the framework upon which subsequent knowledge and understanding are built, be it better advice on preventing soil erosion or incorporating the best management systems into a farming system. Therefore a lack of understanding due to an insufficient educational background can have severe consequences for soil and water management.

Good education and training frameworks are an essential central component of sustainable development (Martindale, 2003). An audit of soils education and awareness found that there was a wealth of soil-related information and services available for those who looked for them, but that this information was often hard to find and difficult to interpret (Defra, 2005). Within the school education system (Key Stages 1-5), the audit focussed on soil within Science and Geography and found that it only receives a cursory mention in the existing National Curriculum. The functions of soil need to be more fully understood at this early stage, as current approaches are piecemeal and only covered briefly with topics such as soil erosion and flooding. The importance of soil functional capability and the impacts of soil degradation, and what that means to the socio-economics of different countries, need to be made part of the national curriculum in order to make it more relevant to school children. Teachers are under increasing pressure to stick to the curriculum to achieve the attainment levels sought for their pupils, and as a result, teachers who might wish to bring soil science and soil issues into the classroom are given little incentive. There needs to be a strong overall assessment of how soil and water management can become part of the core curriculum as well as to the degree of support required to bring this about. The new Diploma in Environmental and Land-based Studies (ELBS) may go some way to rectifying this situation for children aged 14+[15], however the detail of soil and water management education within this diploma is unclear.

For higher and further education, some indicative numbers of people participating at different levels of soil and water science and engineering in England are that: at NVQ level, current student numbers are estimated to be between 1000 and 2000; at Bachelors degree level, the participation with some coverage of soil and water management is estimated to be within the hundreds, while numbers of Masters students are estimated to be within the tens, albeit directed mostly at environmental rather than agricultural science. The number of UK students completing a doctorate in soil and water management is fewer than 10 a year. While these numbers are possibly adequate, a major issue is whether the students obtain the educational content needed to meet current and future national requirements of soil and water management. The table in Appendix D provides a list of the types of courses that are presently available. However, it is not within the remit of this report to analyse individual courses for their specific content of soil and water management education.

6.3.1 Farmers and land managers

At the farm level, knowledge is required that covers the underlying principles of soil and water management. The knowledge base of farmers and land managers tends to be broad with a depth of knowledge based on experience. Experiential knowledge of individual farms is important for effective land management. Educational requirements include the need to develop a wide knowledge base that leads to an understanding of the key processes and also an ability to transform that knowledge into practical applications within a particular farming system. Education therefore needs to provide for the practical application of scientific knowledge.

The educational background of farmers in England ranges from no formal education after 16 years of age/self learning (including cross-generational knowledge transfer) through first-degree to Masters (MSc) and Doctoral research (PhD), obviously in descending order of prevalence as only a very few farmers have postgraduate qualifications. Education determines in part the ease of acceptance of new advice, techniques and technology, and farmers with a more fundamental understanding of the soil and water

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[15] ELBS is part of a range of new qualifications in England, aimed at young people aged between 14 and 19 years, which provides them with practical skills, knowledge and understanding related to one of fourteen different sectors, combined with functional skills in English, maths and ICT.

system are more likely to be innovators and/or early adopters. A lack of understanding can lead to mistrust and therefore late adoption of new techniques or even refusal to adapt by traditionalists. Also, traditional methods of land management are hard to change because of social pressure from previous generations to maintain the *status quo* unless the next generation of farmers has sufficient confidence, based on knowledge and understanding, to augment change.

The move away from support for production-led agriculture has also impacted agricultural education. The results from the PAG questionnaire highlight the fact that with regard to soil and water management, there is no clearly defined educational pathway for the farming sector. There has been a marked decline in agricultural science and engineering degree provision over the past decade or more. For example, Wye College, University of London, has closed while Cranfield University (Silsoe College) ended its provision of undergraduate courses. This decline has resulted from a range of factors including a lack of perceived graduate career opportunities for developers and specialist advisors in UK agriculture. However, research funding also has a knock-on effect as it influences the skills and expertise of lecturing staff and ultimately the type of course that is taught. Demands on the farming sector continue to change and evolve, however, and the general opinion of the farmers in the PAG is that it is very important to have a clearly defined educational pathway, that includes potential career opportunities, to support effective soil and water management in the future.

For new-entrant farmers, it appears that the current education on soil and water management has several limitations. It is reported by educationalists on the PAG (n = 5) that a very limited amount of time is spent teaching soil and water science within agriculture programmes at FE and HE levels. Students may only spend a few hours of a whole course on this topic. Moreover the available resources limit the amount of practical application that can be taught.

Feedback from the PAG members identified structural weaknesses in the delivery of soil and water management education at HE and FE levels, specifically: a lack of connectivity to research and new developments (due to a lack of inputs from the research community); insufficient foundation knowledge e.g. obtained at school level, hindering later higher level development; and, the introduction of modular courses creating knowledge gaps because course selection is based on personal interest rather than a structured range of knowledge. These reported limitations suggest that new-entrant farmers are only receiving a basic and probably inadequate formal education in soil and water management, only gaining a simple technical knowledge that allows them to recognise terms and basic principles but does not equip them to make optimal operational decisions about soil and water management, much less strategic decisions.

Apart from formal education, farmers also participate in continuing professional development. This often takes the form of discussion groups (e.g. Rural Knowledge Hubs) or local soils groups, or workshops run by organisations such as the Farming and Wildlife Advisory Group (FWAG) and the England Catchment Sensitive Farming Delivery Initiative (ECSFDI), or demonstration events run by developers (e.g. Masstock) and advisors (such as Kingshay), as well as training and demonstration events held by a wide range of levy boards and trusts (such as the Game and Wildlife Conservation Trust's Allerton Project). However, participation is voluntary. According to the PAG group those who attend such events do so out of personal curiosity often developed by a higher level of appreciation of the need to understand new developments. Dwyer *et al*. (2007) also report that discussion groups are often highly valued by farmers, but the benefits may be limited to progressive farmers only. Others may be tempted in with the offer of a reward e.g. help with form filling or a free soil test (ECSFDI Technical Team 2008).

6.3.2 Advisors

Advisors tend to have progressed through formal education obtaining degrees and higher degrees in particular at the Masters level, although some also continue on to Doctoral studies. This provides an essential level of fundamental understanding. Continuing professional development also plays a role in their education and may include working towards professional chartered status (e.g. Institute of Professional Soil Scientists (IPSS)) and attending training courses organised by the companies they work for or provided externally (e.g. BASIS).

The results from the project questionnaire showed that advisors within the PAG were divided as to how well defined the educational pathway was for their community, but all agreed that a clearly defined educational pathway was important to ensure that in the future those advisors delivering soil and water management advice hold qualifications in soil and water management.

Currently the formal requirements to become an advisor are unspecified and the general quality of the advice given on soil and water management by advisors is unknown. Unless it is well-defined and justified in terms of gross margin improvement, advice may, in some cases, be ignored by farmers. The above argues for a form of professional standard and accreditation, possibly based in part on completion of BASIS and FACTS or similar courses, for soil and water management advisors – recognisable and valued by farmers and other stakeholders (e.g. Government, suppliers and retailers). Such courses require careful regulation themselves to ensure quality. There is also a need for a mechanism to ensure new, proven, scientific advice is incorporated as quickly as possible into relevant courses.

A concern is that very few soil and water science specialists with agricultural training, as distinct from environmental science, are graduating and the opportunities for their professional development as advisors appear limited (there is no existing formal route). Ideally, good quality science graduates need to be taken through a combination of postgraduate training in soil and water management alongside or followed by immersion in practical agriculture. Only by doing this will advisors have a sufficiently robust approach that will enable them to give relevant and practical advice that will support sustainable agriculture. The provision of education for advisors is discussed under 'Developers' (Section 6.3.3).

6.3.3 Developers

Developers need specialised as well as fundamental knowledge as is gained at Master and Doctorate level. The nature of their work demands an advanced understanding of the underlying science to support its conversion into practical applications and advice. Continuing professional development takes the form of professional chartered status, conferences, workshops, seminars, BASIS training courses and membership of organisations e.g. British Society of Soil Science (BSSS), IPSS, or Institute of Agricultural Engineers.

When completing the questionnaire, developers from the PAG felt there was no clearly defined educational pathway for their community. Whilst most agreed that a clearly defined educational pathway is important to encourage and prepare new-entrant developers, this was not considered absolutely necessary, since experience shows that many successful developers have specialised in soil and water management after graduating in the natural sciences or engineering disciplines.

If a healthy and well-qualified cadre of advisors and developers is to exist, investment appears essential in more agriculturally-orientated degree courses and support for their students. Feedback from the PAG members suggests that there is no obvious education pathway towards specialisation in soil and water management, especially with an agricultural application. This can be linked to decisions by higher education establishments that occurred two decades ago when the profile of agricultural soil science declined somewhat, due in part to the privatisation of near market research and development and advice. This led to the closure of undergraduate soil science degree courses in agriculture faculties. Furthermore, the existing postgraduate courses (for example at Cranfield and Reading Universities) are more oriented towards environmental than agricultural science, in line with current career opportunities.

However, increasing concerns over national and international food security (The Royal Society, 2009; World Food Program, 2009) and sustainable management of our natural resources will drive change that will demand a higher level of production based knowledge. Leaver (2010) states, "UK agriculture can and should increase its contribution to the food supply not only to meet the rising global requirement for food, but also to meet the rising demand for food in the UK" In order to support this knowledge, the continuing absence of soil science courses at undergraduate level is of concern, but the lack of well-funded and supported postgraduate soil and water management courses with an agricultural orientation is particularly concerning. Appendix D lists current UK courses that cover soil and water management, however, very few of these courses take a holistic view of soil and water management and still teach them as separate disciplines. What is required is for soil and water management to be taught as a single integrated subject.

6.3.4 Researchers

Effective research requires people with advanced knowledge and fluency in research methods as provided by postgraduate research training at Master or more normally Doctorate level, often followed by supervised post-doctoral research.

The project questionnaire results show that research group members of the PAG (n = 5) feel there is no clear educational pathway and most accredited their achievements to opportunities that had opened up to them in an unplanned fashion, as they progressed through the formal educational system. The PAG members felt that a clearly defined educational pathway (or choice of pathways) would be beneficial to the soil and water research community and encourage new-entrants. A clear progression pathway was also felt by some to be helpful in presenting soil and water management as an 'attractive' research career choice. The PAG members considered it less essential for researchers to have a formal education in soil science. They felt that a sound scientific foundation in other science disciplines such as chemistry, biology, physics, geography and maths were appropriate backgrounds.

The capacity for educating researchers appears to exist but is under-exploited (see Appendix D). A steady flow of potential researchers are recruited by research institutes and universities and obtain doctorates in soil and water management. Significantly, however, many of these researchers are recruited from outside the UK and do not remain in this country.

6.3.5 Opportunities for improved formal soil and water education

Members of the PAG were asked to suggest potential improvements to the provision of formal education in soil and water management. The suggestions are given in Table 6.

Table 6: PAG views on improving soil and water education in England

PAG views
• Raising the awareness of and interest in soil science and agriculture at all levels, by maintaining it as a compulsory part of the curriculum • Increasing soil education provision at all levels with greater availability of courses and a higher proportion of these courses allocated to soil and water management • Better promotion of those soil and water management courses that exist currently • Increasing the practical element in all courses, particularly at foundation levels, so that all students have an opportunity to gain practical experience • Increasing the potential for industrial placements as a way of gaining practical experience • Redeveloping / re-investing in colleges and university courses that focus on soil and water management in its own right rather than within modular options within non-soil and water management courses • Ensuring that all agricultural courses have a compulsory soil and water management content • Demonstrating the need for appropriate training and professional development within the industry, for example better training on soils, water and agriculture for all advisors working in government agencies (NE, EA) who advise farmers.

Section 6: Gaps and weaknesses in the knowledge infrastructure – Key points

- Knowledge exchange needs to be channelled through production sectors.
- The effectiveness of the advice given depends on the advisor being able to assimilate information about soil and water management and then correctly identify opportunities to deliver optimal productivity and environmental performance.
- Trust in the advice given is imperative and this relates to both knowledge of the topic and understanding of the agricultural system.
- A holistic understanding of the farming industry is needed to enable productivity and environmental requirements to be successfully integrated.
- Better feedback mechanisms are required between the farming community and both research and development.
- The economic value of soil and water management is presently largely unknown and poorly communicated; therefore there is little economic incentive for any of the key communities to invest time or money in this area.
- The economic data we currently do have is limited and therefore difficult to apply across different landscapes or between different sectors.
- The economic advantage to farmers of optimum soil and water management has to be explicit to justify them paying for professional advice.
- New methods of exchanging knowledge in ways more suited to the end user's needs are required e.g. demonstrations.
- The effective adoption of research based solutions will not be achieved without the contribution of a consultant who is experienced in both the particular aspect of research and the particular farming system.
- Better knowledge exchange is needed to support delivery of higher levels of innovation from soil and water research.
- There is a need for a strategic programme for soil and water research, jointly-owned by the industry, the Research Councils and Government, to secure a step-change in research direction to supporting future increased industry performance.
- New-entrant farmers are only receiving a basic and probably inadequate formal education in soil and water management. Soil and water management should be taught as a single integrated subject.
- There are presently few soil and water science specialists with adequate agricultural training. This partly reflects the absence of undergraduate and post graduate courses with an agricultural bias.
- A steady flow of potential researchers are recruited by research institutes and universities and obtain doctorates in soil and water management. Significantly, however, many of these researchers are recruited from outside the UK and do not remain in this country.

7. Future opportunities and capabilities

The present state of soil and water management knowledge transfer in England presents a range of important opportunities. If taken up, these opportunities will ensure that the existing knowledge infrastructure is maintained and supports the industry to become more innovative in soil and water management, so that it is able to meet the simultaneous challenges of increasing yields and environmental performance.

7.1. Sustaining and improving the existing knowledge infrastructure

Better use should be made of information that already exists. More effective archiving and access of research data, reports, advice documents etc., is needed. Good examples of how this can work are the Institution for Agricultural Engineers and the Royal Agricultural Society of England making available, via their web sites, back copies of the Journal of the Soil and Water Management Association (1977 to 1986) and Cranfield University enabling access to the World Soil Survey Archive and Catalogue (WOSSAC). Ideally this information would be held in, or made available through, a centrally accessible data base, such as a virtual knowledge hub. In the future this may include a virtual world where individuals can meet and discuss issues with others without the need to travel. Importantly any such centralisation of information would require a clearly signposted access system so that individuals can find the information they want quickly and efficiently, but where they can also find supporting advice. This is viewed as a resource for all communities therefore the information needs to be held in a variety of formats that are appropriate for individual requirements i.e. tailored to their needs.

In many sectors, including agriculture, practical demonstration of new technology and techniques is an effective means of promoting its uptake. As well as demonstration it provides an opportunity for an exchange of knowledge and views between farmers and experts (advisers and developers). Clearly technical events, such as Grassland and Muck and AgriLIVE Smithfield, demonstration events hosted by companies (e.g. Syngenta) and advisors (e.g. ECSFDI and FWAG), as well as agricultural shows, continue to offer a valuable opportunity for all key communities in the knowledge exchange network to integrate and exchange ideas and opinions.

The decline in independent advice is seen as a major threat to sustainable soil and water management in England. The England Catchment Sensitive Farming Delivery Initiative has employed Catchment Sensitive Farming Officers (CSFO) in each priority catchment and developed a good working relationship with the majority of farmers in the 50 priority catchment areas in England. In a review of the initiative, Critchlow (2007) stated that the CSFO was the single most important factor in determining the extent of farmer engagement within the catchment. The scheme has actively encouraged farmers to adopt new management practices, through discussion, attend workshops and taking advantage of grant schemes to help pay for infrastructure around the farm that will reduce runoff and contaminant transfer to local watercourses. Independent advice is not widely available in England. The opportunity offered here is to extend this scheme, or something similar, across England. So instead of farmers having to be self-sufficient in finding information, advice is brought to them with its benefits clearly demonstrated.

There is a wealth of scientific knowledge about soil and water management already available but this appears under-exploited in agriculture because its economic value is unknown. PAG representatives from all key communities suggested that the value of soil and water management should be made explicit in order to encourage farmers to change their management practices and increase their desire to learn more about soil and water management. To take advantage of this, more opportunities need to be made available to promote the transfer of research information into practical applications that can then be assessed in terms of economic and environmental benefits. Some such pathways do exist already e.g. LEAF, Knowledge Transfer Partnerships (KTPs), Rural Economy and Land Use (RELU) and Living with Environmental Change (LWEC). In particular RELU offers a good example of knowledge exchange in rural communities. Both RELU and LWEC aim to connect researchers with business and policy makers, though as yet neither RELU nor LWEC have had any significant involvement with soil related issues. The Soil Management Initiative (SMI) also represents a good example of an attempt to bring together and disseminate information relating to soil and water management, between researchers, developers, advisors, farmers/land managers and stakeholders. However, SMI has not proved sustainable because of the lack of continued public support. Therefore, it is important to learn from the mistakes of the past to better understand why soil has not been an integral part of some of these knowledge exchange initiatives in the past and when it has e.g. SMI, why public support has been lost and importantly how in the future it can be sustained. However, research also needs to place more value on this type of partnership, which requires Research Councils and other funding bodies, and educational quality indicators to incentivise it.

7.2. Opportunities to meet future challenges

Soil used for agriculture is a finite, resilient, non-renewable resource that requires careful management. To meet future challenges (detailed in Table 7) and sustain a healthy agricultural industry, new and more sophisticated technology is needed, which future farming generations will have to embrace. Education is the key to providing the knowledge base needed by farmers to utilise new technology so that soil and water management delivers higher productivity and environmental performance needed to achieve 'sustainable intensification' (The Royal Society, 2009). FE and HE providers need to be preparing now for such future provision – today's students are the next decades' farmers and land managers. The value of education and the provision of soil and water management within agricultural education need to be strongly promoted and supported.

Table 7: Research and development needed to meet future demands on farming

Demands on farming / Future Challenges

- Increased productivity and product quality
- Higher energy prices
- Restricted choice and application of pesticides
- Competing demands for agricultural land
- Higher fertiliser prices and restricted supplies
- Tighter controls on nutrient additions
- Lower carbon foot print and reducing greenhouse gas emissions
- Changing weather patterns and extreme events; to include wetter winters, drier summers, more intense storms
- Pollution impacts on agriculture
- Reduce environmental footprint – more sustainable systems

Research needs

- Improved management of nutrients including reducing greenhouse gas emissions from soil
- Defining, understanding and managing soil health and resilience
- Understanding the role and management of soil biology in agricultural systems, including potential for pest management and more efficient nutrient cycling
- Better approaches to and understanding of the cost and benefits of soil conservation
- Improved understanding of soil organic carbon dynamics, the value of soil carbon and opportunities for carbon sequestration in soil-plant systems
- Innovation to reduce on-farm energy consumption, including in tillage and cultivation
- Development and application of soil hydrology to improve water management e.g. smart drainage and advanced irrigation
- Assessing long-term impacts of soil pollution on agricultural productivity
- Innovation in agricultural systems to increase productivity whilst lowering environmental impacts e.g. a move towards mixed agro-ecology farming approach or precision farming application of fertilisers

Developing research areas

- Marrying soil science and genomics e.g. species that tolerate poorer soil and use less water
- Improved modelling of the soil-plant-water system to support more precise and dynamic field interventions – including using robotics
- Advanced digital inventories to characterise spatial and temporal changes in soil and water status and properties
- On-the-go and in-field sensor technology to monitor soil parameters in real-time e.g. moisture content, bulk density, N, P, K
- Unravelling the functional relationships of soil biodiversity within the soil system

As discussed in Section 4, important challenges face the farming community, both now and in the future. Research capabilities need to be able to address these challenges and key research needs and developing research areas are highlighted in Table 7. The developing areas include exciting new science, driven by the rapid advances in complex system modelling, informatics and genomics[16]. The type of technology that will be integral to farming in the future is illustrated in Box 1.

It is important to future soil and water management success that the knowledge base of all communities is maintained and improved in all key communities and within key stakeholder groups. Action needs to be taken now to ensure that future generations will choose to progress through the education system to fill future roles of farmer/land managers, advisor, developer and researcher. A clearly structured educational pathway, with compulsory theoretical and practical elements, in soil and water management is needed.

By maintaining and encouraging the development of the existing network of advisors, developers and researchers, and strengthening knowledge transfer within the system, it will be possible to secure a sustainable future for English farming that offers better food security for the UK, whilst delivering other ecosystem goods and services such as landscape aesthetics and maintenance of biodiversity.

7.3. Drivers of future changes

There are many factors that influence changes in soil and water management. However, certain groups have stronger influences than others. Four groups in particular do or could have a strong influence on the knowledge network, these include:

1) Levy boards

Levy boards have the potential to influence management decisions on a product sector basis. The Agriculture and Horticulture Development Board (AHDB) delivers focused advice and support to six sectors (pigs (BPEX), milk (Dairy Co), beef and lamb (EBLEX), horticulture (HDC), cereals (HGCA) and potatoes (PCL)). For these sectors the levy boards have developed good extension materials. Levy boards should provide an important mechanism for disseminating information both to the farming communities and from the farming communities to developers and researchers. In the future more could be made of this with levy boards acting as a major hub for information transfer between different communities. Levy boards also offer the farming sectors of the future a stronger lobbying voice which may enable better economic return for the goods and services each sector can offer and thus promote sustainability within the sector.

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[16] Genomics is the study and mapping of the full deoxyribonucleic acid (DNA) sequence of organisms.

Box 1: The Future of Farming

In order to realise the ecosystems goods and services that will be required to provide a sustainable future, significant changes will need to be made to the way in which we manage food production and farm the land. Inefficiencies inherent in many current systems lead to the production of output streams (other than food, fibre or fuel) that are seen as waste rather than recognising their potential value as resources e.g. waste biomass that is not returned to the land or non-natural waste that is burnt or sent to land fill. However, maximizing ecosystems goods and services within a farm may not provide as optimal a capability as would be achieved by recognising the resources and capabilities across the landscape and managing parcels of land based on an understanding of where things work best. To realise maximum capabilities within a landscape, integrated systems level management would need to be applied across the food chain and at multiple scales e.g. intra-farm and inter-farms. The complexity of the data required to inform such an integrated system would necessitate the use of advanced techniques such as informatics techniques to audit, monitor and manage information relating to what resources there are and how they are spatially distributed. Information would need to be acquired across a range of scales from large scale areas using remotely sensed date down to field scale data.

The demand for higher productivity from a finite area of land will require significant changes to be made in the way we farm. One important change will be the increase in technology used on farms to provide real-time information that will enable quick and appropriate decisions to be made, maximizing productivity while at the same time optimizing resource use and reducing greenhouse gas emissions. Such technology is no longer science fiction but science fact. Precision farming is not a new concept but as yet does not enable the accurate measurement of certain physical and chemical properties of the soil. However, so called 'on-the-go' sensors are currently being developed that will be able to measure some key soil properties, e.g. phosphorus, nitrogen, carbon, soil compaction and clay content by combining a number of sensor technologies including visible and near infrared (Vis-NIR) spectroscopy, electromagnetic induction (EMI) and capacitance sensors.

At present our ability to measure soil physical and chemical properties can be slow if samples have to be sent away for laboratory analysis. These measurements can also provide an incomplete picture of what is happening across a field. Accuracy relies on the number of samples that can be taken and this is always limited by time and money. On-the-go sensors will eventually enable continuous measurements to be made as a tractor travels across a field, increasing the precision, speed and affordability of soil characterization. Data obtained from on-the-go sensors will be combined with a global positioning system (GPS) receiver to provide either map-based or real-time systems. The map based system being used to inform future farming operations and to build-up an accurate record of how conditions change through time thus helping inform future strategic decision making. The real-time system enabling application rates to be varied in response to sensor readings so that chemicals will only be applied where and at a rate appropriate to that parcel of land.

2) Food retailers and service sector

Retailers and buyers (and particularly supermarkets because of their size) have a considerable influence about what is being grown and when things are being harvested. For example the scale of demand from supermarkets gives them economic power over the price of produce, with the possibility of agreeing a price even before the crop is harvested. They also have a reputation for rejecting crops because they do not meet their exacting standards. However, this may be beginning to change with the introduction of the 'groceries supply code of practice' (Competition Commission, 2009). This code of practice calls for "measures to prevent exclusivity arrangements and restrictive covenants being used by grocery retailers to restrict entry by competitors in order to improve competition in local areas".

The influence of food retailers and the food service sector can have negative soil and water management consequences, for example:

- Pressure to grow high value crops on marginal land e.g. potatoes on steep slopes, increasing the risk of soil erosion.
- Pressures to meet supply deadlines drives producers to harvest crops at inappropriate times, such as when the soil is too wet. This can damage soil structure, reduce soil water storage capacity and increase the risk of erosion and flooding downstream.
- Pressures for blemish free products increasing the use of chemical controls such as fungicides and pesticides, the leaching of which can cause issues with water quality
- Pressures to produce more for less encourages intensification of farming systems, which can increase the risk of soil erosion and soil compaction.
- Demand for a particular food type can lead to monocultures and increased reliance on polytunnels (increased risk of soil erosion) and irrigation (increased demand on a finite resource).

However, food retailers and the food service sector can also have a positive influence over soil and water management:

- They can drive the need for better food standards, which can include better environmental awareness, for example Sainsbury's is championing its 'sustainability agenda'
- They have a considerable influence over methods of production based on what their customers will accept, for example supermarkets have refused to buy produce grown on land to which sewage sludge has been applied. This has stimulated the need to produce further supportive evidence to justify the application of this product to the soil.
- They also have the power to educate people i.e. their customers, for example by persuading customers that misshapen and blemished products are as nutritious as perfect specimens, fewer chemicals may be needed and food waste may be reduced.

Therefore, it is important that an increase in education and awareness of soil and water management is also targeted at supermarkets and other larger retailers and buyers. Persuading this group that there is value to be added to their market through increased environmental standards (as well as production capability) will have added benefit as they will then encourage their producers to act more responsibly. Endorsement of such activity can be recognised through farm assurance schemes such as the Red Tractor Scheme, LEAF and the Soil Association.

3. Contractors

Increasingly, field operations are being done by contractors for farmers. Their impact on soil and water management can be considerable. Because of high demand at critical times of the year (such as harvest) they can have a strong influence on operational decision making. Farmers are under pressure to cultivate and harvest when contractors and machinery are available, rather than when conditions are optimal. Contractors can have less experiential understanding of the land they work on, which can lead to potentially inappropriate decisions being made about a particular field.

Future demands may necessitate more formally recognised standards of operational procedures for contractors. Technological advances will also enable those contractors who have the capacity to recognise and implement such advances, for example in on-the-go and real time monitoring technology, to make more effective management decisions.

4. Technology Strategy Board

One of the key limitations in the present knowledge infrastructure has been the limited opportunities for developers and researchers to effectively interact with farmers and vice versa. Funding for research and development has often not encouraged or necessitated interaction with the end user e.g. the farming community. However, in the future, to achieve integrated and sustainable strategies, better communication between all key communities will need to be encouraged through mechanisms such as the Technology Strategy Board (TSB). The TSB is the successor to LINK projects where researchers were encouraged to find industrial partners. Under the TSB, business is the main driver and partnerships are encouraged that can translate government policies and activities into business and market forces with the intention of linking challenges with capabilities. The TSB will be strategic to the provision of funding for technological development that will help meet England’s future food security and sustainability issues.

Section 7: Future opportunities and capabilities – Key points

- Better use should be made of information that already exists.
- The decline in independent advice is seen as a major threat to sustainable soil and water management in England.
- The English Catchment Sensitive Farming Delivery Initiative has worked well at increasing farmer engagement and encouraging new management practices and offers a potential format along which future advice could be delivered.
- Available knowledge is under-exploited. Its economic value needs to be promoted and new mechanisms for transferring knowledge need to be developed.
- FE and HE providers need to be preparing now for future provision of soil and water management.
- A clearly structured educational pathway with compulsory theoretical and practical elements, in soil and water management is needed.
- By maintaining and encouraging the development of the existing network of advisors, developers and researchers, and strengthening knowledge transfer within the system, it will be possible to secure a sustainable future for English farming that offers better food security for the UK, whilst delivering other ecosystem goods and services such as water quality, landscape aesthetics and maintenance of biodiversity.
- Groups such as levy boards, supermarkets, contractors and the Technology Strategy Board have the potential to influence the behaviour of farmers and provide better mechanisms of knowledge transfer between key communities.

8. Conclusions

Many demands are placed on our landscape, and in particular on our rural landscape. There is an expectation that the soil will provide us with food, fibre and fuel. However, there is also expectation that the soil will offer other valued ecosystem goods and services including habitats that can be enjoyed, foundation for homes and businesses, and storage of water and chemicals. As custodians of much of the rural landscape, it is assumed that farmers and land managers will take primary responsibility for providing these ecosystem goods and services. In order for them to be able to do this sustainably, an effective knowledge network is needed that has a strong research and development basis, with participants with appropriate educational background and mechanisms for effective knowledge transfer. This report has considered these issues in response to three key questions and concludes that:

1. Are appropriate data and research in the pipeline to help sustain effective soil and water management in the future?

- Current research and development is principally dictated by funding bodies, such as Research Councils and government and its agencies and as such is aligned to current policy demands. Until very recently these policies have meant that soil and water research and development has been predominantly focused on environmental concerns rather than production *per se.* Independent research and development does exist but on a much smaller scale and is market driven. While 'blue skies' research is much less prevalent in soil and water research because of a decline in core funding to English research institutes and universities.

- Over the past three decades the emphasis has been mainly towards soil and water research for environmental management rather than productivity. However, to meet future challenges in relation to sustainable production, there is a need for a change in direction for research and development:
    1. Research and development need to be realigned with production to meet the demands of a growing global population and impacts of climate change;
    2. at the same time production must go hand in hand with sustainable land management;
    3. it also needs to address multifunctional criteria to deliver the ecosystems goods and services needed for a sustainable future.

- This change in emphasis needs to happen soon because of the inevitable delay between research and development undertaken and delivery of advice to the wider knowledge network.

- To enable research and development to realign to meet future challenges there needs to be a change in the emphasis on the type of research that is being funded. There also needs to be more emphasis placed upon the importance of developing basic research into practical applications.

- An important legacy of data exists from times when production was the focus of research attention. However, this valuable legacy can at times be difficult to access because of the format that the data are held in. For this information to be utilised effectively, there is a need to address how these data and future data are stored and made accessible.

- While there is a substantial legacy of research and development, changing times requires that this information be further developed to meet the new challenge of integrated farm management (food production as well as other ecosystem goods and services).

- The complexity of the system for provision and response to pressures (e.g. climate change and population growth) will require advances in technologies such as on-the-go and in-field sensor technology, improved modelling of soil-plant-water systems and detailed digital soil mapping, which will become important farm management tools in the future.

- Where previously production has relied on the availability of artificial fertilisers, in the future to ensure food security, research will need to refocus on productivity within a sustainable system. For example looking for new methods to increase productivity through biotechnology (e.g. crop breeding) and soil protection solutions. Critical to this will be understanding how productive our soil can be through using a toolbox of techniques.

- To enable appropriate and effective development of information, gaps in the knowledge flows between researchers and developers will need to be bridged. Demand-driven research needs to be encouraged with farmers and advisers feeding back information on their requirements (knowledge gaps) to the researcher and developer communities.

- Key priorities for future research and development will include:
    1) Developing plants that have a lower demand for fertiliser, pesticides and fungicide, and tolerance to water deficiency, whilst maximising productivity;
    2) enabling highly sophisticated real-time measurements of soil physical and chemical properties that farmers will use as an integral component of farming;
    3) developing technology that will maximise water use efficiency, storage and release;
    4) managing the soil system more effectively through better understanding the functional relationships between soil and biology;
    5) enabling evaluation of non-market valued goods and services;

6) more accurate assessment and monitoring of all soil ecosystem goods and services;
7) developing innovative approaches which recognise the multifunctional role of soils and their management at a landscape scale

- To enable a responsive, appropriate and sustainable future there is a need for a strategic initiative for soil and water research and development, jointly-owned by the industry, the Research Councils and Government, with input from other stakeholder groups (e.g. water companies, retailers, not-for-profit and non-governmental organisations), to secure a step-change in the pace of research supporting future industry performance and more emphasis on technological development.

2. Will there be enough specialists to help?

- Currently there is a reasonably strong cohort of researchers in England and the wider UK, spread across universities, research institutes and private sector. This cohort is presently capable of undertaking and delivering fundamental knowledge across all aspects of soil and water management. However, there is concern that this capability is in decline.

- Of greater concern is the declining numbers of developers capable of transforming fundamental research into practical on-farm applications.

- Advisors, in contrast to researchers and developers, consist of a community of people with diverse levels of ability and application ranging from general advisors through to highly specialized advisors. Within this community there are concerns that the number of specialist advisors may be in decline and that general advisors have no or very limited knowledge of soil and water management.

- This decline in numbers of specialists able to deliver research, development and advice is attributed to the closure of some agricultural colleges and university departments, a lack of practical application at all levels of agricultural and environmental education, poor uptake by UK candidates in to higher level education in soil science and land engineering, poor retention of UK and foreign students who have undertaken higher level education in soil and water related topics, lack of perceived job opportunities and a weak emphasis on the importance of soil throughout education.

- Of the current pool of people who may be called upon to provide soil and water management advice now or in the future e.g. graduates, there is growing concern from representatives of the key communities that they may not have all the required skills needed to undertake the role effectively. Although this pool of people should have a capability of acquiring and developing new skills through continuing professional development.

- Of particular concern is the reported lack of agricultural experience of researchers, developers and advisors, which impacts on their ability to communicate with farmers and to provide appropriate information in a format that can be readily interpreted by farmers and land managers.

- Better promotion of soil and water management within the educational network and an increased emphasis on practical application is needed at all levels, but especially in the Further Education sector. As technology and methodology changes to meet future demands, the importance of farmers having a strong educational grounding in soil and water management will become even more essential. This will be especially true if they are to make operational decisions relating to opportunity and risk in a more sophisticated technical environment.

- The complexity of soil and water management within different agricultural sectors requires specialist knowledge within each sector. Agricultural sector specific knowledge and advice is important and localised specialists who understand local conditions are equally important to ensure appropriate, trusted advice is given. Sector specific advice may also encourage more individuals to engage as this may help to demonstrate the value of advice to their particular sector.

3. Is new and relevant information for our future requirements reaching farmers quickly and effectively?

- Examples can be found of researchers and developers delivering information to farmers and land managers as well as some knowledge exchange in the opposite direction, however, this does not seem to be commonplace.

- The majority of researchers, who undertake basic research, tend to work in isolation from all other communities and this type of research may have little direct benefit to farming. However, basic research is fundamental to the future advancement of farming through its development by experimental research into products and management systems that deliver economic, production and environmental benefits.

- To ensure appropriate research and development is undertaken, and to increase the efficiency with which this information reaches relevant communities, there is a need to improve the knowledge feedback mechanism between all communities.

- Advisors are pivotal to the knowledge infrastructure for soil and water management. Independent advice is seen as an important key to achieving more effective soil and water management. Confidence needs to be built and maintained between advisors and farmers. At present the main limiting factors to this are perceived to be a lack of practical farming experience in advisors, generic information that sometimes works and other times does not, and poor understanding of soil and water management because of an inadequate educational background. This argues for more formal professional accreditation of advisers in soil and water management.

- Connectivity throughout the overall knowledge infrastructure is critical. A single, shared soil and water management information hub (e.g. a virtual knowledge hub) that links farmers, advisors, developers and researchers and provides ready access to information at different levels of complexity, would deliver substantial benefits.

- Sound developer groups, strongly connected to the advisors and researchers are the engine-house for innovative technology development. These could be effectively supported by the creation of centres, possibly aligned to agricultural sectors, supporting a productive community of developers and providing effective demonstrations and other promotional activities. Currently levy boards do fulfil some of these roles but their influence could be strengthened in the future.

- The mechanisms by which knowledge is transferred are also important. Time is a primary constraint on knowledge transfer and therefore, for literature to be effective e.g. pamphlets, leaflets, reports, guides etc., it must either be preceded by workshops, demonstrations or one-to-one visits by advisors or get its point across quickly, effectively and show value. One example of the later is the Environment Agency's 'Best Farming Practices' guide, because it has clear examples of how soil and water management can deliver better financial as well as environmental performance. More guides with similar formats are needed.

Most importantly, sustainable production has to include economic affordability. A better understanding and demonstration of the value of soil and water management to production is critical as it will encourage farmers and their advisors to seek out and adopt new systems and technologies. This better understanding should extend to demonstration of how education, research, development and advice leading to improved soil and water management, translate into improved gross margins.

While advisors are presently the key community connecting farmers and land managers with developers and researchers in the future this role may also be met by other groups such as levy boards and the Technology Strategy Board. These groups along with others such as supermarkets and contractors have the potential to influence future soil and water management.

We are currently at a cross roads, because of the re-evaluation of priorities, economic challenges and concerns over the number and quality of farmers, advisors, developers and researchers. The decisions we make now will have long-term implications for future food production and food security in England and the competitiveness of the country's agricultural industry. However, farming and land management is not only about food production – delivery of other ecosystems goods and services is also critical and this may well require significant changes to present farming practice. The growing complexity of integrated farming systems requires that we invest now to ensure that a strong knowledge infrastructure is in place and aligned to strategic priorities. This is essential to underpin the future economic and environmental sustainability of farming and land management in England.

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APPENDIX A

Project Advisory Group (PAG) members

Alastair Leake	Allerton Research and Educational Trust, Head of Project
Anne Verhoef	University of Reading, Senior Lecturer in Soil Physics and Micrometeorology
Bob Evans	Anglia University, Researcher/Consultant
Bob Walker	Senior technical officer, Cranfield University research farm
David Garwes	DairyCo, Interim Head of R&D
David Brightman	Farmer
Fiona Nicholson	ADAS, Senior Research Scientist
Jerry Knox	Cranfield University, Principal Research Fellow in Irrigation and Water Resources
Jo Oborn	FWAG, Resource Protection Specialist
John Conway	Royal Agricultural College, Principal Lecturer Soil Science
Keith Chaney	Harper Adams, Principal Lecturer. Head of the Crops Department
Keith Goulding	Rothamsted, Head Soil Science and Manager of the Cross-Institute Programme for Sustainable Soil Function
Lucy Shenton	Reaseheath College, Agriculture Specialist, KT
Mat Davis	Environment Agency, Soil Protection (Team Leader)
Nathan Morris	TAG, Research Development Agronomist
Nigel Penlington	BPEX, Environment Programme Manager
Paul Burgess	Cranfield University, Senior Lecturer in Crop Ecology and Management
Paul Lewis	Harper Adams, Lecturer in Environmental Management
Phil Haygarth	Lancaster University, Co-Director of the Centre for Sustainable Water Management
Richard Longthorpe	Farmer (Pigs)
Rob Parkinson	Plymouth University, Senior Lecturer in Soil Science
Selwyn Richardson	ADAS (retired)
Simon Griffin	Soyl, Technical Manager
Steven Bailey	Natural England, Catchment Sensitive Farming Regional Co-ordinator (West Midlands)
Tom Newbery	Farmer (mixed)
Tudor Dawkins	Frontier Agriculture, Head of technology

The research team are grateful for the contributions made by the members of the PAG group. This report reflects their opinions but the interpretation, analysis and conclusions drawn are those of the project group alone. In addition we would like to thank Emeritus Professor Richard Godwin and Professor Peter Gregory for advice given during the preparation of the report.

APPENDIX B

The future requirements of soil and water management in England - questionnaire

- Assume all questions relate to the interviewees' experiences relating to soil and water management
- Where possible responses should reflect interviewees' knowledge of soil and water management in their sector as a whole and not just their own direct experiences
- Q10, 11, 14 15, 20, 21 and 23 can have multiple answers. If possible indicate order of priority.
- *Q8 is more specific to Farmers/Land managers but any one should feel free to attempt an answer if they wish from their own perspective

Personal details

1. Name: ………………………………………………………………………….

2. Age:

	<20		20-40		40-60		>60

3. Gender:

	Male		Female

4a. Occupation/job title: ……………………………………………………………….
4b. Agriculture sector:

	Arable		Vegetables and Potatoes		Livestock including dairy		Pig and Poultry		Wildlife management

5. PAG group role (where would you place yourself):
Farmers and land managers: arable, growers, livestock, pig & poultry, wildlife management.
Advisors: connect, articulate problems, offer and explain solutions, provide training
Developers: new tools and processes, experimental trials, specialist consulting
Research: basic and applied research to generate knowledge
Education: training

	Farmer/Land manager		Advisor		Developer		Research		Education

6. Educational background (highest qualification relevant to soil and water management):
……………………………………………………………………………
………………………………………………………………………………………...

7. Have you undertaken any continuing development on soil and water management in the last three years?

	Yes (go to Q7a)		No(go to Q8)

7a. What continuing development have you undertaken (e.g. workshops, short courses (BASIS) etc):
……………………………………………………………………………………….
……………………………………………………………………………………….

Knowledge transfer

8*. When you hear about a new tool or technique, do you:

	Immediately consider how it might be useful on your farm and find out who is the supplier
	Ask your advisor if this is something that might be useful in future years
	Wait to see if other farmers adopt it and how they get on
	Not take too much interest as they are always lots of new tools and techniques in the market place

Additional comment: ……….…………………………………………..………….
……………………………………………………………………………………...

9. Do you agree that soil and water management knowledge is effectively transferred?

	S. agree		Agree		Neutral		Disagree		S. disagree

10. Do you receive knowledge/information on soil and water management in the following way?

		Receive advice from				
		Farmer/Land manager	Advisor	Developer	Research	Education
Format	One to one					
	Leaflets					
	Workshops					
	WWW					
	Courses					
	Group discussions					
	Demonstrations					
	Meeting/ conferences					
	Research papers					
	Other (specify below)					

Other: ……………………………………………………………………………………...

……………………………………………………………………………………..

11. Do you provide knowledge/information on soil and water management in the following way?

		Provide advice to				
		Farmer/Land manager	Advisor	Developer	Research	Education
Format	One to one					
	Leaflets					
	Workshops					
	WWW					
	Courses					
	Group discussions					
	Demonstrations					
	Meeting/ conferences					
	Research papers					
	Other (specify below)					

Other: ………………………………………………………………………………………...

………………………………………………………………………………………..

12. What is your preferred method(s) of knowledge transfer for soil and water management and why?
As a provider: ……………………………………………………………………….
……………………………………………………………………………………….
As a consumer: ………………………………………………………………………
……………………………………………………………………………………….

13. Put in order of priority, where does your knowledge/information on soil and water management come from?

	Farmer/Land manager		Advisor		Developer		Research		Education

Other: ………………………………………………………………………………………...

14. What value do you believe others place on your knowledge/information?

	Farmer/Land manager	Advisor	Developer	Research	Education
Highly valued					
valued					
Neutral					
Not valued					
Of no value					

Notes: ……………………………………………………………………………………..
……………………………………………………………………………………….

15. How relevant is the available knowledge/information on soil and water management from other sectors to your sector?

	Farmer/Land manager	Advisor	Developer	Research	Education
Very specific					
Generic					
Not applicable					

Notes: ……………………………………………………………………………………..
……………………………………………………………………………………….

16. How relevant are the following forms of knowledge to your role?
Operational knowledge: putting knowledge to practical use; knowing what to do and when
Strategic knowledge: long term planning; aggregation of information; setting priorities
Fundamental knowledge: understanding of key processes; why and how things happen

	V. important	Important	Neutral	Not important	Not needed
Operational knowledge					
Strategic knowledge					
Fundamental knowledge					

17. What would encourage you to acquire and/or use new knowledge?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………

Knowledge gaps

18. Are there gaps in the knowledge exchange network?

	Yes		No

If yes what would you say these gaps are? ……………………………………………..
…………………………………………………………………………………………………
……………………………………………………………………………………..

19. Do you agree that knowledge is easily available to you?

	S. agree		Agree		Neutral		Disagree		S. disagree

Any comments: ……………………………………………………………………......
……………………………………………………………………………………………..

20. What barriers are there to you accessing knowledge (tick all that apply)?

	No barriers		Time		Finance
	Understanding		Mistrust		Format e.g. www

Other: ……………………………………………………………………………………
……………………………………………………………………………………………..

21. What barriers are there to you providing information to others (tick all that apply)?

	No barriers		Time		Finance
	Understanding		Mistrust		Format e.g. www

Other: …………………………………………………………………………………
…………………………………………………………………………………………..

22. What improvements would you make to the system to make knowledge transfer more efficient and effective?
……………………………………………………………………………………………
……………………………………………………………………………………………
…………………………………………………………………………

Technical priorities

23. In order of priority, and in relation to your sector, which of the following topics do you consider to be most important for effective soil and water management?

	Nutrients		Erosion		Organic matter / soil carbon		Soil biology		Soil pollution
	Drainage/soil structure		Irrigation		Tillage and traction		Grazing management		Soil maps
	Healthy soil		Crop protection						

Other: …………………………………………………………………………………
…………………………………………………………………………………………..

24. In relation to your sector, please identify which topic you think is covered best and which you think is least well covered by existing knowledge exchange?
Best: ………………………………………………………………………………
Least: ……………………………………………………………………………..

25. Looking ahead, in your view, what is the greatest challenge for effective soil and water management over the next decade?
…………………………………………………………………………………………..

Education

26. Thinking about soil and water management, would you agree that there is a clearly defined educational pathway for someone to enter into, and progress through to, the position that you hold?

	S. agree		Agree		Neutral		Disagree		S. disagree

Additional comment: ………………………………………………………………..
………………………………………………………………………………………….

27. Thinking about soil and water management, how important would you say a clearly defined educational pathway is for your sector?

	V. important		Important		Neutral		Not important		Not needed

Additional comment: ………………………………………………………………..
……………………………………………………………………………………….

28. What improvements would you suggest should be made to the formal education structure to improve soil and water management?
……………………………………………………………………………………………
……………………………………………………………………………………………
………………………………………………………………………

APPENDIX C

Questionnaire responses

A formal questionnaire was designed and used for a semi-structured telephone interview with 24 of the Project Advisory Group (PAG) members, in March 2010. Representatives from the four critical groups recognised as providing knowledge transfer and the overarching educational group were included in the survey. Also, within the construct of this group each of the five agricultural sectors was represented. It should be noted that whilst individuals were selected to represent a specific sector within the knowledge transfer network the individual themselves may also play addition roles within the knowledge transfer network. For example, some developers and educationalist also saw themselves as advisors, while some farmers also acted as developers. For this report the responses have been grouped into the sector that the individuals were selected to represent unless specifically stated otherwise.

Membership of the PAG was based on recommendation from a range of organisations and individuals, including: the British Society of Soil Science, the Institution of Agricultural Engineers, the Institution of Professional Soil Scientists, the Chartered Institute of Water and Environmental Management, the Royal Agricultural Society of England, England Catchment Sensitive Farming Delivery Initiative and recommendations from people approached to be PAG members themselves.

Responses

The distribution of respondents in their representative sectors is given in Table 1 and is compared to individual placement. A total of 20 of the respondents fell within the 40-60 years of age category, 2 respondents reported as being in the 20-40 years of age category and 4 of the respondents were over 60 (Table 2). The survey group were also predominantly male (Table 3), which may partly reflects the gender distribution within the sectors but the balance in this survey is not assumed to be representative of the sectors.

The remained of the tables in this section relate to responses from the questionnaire that could be tabulated. Open ended responses from the questionnaire are not included in here but are used within the main document of this report. The remaining tables show:

- Table 4: All agricultural sectors reported by individuals shown by sector. An individual could report belong to more than one agricultural sector although they were asked which was their primary sector.
- Table 5: sum of individual responses to continuing personal development, shown by sector.
- Table 6: Farmers responses and others sectors perception of farmers responses to uptake of new technology.
- Table 7: Individuals response to effective knowledge transfer in each sector

- Table 8a-e: Format in which knowledge/information was received in each sector from other sectors. Individuals were asked to list all formats.
- Table 9a-e: Format in which knowledge/information was provided from each sector to other sectors. Individuals were asked to list all formats.
- Table 10: The sector that provides the primary source of information based on individual responses listed for each sector.
- Table 11a-e: Individuals response to the value each of the sectors places on their knowledge/information presented by section e.g. farming, advisor etc.
- Table 12a-e: Relevance of knowledge/information coming from other sectors to individuals in a sector.
- Table 13a-e: Relevance of the three identified forms of knowledge involved with effective soil and water management: operational, strategic and fundamental, to each sector. Individuals gave a single response for each type of knowledge.
- Table 14: Individuals response to whether there are gaps in the knowledge exchange network. Responses grouped into sectors.
- Table 15: Individuals responses as to how easy knowledge is available to them. Responses grouped into sectors.
- Table 16: Perceived barriers to accessing knowledge identified by sectors. Table lists all responses from each sector; individual could suggest more than one answer.
- Table 17: Perceived barriers to providing knowledge identified by sectors. Table lists all responses from each sector; individual could suggest more than one answer.
- Table 18: Responses grouped into sectors to the question of whether there was a clearly definable educational pathway to the position individuals presently hold.
- Table 19: Responses grouped into sectors to the question of whether there should be a clearly definable educational pathway to their sector.

Personal details

Table 1 (question 5): Distribution of questionnaire responses within key sector groupings.

	Representative sector*	Self classification
Farming/Land management	4	2
Advisor	5	9
Developer	5	3
Research	5	5
Education	5	5

*Responses were grouped according to this designation in the report

Table 2 (question 2): Age distribution of respondents

	<20	20-40	40-60	>60
Farming/Land management			3	1
Advisor			4	1
Developer		1	3	1
Research			4	1
Education		1	4	

Table 3 (question 3): Gender distribution of respondents.

	Female	Male
Farming/Land management		4
Advisor	1	4
Developer		5
Research	2	3
Education	1	4

Table 4 (question 4b) : Agricultural sectors

	Arable	Vegetables and Potatoes	Livestock including dairy	Pig and Poultry	Wildlife management
Farming/Land management	4	1		1	1
Advisor	3	2	1		
Developer	3	2	2	1	
Research	3	1	1	1	
Education	4	3	3	3	3

Advisor 2 no responses; research 2 no responses; education 1 no response

Table 5 (question 7): Response to question asking if respondent had participated in any continuing development on soil and water management in the last three years.

	Yes	No
Farming/Land management	3	1
Advisor	4	1
Developer	4	1
Research	2	3
Education	4	1

Table 6 (question 8): Response to new technology. Sectors that are not Farmers/Land managers giving impression of how they think farmers respond.

	Innovators	Early adopters	Late adopters	laggards
Farming/Land management	2	1	1	
Advisor		1		
Developer		1		
Research		1		
Education		2		

Table 7 (question 9): Is soil and water management knowledge effectively transferred?

	S. agree	Agree	Neutral	Disagree	S. disagree
Farming/Land management		2		2	
Advisor		1		3	1
Developer			3	2	
Research		1		2	2
Education		1	2	2	

Knowledge transfer

Table 8a (question 10): Do farmers receive knowledge/information on soil and water management formatted in the following ways?

		Farmers receive advice from:				
		Farming/Land management	Advisor	Developer	Research	Education
Format	One to one	2	3	2	1	
	Leaflets		1			
	Workshops		1	4	1	2
	WWW		1	1		
	Courses			1	1	1
	Group discussions	3	1	1	1	
	Demonstrations	2	1	4		1
	Meeting/conferences	1	2	1	1	
	Research papers				2	
	Other	1				

Table 8b (question 10): Do advisors receive knowledge/information on soil and water management formatted in the following ways?

		Advisors receive advice from:				
		Farming/Land management	Advisor	Developer	Research	Education
Format	One to one	2	4	3	3	1
	Leaflets		2	3	3	1
	Workshops	2	5	4	4	1
	WWW	1	2	1	3	
	Courses		1	2	2	2
	Group discussions	2	4	3	2	1
	Demonstrations	3	5	3	3	
	Meeting/conferences	2	3	3	2	1
	Research papers		3	4	5	1
	Other	1				

Table 8c (question 10): Do developers receive knowledge/information on soil and water management formatted in the following ways?

		Developers receive advice from:				
		Farming/Land management	Advisor	Developer	Research	Education
Format	One to one	5	3	2	2	2
	Leaflets		2	1	2	
	Workshops	2	3	2	2	
	WWW		1	1	3	1
	Courses	1	2	1	1	
	Group discussions	2	1	2	2	
	Demonstrations	1	3	2		
	Meeting/conferences	1	3	5	4	
	Research papers		1	1	4	
	Other			1	1	

Table 8d (question 10): Do researchers receive knowledge/information on soil and water management formatted in the following ways?

		Researchers receive advice from:				
		Farming/Land management	Advisor	Developer	Research	Education
Format	One to one	1	1	3	2	1
	Leaflets				3	1
	Workshops	1	1		4	1
	WWW		1		4	1
	Courses				2	1
	Group discussions	2	1	1	4	2
	Demonstrations	2	1	1	3	1
	Meeting/conferences	1	3	1	5	2
	Research papers				5	1
	Other		1			

Table 8e (question 10): Do educationalists receive knowledge/information on soil and water management formatted in the following ways?

		Educationalists Receive advice from:				
		Farming/Land management	Advisor	Developer	Research	Education
Format	One to one	3	4	3	3	5
	Leaflets		2	3	2	3
	Workshops	2	3		3	3
	WWW		2	2	3	2
	Courses	1	2	2	2	2
	Group discussions	4	4	2	3	2
	Demonstrations	2	3	2	2	1
	Meeting/conferences	3	4	4	5	3
	Research papers		2	2	5	2
	Other					

Table 9a (question 11): Do farmers provide knowledge/information on soil and water management formatted in the following ways?

		Farmers provide advice to:				
		Farming/Land management	Advisor	Developer	Research	Education
Format	One to one	3	4	2	2	2
	Leaflets					
	Workshops	1	1	1	1	
	WWW					
	Courses	1	1	1		
	Group discussions	2				
	Demonstrations	1	1	1		
	Meeting/conferences	3			1	
	Research papers					
	Other					

Table 9b (question 11): Do advisors provide knowledge/information on soil and water management formatted in the following ways?

		Advisors provide advice to:				
		Farming/Land management	Advisor	Developer	Research	Education
Format	One to one	5	3	2	3	2
	Leaflets	4	3	1	1	1
	Workshops	5	4	3	3	2
	WWW	1	1	1		
	Courses	3	4	2	2	2
	Group discussions	5	4	3	3	2
	Demonstrations	5	5	2	2	1
	Meeting/conferences	4	4	3	3	3
	Research papers	2	2	1	1	1
	Other		1			

Table 9c (question 11): Do developers provide knowledge/information on soil and water management formatted in the following ways?

		Developers provide advice to:				
		Farming/Land management	Advisor	Developer	Research	Education
Format	One to one	4	4	3	2	1
	Leaflets	2	1	1		1
	Workshops	4	2			
	WWW	3		1		
	Courses	2	2	2		
	Group discussions	2	2			
	Demonstrations	3				
	Meeting/conferences	3	3	2	1	
	Research papers	2	1			
	Other	2	2	2	2	3

Table 9d (question 11): Do researchers provide knowledge/information on soil and water management formatted in the following ways?

		Researchers provide advice to:				
		Farming/Land management	Advisor	Developer	Research	Education
Format	One to one	1	3	4	3	3
	Leaflets	2	2	1	3	3
	Workshops	4	4	2	3	2
	WWW	2	3	1	3	3
	Courses	2	2	1	2	1
	Group discussions	3	3	2	3	3
	Demonstrations	3	3	2	3	3
	Meeting/conferences	2	3	1	5	3
	Research papers	1	1	1	5	3
	Other					

Table 9e (question 10): Do educationalists provide knowledge/information on soil and water management formatted in the following ways?

		Educationalists provide advice to:				
		Farming/Land management	Advisor	Developer	Research	Education
Format	One to one	4	4	3	3	5
	Leaflets	2	2			2
	Workshops	3	3	1	2	4
	WWW	2	1		1	1
	Courses	4	3	1	1	4
	Group discussions	3	3	2	3	4
	Demonstrations	4	4	1	2	3
	Meeting/conferences	3	3	2	5	5
	Research papers	1	3	2	4	4
	Other					

Table 10 (question 13): Where does your knowledge/information on soil and water management come from?

		Sector				
		Farming/Land management	Advisor	Developer	Research	Education
Source of knowledge	Farming/Land management			1		
	Advisor	1		1		
	Developer	1	2	1		1
	Research	2	3	2	5	4
	Education					

Columns = Sector; rows = where knowledge comes from

Table 11a (question 14): What value do other sectors place on farmers knowledge/information?

	Farmer/Land manager	Advisor	Developer	Research	Education
Highly valued				1	1
Valued	3	3	3	2	3
Neutral			1	1	
Not valued	1	1			
Of no value					

Table 11b (question 14): What value do other sectors place on advisors knowledge/information?

	Farmer/Land manager	Advisor	Developer	Research	Education
Highly valued	2	1		1	
Valued	3	4	4	2	1
Neutral			1	1	2
Not valued					
Of no value					

Table 11c (question 14): What value do other sectors place on developers knowledge / information?

	Farmer/Land manager	Advisor	Developer	Research	Education
Highly valued	1				
Valued	4	4	3	4	1
Neutral		1	2	1	4
Not valued					
Of no value					

Table 11d (question 14): What value do other sectors place on researchers knowledge / information?

	Farmer/Land manager	Advisor	Developer	Research	Education
Highly valued		2	2	2	1
Valued	3	2	2	3	3
Neutral	1	1	1		1
Not valued	1				
Of no value					

Table 11e (question 14): What value do other sectors place on education knowledge/information?

	Farmer/Land manager	Advisor	Developer	Research	Education
Highly valued	3	3			2
Valued	1	1	3	4	3
Neutral	1	1	2	1	
Not valued					
Of no value					

Table 12a (question 15): How relevant is the knowledge/information on soil and water management from other sectors to farmers?

	Farming/Land management	Advisor	Developer	Research	Education
Very specific		2	3	2	1
Generic	3	1	1	2	3
Not applicable	1	1			

Table 12b (question 15): How relevant is the knowledge/information on soil and water management from other sectors to advisors?

	Farming/Land management	Advisor	Developer	Research	Education
Very specific	5	3	2	5	1
Generic		2	3		2
Not applicable					2

Table 12c (question 15): How relevant is the knowledge/information on soil and water management from other sectors to developers?

	Farming/Land management	Advisor	Developer	Research	Education
Very specific	4	3	3	3	1
Generic	1	2	2	2	3
Not applicable					1

Table 12d (question 15): How relevant is the knowledge/information on soil and water management from other sectors to researchers?

	Farming/Land management	Advisor	Developer	Research	Education
Very specific	4	3	3	3	1
Generic	1	2	2	2	3
Not applicable					1

Table 12e (question 15): How relevant is the knowledge/information on soil and water management from other sectors to education?

	Farming/Land management	Advisor	Developer	Research	Education
Very specific	4	3	3	4	2
Generic	1	2	2	1	2
Not applicable					1

Table 13a (question 16): How relevant are the following forms of knowledge to farmers? (n = 4)

	V. important	Important	Neutral	Not important	Not needed
Operational	4				
Strategic	3	1			
Fundamental	1	2	1		

Table 13b (question 16): How relevant are the following forms of knowledge to advisors? (n = 5)

	V. important	Important	Neutral	Not important	Not needed
Operational	3	2			
Strategic	2	3			
Fundamental	3	2			

Table 13c (question 16): How relevant are the following forms of knowledge to developers? (n = 5)

	V. important	Important	Neutral	Not important	Not needed
Operational	4	1			
Strategic	3	2			
Fundamental	3	1	1		

Table 13d (question 16): How relevant are the following forms of knowledge to researchers? (n = 5)

	V. important	Important	Neutral	Not important	Not needed
Operational	1	2	1	1	
Strategic	4		1		
Fundamental	4	1			

Table 13e (question 16): How relevant are the following forms of knowledge to education? (n = 5)

	V. important	Important	Neutral	Not important	Not needed
Operational	4	1			
Strategic	3	2			
Fundamental	4	1			

Knowledge gaps

Table 14 (question 18): are there gaps in the knowledge exchange network?

	Yes	No
Farming/Land management	4	
Advisor	5	
Developer	5	
Research	5	
Education	5	

Table 15 (question 19): Do you agree that knowledge is easily available to you?

	S. agree	Agree	Neutral	Disagree	S. disagree
Farming/Land management	1		1	2	
Advisor	1	2		2	
Developer		1	3	1	
Research	3	2			
Education	2	3			

Table 16 (question 20): Barriers to accessing knowledge

	No barriers	Time	Finance	Understanding	Mistrust	Format
Farming/Land management		4	1	2	1	1
Advisor		5	2	1	1	
Developer		3	3	2	1	2
Research	1	4	1	1		
Education		5	1	1	1	2

Table lists all responses from each sector

Table 17 (question 21): Barriers to providing information to others

	No barriers	Time	Finance	Understanding	Mistrust	Format
Farming/Land management	1	1		1	1	
Advisor		5	5		3	1
Developer		3	3	3	2	1
Research		4	3	3		
Education		5	4	2		2

Table lists all responses from each sector

Education

Table 18 (question 26): Is there a clearly defined educational pathway for someone to enter into, and progress through to, the position that you hold?

	S. agree	Agree	Neutral	Disagree	S. disagree
Farming/Land management	1			3	
Advisor		1	2		2
Developer				4	1
Research		1	1	3	
Education	1		1	1	2

Table 19 (question 27): How important is a clearly defined educational pathway to your sector?

	V. important	Important	Neutral	Not important	Not needed
Farming/Land management	3		1		
Advisor	3	2			
Developer	1	3		1	
Research	4	1			
Education	2	3			

APPENDIX D

Soils and Water Management related courses in UK

Initiative	Web address	Ed/Aw*	Content Description/Course Title	Classification
ACS Distance Education	http://www.acsedu.co.uk/Courses/General-Horticulture/SOIL-MANAGEMENT-HORTICULTURE-BHT105-92.aspx	Ed	Soil Management – horticulture. Correspondence course accredited by IARC	Commercial
ACS Distance Education	http://www.acsedu.co.uk/courses/product.aspx?id=236	Ed	Soil Management - Agriculture	Commercial
Bryan Madge Associates, training	http://www.bryanmadge.co.uk/courses/course-details.php?id=288	Ed	Interpreting Soil Test Results for engineers and construction professionals	Commercial
NFU for Farmers and Growers in England and Wales	http://www.nfu.org.uk	Ed/Aw	Environment Agency are running courses on soil, nutrient and track management across England and Wales for farmers.	Commercial
Thomas Telford Training	http://www.tttrain.co.uk/courses/CourseDetails.aspx?CourseID=443-tt http://www.tttrain.co.uk/courses/CourseDetails.aspx?CourseID=720-T http://www.tttrain.co.uk/courses/CourseDetails.aspx?CourseID=68-tt	Ed	Two day course on Slope Stability Problems for civil and geotechnical engineers. Two day course on Earthworks – theory and practice One day Introduction to Contaminated Land	Commercial
Van Walt	http://www.vanwalt.com/training-auger-groundwater-environmental.htm	Ed/Aw	Three day course - Environmental training: practical fieldwork theory and techniques	Commercial
Askham Bryan College	http://www.askham-bryan.ac.uk/index.asp	Ed	ANC, BTEC, National Diploma/Certificate, Foundation Degrees, BSc. Variety of soil-related courses inc. Land management, landscape construction, horticulture, sports surface and greenkeeping	Education
Bishop Burton College	http://www.bishopburton.ac.uk/sitefiles/agriculture/agriculture.html	Ed/Aw	BTEC, Foundation Degrees, BSc, MA various soil-related subjects – agriculture, horticulture, land-based engineering	Education
Cardiff University	http://www.earth.cardiff.ac.uk	Ed	School of Earth and Ocean Sciences. BSc Environmental Geoscience, MSc	Education

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Initiative	Web address	Ed/Aw*	Content Description/Course Title	Classification
			and MESci Applied Environmental Geology	
College of Agriculture, Food and Rural Enterprise	http://www.greenmount.ac.uk/studying_at_greenmount/courses/	Ed	BSc, HNC, HND Agricultural subjects. Agricultural Technology, Rural Skills etc. ½ day introduction to Nutrient Management Planning	Education
Cranfield University	http://www.cranfielda.c.uk	Ed	MSc/PG Dip Land Management, MSC/PGD Dip Water Management, MRes Sport surface technology PhD Land and water management	Education
Guildford College, Merrist Wood Campus	http://www.guildford.ac.uk/College/MerristWood/Welcome.aspx	Ed/Aw	Land-based programmes including horticulture, landscaping, garden design, countryside, sports turf, and arboriculture	Education
Hadlow College	http://www.hadlow.ac.uk/	Ed	BScs and Diplomas in Agricultural and Sustainability, Countryside Management, Horticulture, landscape and design.	Education
Harpur Adams	http://www.harper-adams.ac.uk/	Ed/Aw	BASIS Certificate in Soil and Water Management, for agricultural professionals. BSc Agriculture BSc countryside & environment	Education
Hartpury College	http://www.hartpury.ac.uk/	Ed	First Diploma, National Award, National Certificate. Variety of land-based courses – Agriculture, Countryside Management, Farm Mechanisation etc.	Education
Heriot-Watt University	http://www.hw.ac.uk	Ed	MSc PG Dip Water Resources Catchment Management	Education
Imperial College, London, Dept of Civil and Environmental Engineering	http://www3.imperial.ac.uk/geotechnics/courses	Ed	MSC Soil mechanics. Short courses including: Earthworks and Embankments, The Importance of Soil Suction, Advanced Soil Characterisation	Education
Myerscough College	http://www.myerscough.ac.uk/Pages/Higher_Education/Higher-Education-Subjects	Ed	BSC Agriculture. First Diploma, National Diploma, NVQ, National	Education

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Initiative	Web address	Ed/Aw*	Content Description/Course Title	Classification
			Award in subjects including Agriculture, Woodland Management, Countryside, Sportsturf	
Oatridge College	http://www.oatridge.ac.uk/	Ed	Higher National Diploma (HND), Higher National Certificate (HNC), Certificate Courses, Scottish Vocational Qualification, Certificates of Competence in subjects including Agriculture, Countryside Management, Greenkeeping, Horticulture and Landscaping.	Education
Queens University	http://www.qub.ac.uk/	Ed	Institute of Agri-Food and Landuse. BSc Landuse and environmental management, BSc Agricultural technology, Foundation Degrees in Rural Sustainability and in Land Environmental Sustainability. MSc/PG Dip Water Resources Management	Education
Reaseheath College	http://www.reaseheath.ac.uk/dotnetnuke/Home/AllCourses/tabid/56/Default.aspx	Ed	Foundation/HND/HNC Agriculture, Countryside and Horticulture related courses	Education
Royal Agricultural College, Cirencester, UK	http://www.royagcol.ac.uk/	Ed	BSc Agriculture, Foundation degrees, MSc and PhD study available – pathways for postgraduate study include Natural Resource Management	Education
Scottish Agricultural College (SAC)	http://www.sac.ac.uk/learning/coursefinder/undergraduate/agric/hndagric	Ed	BSc Agriculture, HND/HNC/Diploma Agriculture, MSc/PG Dip Organic Farming, Environmental Protection and Management, Countryside Management	Education
Sparsholt College	http://www.sparsholt.ac.uk/	Ed/Aw	Full and part-time courses in Agriculture and rural land management, Woodland management, Countryside management, Horticulture	Education
The University of Greenwich	http://www.gre.ac.uk/courses/ug/agr	Ed	BSc Hons/HND International Agriculture, BSc Sustainable Land Management, BSc Environmental	Education

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Initiative	Web address	Ed/Aw*	Content Description/Course Title	Classification
			Science, BSc Horticulture, PGDip/MSc/MSc by Research Natural Resources,	
The University of Nottingham	http://www.nottingham.ac.uk/ugstudy/course.php?code=000218	Ed	BSc Agriculture	Education
University College London	http://www.civeng.ucl.ac.uk/teaching/index.asp	Ed	Soil Mechanics-related courses. Civil and Environmental Engineering	Education
University of Aberdeen, Soil Science	http://www.abdn.ac.uk/	Ed	Soil Science courses at degree level 2. MSc/PG Dip Soil Science. PhD/MPhil/MRes Soil Microbes and the Environment	Education
University of Bradford	http://www.bradford.ac.uk/archenvi/courses/ugges.php	Ed	BSc Environmental Science, BSc Geography & Environmental Management	Education
University of Bristol	http://www.bristol.ac.uk	Ed	PhD/MRes Civil engineering – soil mechanics, water management	Education
University of Central Lancashire	http://www.uclan.ac.uk/information/courses/index.php?discipline=Geography&level=All&study_mode=All	Ed	PhD/MSc/MPhil/BSc Environmental Management	Education
University of Durham	http://www.dur.ac.uk/earth.sciences/undergrad/	Ed	BSc Earth Sciences	Education
University of Edinburgh	http://www.ed.ac.uk/studying/undergraduate/finder/subject.php?id=0,7	Ed	BSc Earth Sciences MSc Integrated Resource Management MRes Environmental Sustainability	Education
University of Exeter, Dept of Biological Sciences	http://www.exeter.ac.uk/undergraduate/degrees/environment/	Ed	BSc Environment and sustainability. MSc/PG Dip Applied Geotechnics, MSc/PG Dip Surveying & Land, Environmental Management	Education
University of Glasgow	http://www.gla.ac.uk/	Ed	BSc Earth Science BSc Environmental Stewardship MSc Environmental Science Soil Mechanics 10 credit course. MSc Geotechnical Engineering. MSc Global Water Sustainability, PhD/Mres Civil engineering	Education
University of Hertfordshire	http://www.herts.ac.uk	Ed	MSc/PG DipWater and Environmental Management	Education
University of Newcastle upon Tyne	http://www.ncl.ac.uk/	Ed	Various soil and water related PhDs, Mphil, MSc, Mres, BSc in school of Agriculture, Food and Rural	Education

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Initiative	Web address	Ed/Aw*	Content Description/Course Title	Classification
			Development e.g. MSc Agriculture and Environmental Science, MSc Environmental Resource Assessment, BSc Agriculture, BSc Environmental Studies	
University of Plymouth	http://www.plymouth.ac.uk/	Ed	BSc Agriculture, BSc Horticulture, BSc Environmental Science, MSc/MRes Earth Science	Education
University of Reading	http://www.reading.ac.uk/soilscience/	Ed	Department of Soil Science. PhDs, MSc Soils and Environmental Pollution, MSc Environmental management, BSc Environmental Science.	Education
University of Southampton	http://www.soton.ac.uk	Ed	MSc Water resources management	Education
University of Stirling	http://www.sbes.stir.ac.uk/	Ed	School of Biological and Environmental Sciences BSc Environmenal Geography, Environmental Science, MSc/Diploma/Certificate in River Basin Management. PhDs also available	Education
University of the Highlands and Islands (UHI)	http://www.uhi.ac.uk/	Ed	Environmental and rural industries – various HND/HNC	Education
Aberystwyth University	http://www.aber.ac.uk/en/ibers/	Ed	Institute of Biology, Environment and Rural Sciences: BSc/HND Agriculture, BSc Environmental Science, BSc/HND Countryside Management MSc/PG Dip River basin dynamics	Education
University of Wales, Bangor	http://www.bangor.ac.uk	Ed	BSc Agriculture, Conservation and Environment, BSc Environmental conservation, BSc Environmental Management, BSc Environmental Science, MSc Conservation and land management, PhD/MPhil Environmental and soil science	Education
University of Warwick	http://www.warwick.ac.uk	Ed	MSc Sustainable crop protection, MSc	Education

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Initiative	Web address	Ed/Aw*	Content Description/Course Title	Classification
			Food security	
Wiltshire College	http://www.wiltscoll.ac.uk/	Ed	HND/Foundation degree Countryside Management, Foundation degree Garden Planning and Design,	Education
Writtle College	http://www.writtle.ac.uk/	Ed/Aw	Variety of horticultural and soil-related courses. BSc Agriculture, MSc Environmental Resource Management	Education
University of York	http://www.york.ac.uk	Ed	PhD/MPhil Environmental Science	
University of St Andrews	http://www.st-andrews.ac.uk/gg/index.shtml	Ed	School of Geography & Geosciences. BSc Geography, BSc Sustainable development	Eductaion
The Macaulay Institute	http://www.macaulay.ac.uk	Ed/Aw	Soil information, soil maps and posters for schools Training courses: Soil recognition, soil quality and protection Land Capability for Agriculture mapping Understanding and use of digital soils and soil-derived data with GIS	Government
BSSS/IPSS Education & research activities	http://www.soils.org.uk/pages/home/	Aw	The BSSS Education Committee promotes Soil Science through a range of activities such as developing education resources and grant funding.	Lobbyist

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