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Critical Appraisal of State and Pressures and Controls on the Sustainable Use of Soils in Wales

Final Report, September 2002

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Background to project

Soil is the weathered surface layer of the earth within which soil organisms live and plants root. Extending to one or two metres, it is the interface and mixing zone between living ecosystems and mineral rock.

Soil is one of Wales's most valuable natural assets and, through its natural functions it underwrites and supports significant components of the Welsh economy. It is also the foundation for its environment, landscape and wildlife. Without soil, land is infertile and barren. The condition and therefore performance of Welsh soils is key to achievement of the Welsh Assembly Government policies for farming, the wider economy, rural development and sustainable development.

Soil protection is now regarded as a key but previously under-resourced area of policy. Following a Royal Commission on Environmental Pollution report, England is developing a soil protection strategy and, after previous leadership from the Council of Europe, the European Commission is now taking the lead in developing policy and draft legislation for the whole of Europe. Key targets will be the control of waste to land, loss of soil organic matter, erosion and desertification processes, and the introduction by member states of adequate national soil monitoring networks. More sustainable soil management, driven by a Welsh soil protection strategy, will be essential to the achievement of compliance with a number of key European environmental directives such as the Water Framework, Groundwater and Environmental Liability Directives.

This aim of this project is to inform Welsh Assembly Government (WAG) staff of the required components and targets for a national soil protection strategy for Wales.

Project objectives

This project was commissioned by the Welsh Assembly Government, Environment Department and managed by the Environment Agency Land Quality Department. The objectives were to:

- Provide a document for use by the WAG in producing their strategy for the sustainable use of soil that summarises the state of Welsh soils, both current and likely future pressures on soil, reviews current response and recommends new ones.
- Conduct a critical appraisal of the current quality, use and diversity of Welsh soil and identify the pressures, conflicts and relevant policies and guidelines. The work will identify gaps in existing controls, and consider options for a more sustainable use of soils and advise on how this might be achieved.

Project team

The project was managed by the Centre for Ecology and Hydrology (CEH), Bangor and conducted by CEH, the National Soil Resources Institute, Institute for Grassland and Environmental Research, North Wyke with specialist assistance from the Geoenvironmental Research Centre in Cardiff University and Cynefin Consultants.

Approach

The contractors were asked to:

- Report on the nature and functioning of Welsh soils;
- Identify the key issues that threaten the soil resources of Wales;
- Consider options for better soil conservation.

For each issue, the scientific background is described, sources of information identified, and current state and likely future scenarios described. Impacts are described on the basis of there effects on the key soil functions. Present and potential future policy responses are described.

Findings

The soils resource in Wales

With the exceptions of the Snowdonian volcanics and younger rocks of the north and south coastal fringes, Wales is underlain by hard sedimentary rocks that are overlain by a characteristic suite of acid soils. About a quarter of Wales is underlain by impermeable and therefore poorly drained soils. While thin peaty surface layers are characteristic of soils on the main hill tops, thicker peat covers less than 5 per cent of the land area of Wales.

The nature of soil development and many of the properties of Welsh soils are the product of several millennia of human occupation. Clearance of the original forest cover had a major impact and resulted in extensive acidification, exacerbated by acid deposition. Wales's industrial past has left a legacy of gross and more widespread chronic contamination of the soil. There is very little information about the biological properties of Welsh soils.

There is a national soil map for Wales at reconnaissance scale but the more detailed information required to inform land management planning and actual decisions is patchy. Various soil monitoring schemes hold information on the state of soils in Wales and the largest is the National Soil Inventory conducted by the Soil Survey of England and Wales in the early 1980s. The number of soil scientists with practical experience of Welsh soils is very small (single figures) and even fewer are active in Wales. Education and training is therefore an issue to be addressed at an early stage.

The following threats to soil were identified:

Soil loss to development

Less than 5 per cent of the land area of Wales is developed and most of this is located in the southern coastal zone and the northeast. Information on rates of new development are not collected at national level and methods used locally are inconsistent. The productive capacity of soil is the only function that receives formal protection under planning law and guidance. Legislation is still in place to protect the Best and Most Versatile agricultural land in Wales but, because of the small extent of grades 1, 2 and 3a in the Principality, these measures are less effective at protecting the soil resource as a whole compared to other parts of the UK. Ecologically valuable soils of lower agricultural productivity, which are widespread in Wales, and are not specifically protected by the legislation. Modification to these measures to include a wider variety of soils would better protect the productive land resource of Wales if new Greenfield development is considered a risk. One local planning authority, Conwy UDP, has a stated policy of protecting the quality of soils through development control.

The treatment of stripped soil materials is covered in guidance to the mineral extraction industry but no such guidance is given to the building and construction industry. Such an extension to guidance would seem sensible.

Soil loss to mineral and peat extraction

While there is an active minerals industry in Wales, no peat has been taken in recent years. Planning guidance specifies that progressive restoration of mineral sites should take place if possible thus reducing soil storage time. The experience of whole turf stripping of herb-rich swards has been mixed possibly because of failure to recreate appropriate soil water and mineral regimes at the new site.

Soil loss by erosion

There can be confusion in the definition of soil erosion. Here it is taken to include all forms of particulate loss and all issues associated with the resulting sediment gain by other parts of the environment.
Soil erosion is occurring throughout Wales as a result of land use and management practices. The majority of upland soil erosion is the result of over-stocking with sheep and of the over-use of footpaths on vulnerable soils. In terms of impact, the 'off-site' effects of sediment on water quality and the resulting eutrophication of freshwater ecosystems, far exceed any loss of productive capacity in the source soil. Insufficient information exists to accurately assess whether erosion is a growing problem and whether particular practices are driving it.

Codes of Practice exist but only the forestry and construction industries pay heed to these. Current responses to soil erosion from farmland and grazed moorland are inadequate. Better education and extension services are required. Soil conservation should become a basic requirement of agri-environment schemes such as Tir Gofal. Minimum standards of soil husbandry and conservation should be required of all beneficiaries of subsidies. Soil erosion almost certainly should be a key target for Wales's Soil Protection Strategy but more research and monitoring is required to better understand the precise nature, scale and drivers of this process.

Soil structure

The soil's physical structure is important to its functional performance. It affects productivity in the agricultural context, is a factor in soil biodiversity and influences soil hydrology. The degradation of soil structure is most likely to be an issue in agricultural soils. However virtually no data exist on the structural condition of Welsh soils and no reliable conclusions can be drawn as to whether action is required. Anecdotal information, largely from England, suggests that soils may be becoming less permeable through a combination of surface capping of arable soils, poaching of grassland soils and topsoil compaction in both.

The acquisition of more information on Welsh soil structural condition is the primary recommendation. Advisory leaflets on soil management exist but mechanisms are required that will encourage farmers to adopt better practice, if monitoring proves that this is needed. The inclusion of soil management obligations in Tir Gofal is identified as one option along with a network of demonstration farms on different soils and land types to act as beacons of good practice.

Soil organic matter

The gradual accumulation of organic matter in the surface layers of soil is one of the processes that forms soil. In climate change, the soil can be both a source and a sink for carbon. The total organic matter content of Wales's soils is unknown but their topsoil contains 37Mt of organic carbon. The best source of information on organic matter is the National Soil Inventory. The mean concentration of 10.8 per cent organic carbon reflects the widespread occurrence of peaty surface layers in moorland soils. There are significant differences in similar soils under different forms of land use. Non-peaty farmland soils lost 0.5 per cent organic carbon content during the period 1980 to 1996, including those under permanent grass. This has implications for Wales's contribution to the Kyoto Protocol on greenhouse gas controls. Declining organic carbon also has implications for structural stability, erodability and the soil's ability to adsorb organic and inorganic contaminants. Some organic matter can be lost from the soil in solution. The growing incidence of discoloured 'dark water' presents a problem to water supply companies.

There is an urgent need for more information to be collected on soil organic matter in Wales. Current data are inadequate and old.

Soil nutrient issues

Soil nutrient status is a two-edged sword. Nutrient depletion of farmland soils results in the lowering of yields while uncontrolled losses of nitrate through leaching and of phosphorus, principally on eroding particles, present a threat to the water environment where they cause eutrophication (nutrient enrichment). Nitrogen (N) and phosphorus (P) controls will be strengthened under the emerging Water Framework Directive. In general however Wales's wet climate purges the river systems of nutrients and result in water of high quality. There is evidence of a gradual but accelerating enrichment of lakes. Many of Wales's freshwaters are naturally poor in nutrients and therefore particularly vulnerable to damage from nutrient losses from soil.

Various codes of practice have been produced that address nutrient management but better advisory and technology transfer mechanisms are needed.

Diffuse soil contamination

Diffuse contamination is distinct from contaminated land sites. The concentrations of particular contaminants in diffuse contamination is not necessarily any lower but the sources of contamination are different and principally aerial deposition, land spreading of wastes, mining and smelting activity and the use of low-grade fertilisers. There is widespread diffuse contamination in Wales. The chief contaminants are heavy metals (lead, zinc, cadmium, copper, chromium), man-made organic compounds (PCBs, PAHs and dioxins), antibiotics, radiocaesium and a range of pathogens and sub-viral particles from faecal and food wastes applied to land. The extent of heavy metal contamination is clouded by the natural variability of background levels.

There is reasonable information on heavy metals at a national level from the National Soil Inventory but little or no information on organic contaminants. Radiocaesium fall out from Chernobyl is still at a level to maintain restrictions on livestock from 360 holdings in North Wales.

While inorganic contaminants are of very low solubility, indestructible and therefore extremely long-lasting, organic contaminants are of varying degradability and longevity. Inputs of zinc have been exceeded by off-take and concentrations have fallen since 1980. The toxicity of contaminants is complex but one estimate is that Lead concentrations in upland soils exceed critical limits for soil biota. Soil conditions are influential in determining the bio-availability of metals, rates of degradation of organic compounds and the viability of pathogenic particles. Metal solubility is strongly influenced by soil acidity. Radiocaesium has cycled between soil and vegetation in peaty upland soils, and thereby remained available for uptake by stock. Persistently moist conditions favour bacterial survival in soil. Insufficient information is available on the durability of particles such as prions (BSE and scrapie).

Controls over the spreading of wastes containing contaminants and pathogens are increasing. There are legal limits However there is insufficient understanding of the fate and behaviour of these materials and organisms in soil, and inadequate information on current concentrations of most of them.

Gross contamination of soils

Past industrial activity in north and south Wales has left a legacy of grossly contaminated land. The extraction and smelting of metal ores has contributed to this throughout Wales. There is a new regulatory framework for dealing with contaminated land that involved the local authorities and the Environment Agency.

A 1988 Welsh Office report suggested that there were 749 potential contaminated land sites, more than 40,000 ha, in Wales. Some of this land has since been reclaimed. This survey excluded sites in current use and small sites of less than 0.5 ha extent. The full extent of contaminated land is unknown.

A three-pronged approach to land contamination through development planning, the regulation of potentially polluting industry through integrated pollution prevention and control (IPPC), and the risk-based clean up of contaminated land will provide effective future control. The extent of gross land contamination should decrease into the future. Existing contamination will be cleaned up on a 'fitness for purpose' basis.

Acidification

Soil acidity reflects the balance within the soil's cation exchange complex between hydrogen ions and acidic forms of aluminium on the one hand and basic metal ions on the other. In the absence of counter-measures such as liming, the natural process is for soil to become gradually more acid if for no other reason than the fact that rainfall is weakly acidic. Welsh topsoils are acid with mean values from various sampling programmes ranging around pH 5.0 to 5.5. Land use has a major influence and under coniferous woodland, for instance, soils are more acid at pH 4.2.

Soil acidification and the associated release of aluminium into Welsh rivers became an issue because of acid deposition of sulphur and nitrogen oxides from industrial production sites and the burning of fossil fuels. Ammonia released from livestock wastes adds to the problem locally. Increased soil acidification has major impacts on moorland vegetation and on freshwater ecosystems and fish stocks. International emission control strategies have sought to deliver reductions in emissions. Much research was carried out in Wales and models predicted gross exceedance of the acid neutralising ability of soils throughout the 1990s. The recent and continuing decline in acid deposition suggests some recovery from that position although high moorland soils will still receive excessive acid inputs well into the current millennium. The impact of certain forms of nitrogen (NH_x) on the acid load is critical to the outcome. If they are included then the future appears much more bleak.

Implementation of the Gothenburg protocol will deliver further reductions in acid deposition loading in the future which will result in a reduction in critical load exceedance for soils. There are very few predictions as to the timescale and degree of recovery from acidification expected as a result of reducing emissions.

Climate change

There is increasing evidence that the UK climate is changing driven by increased emissions of greenhouse gases. Within Wales, the mean temperature of Wales has increased a rate of about 0.3 ^{o}C over the last century whilst annual precipitation has increased by 3%. These trends are expected to continue with predictions of increased temperature of 2 - 4 ^{o}C by 2080 together with increased seasonality in rainfall and a net change in sea-level change of 11 – 71cm. Assessing the impact of these changes on soil is highly problematic, as climate is just one anthropogenic factor which affect the state and function of soils. Other factors which will have had a major influence on soil in the last century include agricultural and forestry practices and atmospheric deposition. Many potential impacts of climate change on soils have been proposed and these may have profound implications for agricultural and forests systems, infrastructure and the natural environment. However, the direction and magnitude of change is frequently uncertain and the complexity of feedbacks between plants, soil and the atmosphere are poorly quantified. Examples of proposed changes include altered rates of greenhouse gases emissions from soils and soil carbon storage, an increased risk of erosion and poaching, reduced stability of infrastructure slopes and increased risk of contaminant transfer to streams and rivers. The current policy driver is the Kyoto protocol adopted by the United Nations Framework Convention on Climate Change which set new greenhouse gas emission reduction targets. The UK has a commitment to reduce emissions by 12.5% by 2010 and a domestic goal of cutting carbon dioxide emissions by 20% by 2010. As carbon sinks may be used as a component of the Kyoto targets, soil carbon stocks and sinks have been estimated for the UK. The greenhouse gas inventory for the UK provides estimates for carbon dioxide sinks specifically for Wales. However, these inventories have many uncertainties and there is a need to significantly enhance the monitoring and survey of soils in Wales, and to increase our understanding of underlying controls of key soil functions if the reliability of future assessments are to improve.

Protection of representative soil systems

Precedents have been set by legal duties to designate the best representatives of the full range of floristic, faunal, geological and physiographic features in Wales, not just those forms that are rare or least disturbed. There are strong reasons for extending the principle of designated sites to soil, even if such designations are voluntary and lack legal status. While the existing biological sites (SSSIs and nature reserves) have been shown to include a wide range of the soil types identified on the National Soil Map of Wales, this is not thought to be adequate. It is concluded that land in certain classes of ownership and in schemes such as Tir Gofal offer opportunities to protect representatives of the full range of soil landscape systems that incorporate soil types, soil biological communities, soil heritage sites and soil features. A recognised network under the management of CCW and with standard recording formats is recommended but will require a comprehensive study of the target sequences, types and features to be included.

Less disturbed soils are more likely to support species-rich ecosystems, and are therefore of value to nature conservation. However this is seen to be a separate issue from the scientific and educational interest and value of designating and protecting a representative range of all soil landscape systems and their component parts, not just those that are rare or least disturbed. All soils should be seen as possessing intrinsic value, not just those that are considered rare or that support semi-natural vegetation.

General conclusions regarding Welsh soil protection policy

A number of overall conclusions are identified.

Education of the wider community

The importance of soil and its significance to the economy and environment is not widely appreciated even in professional circles. The numbers of qualified soil scientists employed in relevant organisations is testament to this lack of understanding.

Soil management will play a vital role in the future achievement of sustainable development. It will impact on the rural economy, agriculture, forestry, land development, nature conservation, landscape management, environmental protection and water and waste management. Training materials and programmes will be needed that cover all these professions. Better provisions for school-age children, for tertiary education and for the general public will also yield a valuable return.

The proposed network of designated soil landscape sites will be a valuable education resource.

Better information and greater knowledge

Throughout the report, the need for more and better, up to date information on the nature and state of soils in Wales is brought up. There is insufficient information and inadequate numbers of trained professional soil scientists to interpret it.

A small Wales Soil Resources Unit staffed by field soil scientists and engaged in the collection of relevant information about the soils of Wales would provide both the information and expertise that is urgently required.

The need to integrate soil protection into other relevant policies

A Welsh Soil Protection Strategy alone will have little impact unless it is clearly integrated into other existing and future strategies and policies. It seems vital that the relevance of the strategy's objectives to policy for a sustainable economy, farming industry, forestry sector, tourist industry and system of development planning is underlined and clearly stated. Management of the Welsh environment, wildlife and landscape is an essential part of sustainable development and pivotal role of soil management in these activities will also need clearly stating.

Most of the threats to soil quality are driven directly or indirectly by other WAG policies (agricultural development, economic investment and growth). It is important that these linkages are understood and parameterised through appropriate strategic environmental impact assessment. Soil is a cross-cutting policy issue, and cross-compliance with other policies will be key to the success of the future soil protection policy.

Immediate opportunities to improve soil protection in Wales

The WAG is well-placed to exploit the following opportunities and to make some early gains in the sustainable management of Welsh soils:

- The incorporation of good soil husbandry measures as a condition of awards under Tir Gofal will fit in with ideas coming from Europe regarding mid-term revision of the CAP.
- The offer of soil management advise through Farming Connect and development of a set of good practice leaflets attuned to Welsh conditions and soils.
- The development of a network of educational facilities in conjunction with establishment of a set of soil landscape sites in partnership with host landowners such as the National Trust and RSPB, the Forest Enterprise, MoD and the water companies.

CRYNODEB GWEITHREDOL

Cefndir i'r prosiect

Pridd yw'r haen hindreuliedig ar wyneb y ddaear lle mae organebau pridd yn byw a lle mae planhigion yn gwreiddio. Mae'n ymestyn hyd at un neu ddau metr o ddyfnder, a hwn yw'r rhyngwyneb rhwng ecosystemau byw a chreigiau mwynol a'r parth lle maent yn cymysgu gyda'i gilydd.

Mae pridd yn un o asedau naturiol mwyaf gwerthfawr Cymru a thrwy ei weithgareddau naturiol mae'n gosod sylfaen i, ac yn cefnogi, rannau pwysig o economi Cymru. Hefyd, pridd yw'r sylfaen ar gyfer amgylchedd, tirwedd a bywyd gwyllt Cymru. Heb bridd, mae'r tir yn anffrwythlon ac yn ddiffrwyth. Mae cyflwr ac felly perfformiad priddoedd Cymru yn allweddol i lwyddiant polisïau Llywodraeth Cynulliad Cymru yngl n â ffermio, yr economi yn fwy eang, datblygiad gwledig a datblygiad cynaliadwy.

Mae diogelu pridd yn cael ei ystyried erbyn hyn fel rhan allweddol o bolisi nad oedd yn cael digon o adnoddau o'r blaen. Yn dilyn Comisiwn Brenhinol ar Lygredd Amgylcheddol, mae Lloegr yn datblygu strategaeth diogelu pridd, ac ar ôl arweinyddiaeth flaenorol o Gyngor Ewrop, mae'r Comisiwn Ewropeaidd yn awr yn cymryd yr awennau wrth ddatblygu polisi a deddfwriaeth ddrafft ar gyfer Ewrop yn gyfan. Y targedau allweddol fydd rheoli gwastraff i dir, colli defnydd organig pridd, prosesau erydu a chreu diffeithiwch a chael y gwledydd sy'n aelodau o'r Comisiwn Ewropeaidd i gyflwyno rhwydweithiau digonol i fonitro pridd yn genedlaethol. Bydd rheoli pridd yn fwy cynaliadwy, ac yn cael ei yrru gan strategaeth diogelu pridd Cymru. Bydd hyn yn hanfodol er mwyn cydymffurfio â llawer o gyfarwyddebau amgylcheddol ac allweddol Ewrop, er enghraifft y Fframwaith D r, a'r Cyfarwyddebau Atebolrwydd D r Daear ac Amgylcheddol.

Nod y prosiect hwn yw rhoi gwybodaeth i Staff Llywodraeth Cynulliad Cymru yngl n â'r cydrannau a'r targedau sydd eu hangen ar gyfer strategaeth diogelu pridd cenedlaethol i Gymru.

Amcanion y Prosiect

Comisiynwyd y prosiect hwn gan Gynulliad Llywodraeth Cymru, Adran yr Amgylchedd ac fe'i rheolwyd gan Adran Ansawdd Tir Asiantaeth yr Amgylchedd. Dyma'r amcanion:

- Darparu dogfen i'w defnyddio gan Lywodraeth Cynulliad Cymru wrth gynhyrchu eu strategaeth ar ddefnyddio pridd yn gynaliadwy, fydd yn crynhoi cyflwr pridd Cymru, y pwysau presennol ar bridd a'r pwysau tebygol yn y dyfodol, ac a fydd yn adolygu'r ymateb ar hyn o bryd ac yn argymell ffyrdd newydd o ymateb.
- Cynnal gwerthusiad beirniadol o'r ansawdd presennol, y defnydd a'r amrywiaeth o bridd Cymru gan nodi'r pwysau, y gwrthdaro a'r polisïau a'r canllawiau perthnasol. Bydd y gwaith yn dynodi bylchau yn y rheoliadau presennol, ac yn ystyried opsiynau ar gyfer defnyddio priddoedd yn fwy cynaliadwy gan gynghori ar sut y gellid cyflawni hyn.

Tîm y prosiect

Rheolwyd y prosiect gan Ganolfan Ecoleg a Hydroleg (CEH), Bangor ac fe'i gynhaliwyd gan CEH, y Sefydliad Cenedlaethol Adnoddau Pridd, Sefydliad ar gyfer Ymchwil Glaswelltir ac Amgylcheddol, Gogledd Wyke gyda chymorth arbenigol oddi wrth y Ganolfan Ymchwil Daearamgylcheddol ym Mhrifysgol Caerdydd ac Ymgynghorwyr Cynefin.

Dull o Weithredu

Gofynnwyd i'r contractwyr:

- Adrodd ar natur a gweithgaredd priddoedd Cymru;
- Nodi'r prif ystyriaethau sy'n bygwth adnoddau pridd Cymru;
- Ystyried opsiynau ar gyfer gwell cadwraeth pridd.

Gyda pob un o'r penawdau hyn ceir disgrifiad o'r cefndir gwyddonol, dynodir y ffynonellau gwybodaeth, a rhoi disgrifiad o'r cyflwr presennol a'r sefyllfaoedd tebygol yn y dyfodol. Caiff yr effeithiau eu disgrifio ar sail y ffordd y maent wedi effeithio ar weithgareddau allweddol pridd. Ceir disgrifiad hefyd o'r ymatebion i'r polisïau presennol ac i'r polisïau tebygol yn y dyfodol.

Casgliadau

Adnodd priddoedd yng Nghymru

Ag eithrio creigiau folcanig Eryri a'r creigiau ieuengach ar gyrion arfordirol y de a'r gogledd, mae gan Gymru haen waelodol o greigiau gwaddod caled sydd wedi eu gorchuddio gan gyfres nodweddiadol o briddoedd asid. Felly, mae oddeutu chwarter Cymru gyda haen waelodol o briddoedd anathraidd nad ydynt wedi eu draenio'n dda. Tra bod haenau arwynebol mawnog tenau yn nodweddiadol o briddoedd ar frig y prif fryniau, mae mawn mwy trwchus yn gorchuddio llai na 5 y cant o arwynebedd tir Cymru.

Mae natur datblygiad pridd a llawer o briodweddau priddoedd Cymru wedi ei achosi gan feddiannaeth dynol dros sawl mileniwm. Cafodd clirio'r goedwig wreiddiol effaith sylweddol ac arweiniodd at asideiddio helaeth a waethygwyd gan ddyddodiad asid. Mae gorffennol diwydiannol Cymru wedi gadael etifeddiaeth o halogiad cronig helaeth a mwy eang o'r pridd. Nid oes llawer o wybodaeth yngl n â phriodweddau biolegol priddoedd Cymru.

Mae yna fap pridd cenedlaethol ar gyfer Cymru ar raddfa addas i ddod o hyd i wahanol fathau o bridd, ond tenau iawn yw'r wybodaeth fanwl sydd ei hangen i roi gwybodaeth ar gyfer cynlluniau a phenderfyniadau yngl n â rheoli tir. Mae amryw o gynlluniau monitro pridd yn cynnwys gwybodaeth yngl n â chyflwr priddoedd yng Nghymru. Y mwyaf yw'r Rhestr Bridd Genedlaethol a gynhaliwyd gan Arolwg Pridd Cymru a Lloegr yn y 1980au cynnar. Mae nifer y gwyddonwyr pridd gyda phrofiad ymarferol o briddoedd Cymru yn fychan iawn (llai na 10) ac mae llai fyth ohonynt un yn weithredol yng Nghymru. Felly mae addysg a hyfforddiant yn ystyriaeth sydd angen ei wynebu yn fuan.

Nodwyd y bygythiadau canlynol i bridd:

Colli pridd i ddatblygiadau

Mae llai na 5 y cant o arwynebedd tir Cymru wedi ei ddatblygu ac mae y rhan fwyaf ohono wedi ei leoli yn ardal arfordirol y de a'r gogledd-ddwyrain. Nid yw gwybodaeth yn cael ei casglu ar lefel cenedlaethol yngl n â graddfa datblygiadau newydd ac mae'r dulliau a ddefnyddir yn lleol yn anghyson. Yr unig weithgaredd sy'n cael ei ddiogelu'n ffurfiol o dan gyfraith a chanllawiau cynllunio yw gallu cynhyrchiol y pridd. Mae deddfwriaeth yn parhau i fod mewn grym i ddiogelu'r tir amaethyddol Gorau a Mwyaf Amlbwrpas yng Nghymru. Ond, oherwydd prinder tir graddfa 1, 2 a 3a yng Nghymru, ar y cyfan nid yw'r dulliau hyn yn ffyrdd mor effeithiol o ddiogelu pridd fel adnodd o'i gymharu â rhannau eraill o'r Deyrnas Gyfunol. Nid yw priddoedd sydd yn werthfawr o ran ecoleg ac yn isel o ran cynhyrchedd amaethyddol yn cael eu diogelu'n benodol gan y ddeddfwriaeth, ac mae llawer o'r priddoedd hyn yng Nghymru. Byddai addasu'r dulliau hyn i gynnwys amrywiaeth ehangach o briddoedd yn diogelu tir cynhyrchu Cymru yn well pe byddid yn ystyried datblygiadau Caeaeu Gwyrdd yn risg. Mae gan un awdurdod cynllunio lleol, yng Nghynllun Datblygu Unedol Conwy, bolisi cydnabyddedig o ddiogelu ansawdd y priddoedd trwy reoli datblygiadau.

Mae canllawiau i'r diwydiant echdynnu mwynau yngl n â sut i drin defnyddiau pridd sydd wedi eu stripio. Ond ni roddir canllawiau o'r fath i'r diwydiant adeiladu ac adeiladwaith. Byddai ymddangos yn synhwyrol ymestyn y canllawiau i'r perwyl hwnnw.

Colli pridd o ganlyniad i echdynnu mwynau a mawn

Er bod yna ddiwydiant mwynau gweithredol yng Nghymru, nid oes mawn wedi cael ei gymryd yn y blynyddoedd diweddaraf. Mae canllawiau cynllunio yn nodi y dylid adfer safleoedd mwynau yn gynyddol os yn bosib, gan felly gostwng yr amser storio pridd. Mae'r profiad o stripio tywyrch cyfan o lastir yn llawn perlysiau wedi bod yn un cymysg o bosib, oherwydd y methiant i ailgreu d r pridd priodol a phatrymedd mwynau priodol yn y safle newydd.

Colli pridd trwy erydiad

Mae'r diffiniad o erydu pridd yn gallu achosi dryswch. Mae ei ystyr yn y fan hon yn cynnwys pob math o golled ronynnol a phob mater sy'n gysylltiedig â'r gwaddodion a enillir o ganlyniad gan rannau eraill o'r amgylchedd. Mae erydiad pridd yn digwydd ar hyd a lled Cymru o ganlyniad i'r defnydd o'r tir ac arferion rheoli. Mae'r rhan fwyaf o erydiad pridd tir uchel yn digwydd oherwydd cadw gormod o stoc o ddefaid a gorddefnyddio llwybrau ar briddoedd sy'n agored i niwed. O ran effaith, mae effeithiau gwaddodion "oddi ar y safle" ar ansawdd d r, a'r ewtroffeiddio sy'n digwydd i ecosystemau d r croyw yn sgil hynny, yn llawer mwy nag unrhyw golled yng ngallu cynhyrchiol y pridd gwreiddiol. Nid oes digon o wybodaeth yn bodoli i asesu'n gywir a yw erydiad yn broblem sy'n tyfu ac os yw'n cael ei brysuro gan arferion penodol.

Mae Codau Ymarfer yn bodoli ond dim ond y diwydiannau coedwigaeth ac adeiladu sy'n talu sylw i'r rhain. Nid yw'r ymateb presennol i erydiad pridd o diroedd ffermio a gweundir pori yn ddigonol. Mae'n rhaid cael gwell addysg yn ogystal â gwasanaethau estyniad. Dylai cadwraeth pridd fod yn un o ofynion sylfaenol cynlluniau amaeth-amgylcheddol megis Tir Gofal. Dylai isafswm safonau hwsmonaeth pridd a chadwraeth gael eu gosod i'r rhai sy'n derbyn cymorthdaliadau. Dylai erydiad pridd fod yn darged allweddol ar gyfer Strategaeth Diogelu Pridd Cymru, ond mae angen gwneud mwy o ymchwil a monitro i ddeall natur, maint a gyrwyr penodol y broses hon yn well.

Strwythur y Pridd

Mae strwythur ffisegol y pridd yn bwysig i'w berfformiad gweithredol. Mae'n cael effaith ar gynhyrchedd yn y cyd-destun amaethyddol, mae'n ffactor mewn bioamrywiaeth pridd ac mae'n dylanwadu ar hydroleg pridd. Mae diraddiad strwythur y pridd yn fwy tebygol o fod yn ystyriaeth mewn priddoedd amaethyddol. Serch hynny, nid oes nemor ddim data yn bodoli ar gyflwr strwythurol priddoedd Cymru ac ni ellir dod i unrhyw gasgliad dibynadwy i ddweud a oes angen gweithredu. Mae gwybodaeth ar lafar, yn bennaf o Loegr, yn awgrymu y gall priddoedd fod yn mynd yn llai athraidd oherwydd cyfuniad o gapio arwyneb priddoedd âr, cymryd priddoedd glastir a chywasgu'r uwchbridd yn y ddau achos.

Y prif argymhelliad yw cael rhagor o wybodaeth yngl n â chyflwr strwythurol pridd Cymru. Mae taflenni ymgynghorol ar reoli pridd yn bodoli ond mae angen gweithdrefnau a fydd yn annog ffermwyr i fabwysiadu gwell arfer, os bydd monitro yn dangos bod angen hynny. Mae cynnwys ymrwymiadau rheoli pridd yn Tir Gofal yn cael ei nodi fel un dewis, ynghyd â chreu rhwydwaith o ffermydd arddangos yn dangos gwahanol briddoedd a mathau o dir i weithredu fel ffermydd disglair o arfer dda.

Defnydd organig pridd

Mae'r croniad graddol o ddefnydd organig yn haenau arwyneb y pridd yn un o'r prosesau sy'n ffurfio pridd. Mewn newidiadau yn yr hinsawdd, gall y pridd fod yn ffynhonnell ac yn suddfan i garbon. Nid ydym yn gwybod beth yw holl gynnwys defnydd organig priddoedd Cymru, ond mae'r uwchbridd yn cynnwys 37Mt o garbon organig. Y Rhestr Bridd Genedlaethol yw'r ffynhonnell orau o wybodaeth yngl n â defnydd organig. Mae'r crynodiad cymedr o 10.8 y cant o garbon organig yn adlewyrchu pa mor eang yw haenau arwyneb mawnog mewn priddoedd gweundirol. Mae gwahaniaethau o bwys mewn priddoedd cyffelyb ar dir sy'n cael ei ddefnyddio mewn ffyrdd gwahanol. Yn y cyfnod 1980 i 1996 collodd priddoedd fferm oedd ddim yn fawnog 0.5 y cant o'u cynnwys carbon organig, ac roedd hyn yn cynnwys tir dan laswellt parhaol. Mae gan hynny oblygiadau i gyfraniad Cymru at Brotocol Kyoto yngl n â rheoli nwyon t gwydr. Mae gostyngiad yn y carbon organig yn effeithio hefyd ar sefydlogrwydd strwythurol, a natur erydol y pridd, yn ogystal a'i allu i arsugno halogion organig ac anorganig. Gellir colli peth deunydd organig o'r pridd mewn d r. Mae'r cynnydd mewn 'd r tywyll' yn broblem i gwmnïau cyflenwi d r.

Mae angen brys i ragor o wybodaeth gael ei chasglu yngl n a deunydd organig pridd yng Nghymru. Mae'r data presennol yn hen ac yn annigonol.

Maetholion y Pridd

Mae statws maetholion y pridd yn gleddyf deufin. Mae colli maetholion o briddoedd fferm yn arwain at gnydau llai ac mae colli nitradau yn ddireolaeth trwy drwytholchiad, a cholli ffosfforws, yn bennaf trwy erydiad gronynnau, yn fygythiad i amgylchedd y d r lle maent yn achosi ewtroffigedd (cyfoethogiad maetholion). Bydd rheolaeth ar Nitrogen (N) a ffosfforws (P) yn cael ei gryfhau gan y Cyfarwyddeb Fframwaith D r sydd ar y gweill. Ond yn gyffredinol mae hinsawdd gwlyb Cymru yn golchi'r maetholion allan o afonydd y wlad ac mae hynny yn arwain at dd r o ansawdd uchel. Mae tystiolaeth bod cyfoethogiad graddol ond cynyddol yn digwydd yn y llynnoedd. Mae llawer o ddyfroedd croyw Cymru yn dlawd mewn maetholion o ran natur; maent felly yn arbennig o agored i niwed trwy golli maetholion o'r pridd.

Cynhyrchwyd amryw god ymarfer sy’n mynd i’r afael â rheoli maetholion, ond mae angen gwell trefniadau ymgynghorol a gwell dulliau o drosglwyddo technoleg.

Halogiad pridd tryledol

Mae halogiad tryledol yn wahanol i safleoedd tir sydd wedi eu halogi. Nid yw’n golygu dim llai o halogion penodol mewn crynodiadau tryledol ond mae ffynonellau’r halogiad yn wahanol, yn bennaf maent yn cael eu dyddodi o’r awyr, o wasgaru gwastraff ar y tir, o waith cloddio a mwyndoddi ac o ddefnyddio gwrtaith graddfa isel. Yng Nghymru mae halogiad tryledol yn eithaf amlwg ar hyd a lled y wlad. Y prif halogion yw’r metelau trwm (plwm, sinc, cadmiwm, copr, cromiwm), cyfansoddion organig o waith dyn (PCBs, PAHs a diocsins), gwrthfiotigau, radiocaesium ac amrywiaeth o wahanol bathogenau a gronynnau is-firal o wastraff carthion a gwastraff bwyd a wasgerir ar y tir. Mae maint yr halogiad trwm yn cael ei guddio gan y ffaith bod y lefelau cefndir yn amrywio yn naturiol.

Mae gwybodaeth resymol am fetelau trymion ar lefel genedlaethol ar gael o’r Rhestr Briddoedd Cenedlaethol *(National Soil Inventory)* ond does dim, neu fawr ddim gwybodaeth am halogion organig. Mae’r gwaddodiad radiocaesium o Chernobyl yn dal i fod mor uchel fel bod cyfyngiadau ar dda byw mewn 360 o ffermydd yng Ngogledd Cymru.

Mae halogion anorganig yn wael iawn am hydoddi ac ni ellir eu dinistrio. Maent felly yn para yn eithriadol o hir tra bod halogion organaidd yn amrywio o ran eu diraddiad a’u hirhoedledd. Mae mwy o sinc wedi cael ei golli na’i ennill ers 1980 ac mae lefelau crynodiad ohono wedi gostwng. Mae gwenwyndra halogion yn beth cymhleth ond yn ôl un amcangyfrif mae crynodiad Plwm ym mhriddoedd yr ucheldir yn uwch na’r cyfyngiadau critigol ar gyfer y biota pridd. Mae cyflwr y pridd yn dylanwadu ar benderfynu bio-argaeledd metelau, cyfradd diraddiad sylweddau organig a dichonoldeb gronynnau pathogenig. Mae asidrwydd y pridd yn dylanwadu’n gryf ar hydoddiad metelau. Mae radiocaesiwm wedi cylchu rhwng pridd a llystyfiant mewn pridd mawnog yn yr ucheldir ac felly wedi bod ar gael i stoc fferm. Mae lleithder parhaus yn ffafrio goroesiad bacteria yn y pridd. Does dim digon o wybodaeth ar gael yngl n a gwydnwch a pharhad gronynnau megis prionau (BSE a Chlefyd y Crafu *(scrapie))*.

Mae mesurau rheoli mewn perthynas â gwasgaru defnyddiau gwastraff sy’n cynnwys halogion a pathogenau yn cynyddu. Mae cyfyngiadau cyfreithiol ond does dim digon o ddealltwriaeth yngl n â thynged y sylweddau a’r organebau hyn ac am y ffordd y maent yn ymddwyn yn y pridd, na digon o wybodaeth am grynodiad presennol y rhan fwyaf ohonynt.

Halogi pridd yn ddifrifol

Yn sgil gweithgarwch diwydiannol y gorffennol yng ngogledd a de Cymru mae llawer o dir wedi cael ei halogi yn ddifrifol. Mae cloddio a mwyndoddi mwynau metel wedi cyfrannu at hyn ym mhob ran o Gymru. Erbyn hyn mae yna fframwaith reolaethiol newydd i ddelio gyda thir wedi ei halogi ac mae’r awdurdodau lleol ac Asiantaeth yr Amgylchedd yn gyfrannog yn y broses.

Ym 1988 awgrymodd adroddiad gan y Swyddfa Gymreig bod 749 o safleoedd halogedig posib yng Nghymru, mwy na 40,000 hectar. Ers hynny mae peth o’r tir wedi cael ei adfer. Nid oedd yr arolwg hwnnw yn cynnwys safleoedd a oedd yn dal i gael eu defnyddio ar y pryd na safleoedd bychan o lai na 0.5 hectar. Nid oes neb yn gwybod yn iawn faint o dir sydd wedi ei halogi.

Yn y dyfodol bydd tri dull o weithredu mewn perthynas â halogiad tir, sef cynllunio datblygu, rheoli diwydiant sydd â’r potensial o lygru trwy gynllun integredig rheoli ac atal llygredd *(IPC)*, a glanhau tir halogedig ar sail y risg. Yn y dyfodol dylai maint y tir sydd wedi cael ei halogi leihau. Bydd yr halogiad presennol yn cael ei lanhau ar sail bod yn ‘ffit i’r pwrpas’.

Asideiddio

Mae asidedd pridd yn adlewyrchiad o’r cydbwysedd sydd o fewn cymhlyg cyfnewid catïon rhwng ionau hydrogen a ffurfiau asidig o alwminiwm ar yr un llaw ac ionau metel sylfaenol ar y llaw arall. Oni ddefnyddir mesurau megis calchu i wrthweithio’r broses, y broses naturiol fydd i’r pridd ddod yn fwy asidig dros amser gan bod glaw ei hun yn asid gwan iawn. Mae uwchbriddoedd Cymru yn asidig gyda gwerthoedd cymedrig, yn ôl gwahanol raglenni sampl, yn amrywio rhwng pH 5.0 a 5.5. Mae’r defnydd a wneir o’r tir yn ddylanwad mawr ac mae’r pridd yn fwy asidig o dan goed conwydd sef pH 4.2.

Daeth asideiddio pridd ac yn sgil hynny rhyddhau alwminiwm i afonydd Cymru yn fater llosg oherwydd dyddodiad asid swlffwr a nitrogen ocsid o safleoedd cynhyrchu diwydiannol ac oherwydd llosgi tanwydd ffosil. Mae amonia sy’n cael ei ryddhau o wastraff da byw yn ychwanegu at y broblem yn lleol. Mae’r cynnydd yn asideiddiad y pridd wedi cael effaith fawr ar lystyfiant gweundir ac ar ecosystemau d r croyw ac ar y stoc pysgod. Mae strategaethau rhyngwladol i reoli allyriad wedi ceisio sicrhau gostyngiad mewn allyriant.

Gwnaethpwyd llawer o ymchwil yng Nghymru ac yr oedd y modelau yn rhagweld na fyddai priddoedd yn gallu niwtraleiddio cymaint â hynny o asid yn ystod y 1990au. Mae'r gostyngiad diweddar mewn dyddodiad asid, gostyngiad sy'n parhau, yn awgrymu peth adferiad o'r sefyllfa honno er y bydd lefelau asid sy'n cael ei fewnbynnu i briddoedd gweundir yn ormodol am ran fawr o'r mileniwm presennol. Mae effaith rhai mathau o nitrogen (NH_x) ar y llwyth asid yn gritigol i ganlyniad hynny. Os ydynt hwy yn cael eu cynnwys mae'r dyfodol yn edrych yn llawer mwy llwm.

Bydd gweithredu protocol Gothenburg yn achosi gostyngiadau pellach yn y llwyth asid a ddyddodir yn y dyfodol, fydd yn achosi gostyngiad yn y gorfewnbwn critigol ar gyfer priddoedd. Ychydig iawn sy'n fodlon proffwydo yngl n â ffrâm amser a graddfa adferiad o asideiddio o ganlyniad i leihau allyriant.

Newid hinsawdd

Mae tystiolaeth gynyddol fod hinsawdd y Deyrnas Gyfunol yn cael ei newid oherwydd cynnydd yn allyriant nwyon t gwydr. Yng Nghymru mae'r tymheredd cymhedrig wedi cynyddu ar gyfradd o 0.3^{oC} dros y ganrif ddiwethaf, tra bod y dyddodiad blynyddol wedi codi o 3%. Disgwylir y bydd y tueddiadau hyn yn parhau a phroffwydir y bydd y tymheredd yn uwch o 2 - 4 ^{oC} erbyn 2080 ynghyd â chynnydd yn natur dymhorol glawiad a newid net yng nghyfnewidiad lefel y môr o 11 – 71cm. Mae asesu effaith y newidiadau hyn ar y pridd yn llawn problemau, gan nad yw'r hinsawdd ond yn un ffactor anthropogenig sy'n effeithio ar gyflwr a gweithgaredd priddoedd. Mae'r ffactorau eraill fydd wedi cael effaith fawr ar bridd yn ystod y ganrif ddiwethaf yn cynnwys arferion coedwigaeth a ffermio, isadeiledd a'r amgylchedd naturiol. Ond mae cyfeiriad a maint y newid yn ansicr yn aml, a chymhlethdod y cydberthynas rhwng planhigion, pridd a'r awyrgylch heb eu mesur yn dda. Mae'r enghreifftiau o newidiadau arfaethedig yn cynnwys cyfraddau newydd o allyriant nwyon t gwydr o briddoedd ac o storfeydd carbon y pridd, a chynnydd yn y risg o erydu a chipio *(poaching)*, gostyngiad yn sefydlogrwydd isadeiledd goleddfau a chynnydd yn y risg bod halogion yn cael eu trosglwyddo i nentydd ac afonydd. Yr hyn sy'n gyrru'r polisi presennol yw protocol Kyoto a fabwysiadwyd gan Fframwaith Confensiwn y Cenhedloedd Unedig ar Newid Hinsawdd. Yr oedd hyn yn gosod targedau newydd ar gyfer gostwng allyriant nwyon t gwydr. Mae'r Deyrnas Gyfunol wedi ymrwymo i ostwng 12.5% ar allyriant erbyn 2010 ac mae ganddo nod domestig o dorri 20% ar allyriant carbon deuocsid erbyn 2010. Gan bod modd defnyddio sinciau carbon fel un rhan o dargedau Kyoto, gwnaethpwyd amcangyfrif o stociau a sinciau carbon pridd yn y Deyrnas Gyfunol. Mae'r rhestr ar gyfer nwyon t gwydr y Deyrnas Gyfunol yn cynnwys amcangyfrifon penodol am sinciau carbon deuocsid yng Nghymru. Ond mae llawer o ansicrwydd yngl n â'r rhestrau hyn ac mae angen gwelliant sylweddol mewn monitro ac arolygu priddoedd yng Nghymru ac angen gwella ein dealltwriaeth o'r ffactorau gwaelodol sy'n rheoli gweithgareddau allweddol y pridd os ydym am wneud asesiadau mwy dibynadwy yn y dyfodol.

Gwarchod systemau pridd cynrychioliadol

Mae cynsail i hyn yn y dyletswyddau cyfreithiol sydd i ddynodi y systemau sy'n cynrychioli orau yr **holl** amrediad o nodweddion ffawna, fflora, daeareg a ffisiograffig yng Nghymru - nid yn unig y rhai sydd fwyaf prin neu sydd wedi cael eu styrbio leiaf. Mae rhesymau da dros ymestyn yr egwyddor o ddynodi safleoedd fel bod safleoedd yn cael eu dynodi ar gyfer pridd hefyd, hyd yn oed os bydd hynny'n wirfoddol a heb statws cyfreithiol. Er bod y safleoedd biolegol presennol (SoDDGA a gwarchodfeydd natur) yn cynnwys amrediad eang o wahanol fathau o briddoedd sy'n cael eu dangos ar fap cenedlaethol Priddoedd Cymru, ni chredir bod hyn yn ddigonol. Yr ydym yn dod i'r casgliad bod tiroedd mewn rhai mathau o berchenogaeth ac mewn cynlluniau megis Tir Gofal yn cynnig cyfleoedd i warchod systemau cynrychioladol ar draws yr amrediad llawn o systemau tirwedd pridd sy'n ymgorffori gwahanol fathau o bridd, cymunedau biolegol pridd, safleoedd treftadaeth pridd a nodweddion pridd. Argymhellir sefydlu rhwydwaith gydnabyddedig dan reolaeth Comisiwn Cefn Gwlad Cymru gyda dulliau safonol o gofnodi ond bydd angen astudiaeth gynhwysfawr o'r dilyniant yr anelir ato, ac o'r mathau a'r priodeoleddau fydd yn cael eu cynnwys.

Mae priddoedd yr ymyrrwyd llai â nhw yn fwy tebygol o gynnal ecosystemau sy'n gyfoethog mewn rhywogaethau, ac felly y maent yn werthfawr o safbwynt cadwraeth natur. Serch hynny mae hyn yn beth gwahanol i'r diddordeb gwyddonol ac addysgol, ac i'r gwerth a welir mewn dynodi a gwarchod amrediad cynrychioliadol o bob system tirwedd pridd a'u rhannau cyfansoddol, nid yn unig y rhai sy'n brin neu heb gael eu hymyrryd lawer. Dylid cydnabod bod gan bob pridd ei werth cynhenid nid yn unig y priddoedd sy'n cael eu hystyried yn brin neu sy'n cynnal llystyfiant semi naturiol.

Casgliadau cyffredinol yngl n â pholisi gwarchod priddoedd Cymru

Mae nifer o gasgliadau cyffredinol.

Addysg yn y gymuned ehangach

Nid yw pwysigrwydd pridd a'i werth i'r economi ac i'r amgylchedd yn cael ei gydnabod yn eang hyd yn oed mewn cylchoedd proffesiynol. Mae nifer y gwyddonwyr pridd cymwysedig sy'n cael eu cyflogi gan y mudiadau perthnasol yn dyst i'r diffyg dealltwriaeth hwn.

Bydd lle hanfodol i reolaeth pridd yn nyfodol datblygiad cynaliadwy a bydd yn ffactor bwysig yn yr hyn fydd yn cael ei gyflawni yn y dyfodol. Bydd yn effeithio ar yr economi wledig, ar amaethyddiaeth, ar goedwigaeth, ar ddatblygiad tir, ar gadwraeth natur, ar reolaeth tirwedd, as warchod yr amgylchedd, ac ar reoli d r a gwastraff. Bydd angen defnyddiau a rhaglenni hyfforddi fydd yn ymwneud â phob un o'r proffesiynau hyn. Byddai hefyd yn werth gwneud yn si r bod gwell ddarpariaeth ar gyfer plant o oed ysgol, addysg drydyddol a'r cyhoedd yn gyffredinol.

Bydd y rhwydwaith arfaethedig o safleoedd tirwedd pridd dynodedig yn adnodd addysgol gwerthfawr.

Gwell hysbysrwydd a mwy o wybodaeth

Trwy gydol yr adroddiad yr ydym wedi pwysleisio'r angen am fwy o wybodaeth, gwell gwybodaeth a gwybodaeth fwy cyfredol yngl n â natur a chyflwr y priddoedd yng Nghymru. Mae'r wybodaeth yn annigonol a nifer y gwyddonwyr pridd proffesiynol hyfforddedig a all ei dehongli, yn annigonol.

Byddai Uned Adnoddau Pridd bychan ar gyfer Cymru, wedi ei staffio gan wyddonwyr pridd yn y maes, ac a fydd yn prysur gasglu'r wybodaeth berthnasol am briddoedd Cymru, yn darparu'r wybodaeth a'r arbenigedd y mae cymaint o angen amdano.

Yr angen i integreiddio gwarchod pridd gyda pholisïau perthnasol eraill

Ynddo'i hun, ychydig effaith a gaiff Strategaeth Gwarchod Pridd Cymru oni fydd y Strategaeth wedi cael ei hintegreiddio yn amlwg gyda strategaethau a pholisïau eraill sy'n bodoli ac a fydd yn bodoli yn y dyfodol. Mae'n ymddangos yn hanfodol tanlinellu a datgan yn glir beth yw perthnasedd amcanion y strategaeth i'r polisi o blaid economi gynaliadwy, diwydiant ffermio, sector coedwigaeth, diwydiant twristiaeth a system o gynllunio datblygu. Mae rheoli amgylchedd Cymru, ei bywyd gwyllt a'i thirwedd, yn rhan hanfodol o ddatblygu cynaliadwy a bydd angen pwysleisio'r rôl allweddol sydd gan reoli pridd yn y gweithgareddau hyn.

Mae'r rhan fwyaf o'r bygythiadau i ansawdd pridd yn cael eu hachosi yn uniongyrchol neu yn anuniongyrchol gan bolisïau eraill Llywodraeth Cynulliad Cymru (Datblygiad economaidd, buddsoddi economaidd a thwf). Mae'n bwysig bod y cysylltiadau hyn yn cael eu deall a bod eu paramedrau yn cael eu gosod yn sgil asesiad effaith amgylcheddol strategol priodol. Mae pridd yn fater o bolisi trawsdestunol a'r allwedd i lwyddiant polisi gwarchod pridd yn y dyfodol fydd sicrhau ei fod yn cydymffurfio â pholisïau eraill.

Cyfleoedd ar unwaith i wella gwarchod priddoedd yng Nghymru

Mae Llywodraeth Cynulliad Cymru mewn sefyllfa dda i fanteisio ar y cyfleoedd sy'n dilyn ac i wneud cynnydd buan o safbwynt rheolaeth gynaliadwy priddoedd Cymru.:

- Byddai ymgorffori mesurau o hwsmonaeth bridd dda fel amod dyfarniadau o dan Tir Gofal yn gyson â'r syniadau sy'n deillio o Ewrop yngl nag adolygiad canol tymor y Polisi Amaethyddol Cyffredin.
- Cynnig cyngor yngl n â rheolaeth pridd trwy Cyswllt Ffermio a datblygu cyfres o daflenni arfer dda yn benodol ar gyfer amgylchiadau a phriddoedd Cymru.
- Datblygu rhwydwaith o gyfleusterau addysgol yn gysylltiedig â sefydlu cyfres o safleoedd tirwedd pridd mewn partneriaeth â thirfeddianwyr megis yr Ymddiriedolaeth Cenedlaethol, RSPB, y Fenter Goedwigaeth, y Weinyddiaeth Amddiffyn a'r cwmnïau d r.

1. INTRODUCTION

Soils are an essential earth-system resource occurring at the interface of the lithosphere, biosphere, hydrosphere and atmosphere. Soils constitute a unique system comprising distinctive biological, physical and chemical components which provide a number of important economic, social and environmental functions. Soils support the production of food and fibre through agriculture and forestry which depend on soil for the supplies of water and nutrients and for rooting. Soil provides a sink for terrestrial carbon and a historical record of previous land use, climate and human activity. Soils also acts as a sink for many contaminants protecting both water and air from pollution. Soils are intimately involved with the water cycle through the regulation of runoff. The soil resource is finite and fragile and can take many thousands of years to develop. Soils are increasingly subject to wide variety of external pressures including physical erosion, loss through development, chemical contamination, acidification, nutrient enrichment and nutrient depletion. The purpose of this study is to evaluate the current and likely future effects of these pressures on soils in Wales in order to inform the development of a soil strategy for Wales.

The importance of soil protection has been recognised internationally as well as within the EU and the UK. The Rio Summit in 1992 adopted a number of measures with direct relevance to soil protection through the concept of sustainable development, and conventions on biodiversity and climate change. Within the EU, the 6th Environment Action Programme includes a thematic strategy on soil protection with particular emphasis on preventing erosion, deterioration, contamination and desertification. The strategy is described in more detail in the recent EU publication "Towards a Thematic Strategy for Soils" (CEC, 2002). In releasing this document, the Environment Commissioner has acknowledged that until very recently, soils have lagged behind air and water in terms of the action taken for their preservation and protection. The current EU publication places emphasis on protection of soil function and is essentially a scoping document rather than proposal for detailed strategies. However it indicates the areas of concern at EU level and provides a framework and timetable for more specific technical and policy measures. A key date is June 2004 for the publication of a report on the technical measures, legislative and policy initiatives taken by the EU for the protection of soils. Priority areas will be:

- A proposal for soil monitoring
- A communication on soil erosion, soil organic matter decline and soil contamination which will include detailed recommendations for future measures and actions.

Within the UK, the Royal Commission on Environmental Pollution published its 19th report on 'The Sustainable Use of Soils' in 1996 (RCEP, 1996). It stated that soils in the UK are an important environmental resource and should be given the same high level of protection as the other environmental media, namely air and water. The RCEP report made a total of 91 recommendations of which the first was that "the Environment and Agriculture Departments jointly draw up and implement a soil protection policy for the UK". In response to this and other RCEP recommendations, a number of consultation and policy documents have emerged from Scotland and England. These include:

- "Issues associated with the development of a soil protection strategy for Scotland" (Adderley *et al*., 2001)
- "State of the Environment Soil Quality Report" (SEPA, 2001)
- "Identification and development of a set of national indicators for soil quality" (Loveland and Thompson (Eds.), 2001)
- The draft soil strategy for England – a consultation paper (DETR, 2001)

Against this background of EU and UK activity, Welsh Assembly Government (WAG) commissioned this report to provide a critical appraisal of the state of Welsh soils, the current and future pressures on soils in Wales and the control measures in place for their protection.

The report is structured in the following way. Chapter 2 provides an overview of the soil resource in Wales including an assessment of soil information sources. The following ten chapters consider ten issues by examining the pressures they impose on six key soil functions. These functions are summarised with short explanatory notes in Table 1.1.

The issues are broadly grouped into three categories:

- physical (Chapters 3 through 6);
- chemical (Chapters 8 through 10);
- transboundary / cross cutting (Chapter 11 – Acidification and 12 - Climate change).

Table 1.1 Brief explanatory descriptions of the six key soil functions considered in this report (Adapted from DETR, 2001 and Blum, 1993).

Biomass, food and fibre production • Growing medium for food, timber & energy crops & the basis of livestock production • Interacting with climate to determine which crops can be grown	**Ecosystems, habitats and biodiversity** • Determining the nature and distribution of life • Foundation for terrestrial ecosystems: nutrient & water supply, rooting medium, seed-bank & habitat for soil fauna
Environmental interactions • At the interface between the atmosphere, biosphere, geosphere and hydrosphere • Filtering substances from water and recipient of particles deposited from the atmosphere • Exchange of atmospheric gases & carbon store • Regulating runoff to surface waters and recharge to aquifers	**Provision of raw materials** • Direct source of minerals & resources such as peat and top soil • Natural reservoir for water
Provision of a platform • Foundation for civilisation such as buildings and infrastructure • Influence of land use and landscape	**Protection of cultural heritage** • Storage & protection of evidence of cultural heritage such as archaeological artefacts and history of climate change

Loss of soil organic matter is recognised as a key issue with physical and chemical implications for soil function. These are described in Chapter 7 which provides a bridge between the physical and chemical issues affecting soils.

Acidification and climate change (Chapters 11 and 12) are two issues which have a transboundary context and rely mainly on the implementation of control measures at a much larger scale than for many of the others with the possible exception of atmospheric deposition of metals and organic contaminants to soils. Climate change in particular is a cross-cutting issue which may interact with many of the others in a complex manner to either alleviate or exacerbate the pressures on soils. Thus, for example, any changes in rainfall patterns and intensity due to climate change may affect soil erosion, soil structure and the leaching of nutrients and contaminants.

Chapter 13 examines the principals behind the conservation of representative soil systems in a manner analagous to the conservation and designation of floristic, faunal, geological and physiographic features in Wales. Its link to soil function is through the provision of a network of soil conservation sites which can provide WAG with a resource to facilitate better understanding of soil processes through research, leading to improved management and control measures to enhance soil function. Such sites would also provide an educational resource for those with an interest or involvement with soil.

Chapter 14 concludes the report with a succinct consideration of each issue in relation to soil function by analysing its:

- Significance to a function
- The spatial extent – is it a local, regional or national issue and at what scale can it be addressed?
- The current level of understanding and characterisation of the issue
- The level of control currently available
- Ease of control for Welsh Assembly Government

The consortium also undertook a survey of stakeholders with interests in soils in Wales. The findings are presented in full in Appendix I and are summarised in Chapter 14. Appendices have also been used to provide supplementary information for some individual chapters.

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2. THE SOILS RESOURCE IN WALES

Summary

- The majority of Wales is underlain by hard sedimentary rocks that are overlain by a charactistic suite of acid soils, characterised by a peaty surface horizon. Thicker peat covers less than 5% of the land area
- Several millenia of human occupation have had a major influence on soil properties and development through forest clearance, extensive agriculture and industrial contamination
- The national soil map for Wales is only available at reconnaisance scale**.** More detailed spatial data will be required to support local decision making on land use, land and soil protection and land management. Assessment of the predictive accuracy of the current National Soil Map should form part of any further systematic data collection programme.
- Insufficient data exist from soil monitoring in Wales to adequately quantify the state and quality of the Welsh soil resource, and no agreed prescription exists for what should be measured, when and how and where.
- Apart from soil nutrient data from the RSSS survey, no trend data of any significance exist although the second sampling of a subset of National Soil Inventory provides comparative data for two points in time roughly fifteen years apart.

2.1 Introduction

Soil is commonly regarded as the weathered surface layer of the earth within which soil organisms live and plants root. It is the interface and common ground between the biosphere and the geosphere. In the Welsh lowlands, soil is developed to one to two metres depth but some upland soils are less than 0.25 metres deep. Soil is distinguished from underlying superficial geological deposits and rock by having:

- Physical structure that causes it to break easily into discrete crumbs and clods of soil. These in turn have a microscopic structure and organisation that is the result of biological and chemical activity.
- Chemical properties that differentiate it from underlying unweathered material. In unfertilised soils, it is the weathering of clay and other minerals that initially supplies the nutrients required for plant growth. The enrichment of surface layers with complex organic material is one of the chemical properties that differentiate soil from its geological parent material.
- Complex microbial and biological communities of soil organisms. These organisms help give the soil its physical structure. They also drive many of the processes that recycle dead plant and animal remains to release the nutrients and carbon held in them.

The soil is a multi-functional resource. Without soil, land is infertile, barren and unable to support vegetation. The soils of Wales are the foundation of its land-based economy and a strong influence on its landscape. The diversity of Wales's vegetation is a reflection of its range of climate and soil conditions and the future conservation of its biodiversity is in part dependent on future soil management. The quality and flows of Welsh rivers reflect the nature of the soils within their catchments. The soil is also a significant carbon sink or source depending on its management.

2.2 Soil formation

Soil formation results in the creation of a *soil profile,* a vertical sequence of distinct layers as seen in the exposed face of a pit. These layers are known as *horizons.* They roughly parallel the ground surface passing down to relatively unaltered material, which may represent the *parent material* in which the soil above has formed. The term *parent material* is used here to indicate the principal source of weatherable material. Soil profiles are actually three-dimensional and the exact nature of the soil that develops at a point in the landscape is a function of several interacting influences – geology, weather, topography, vegetation and man. At least three of these are dynamic influences capable of changing with time, and the nature and functioning of soils also therefore capable of change over quite short periods of time. Any soil protection policy aimed at preventing undesirable changes in soil must be founded on a good understanding of the natural evolution of soil through soil forming processes.

2.2.1 Soil forming processes

Soils form as a result of a number of processes:

- *Organic matter accumulation* Under a cover of vegetation, plant and animal remains are added to the soil where they are gradually decomposed and mixed with mineral material. Nutrients are released for plant growth but part of the organic matter is transformed to dark coloured humus that decomposes at a slower rate. In nutrient-rich, well-aerated soils, rapid decomposition and vigorous faunal activity, particularly that of earthworms, achieve intimate mixing of mineral and organic components. The rate of organic matter accumulation and the formation of acid peat deposits is controlled by the balance between accumulation and decomposition.
- *Physical weathering* Soil layers develop through the accumulation of unconsolidated mineral grains and rock fragments created by physical breakdown through the action of freezing and thawing, or wetting and drying.
- *Chemical weathering*. Rainwater and acids from plant exudates and plant residues dissolve minerals releasing ions, especially basic cations to provide nutrients for further plant growth.
- *Leaching* transports soluble forms of nutrients and trace elements downwards beyond the root zone or laterally through the soil by seepage. In natural soils, the degree of leaching, which is related to annual rainfall and soil permeability, is roughly indicated by the acidity of soils. Intense leaching and translocation can lead to *podzolization*. In agriculture, leaching losses are balanced by liming and fertilizer dressings.
- *Gleying.* Waterlogging leads to the reduction, mobilization and removal or redeposition of iron and manganese compounds and produces distinctive soil horizons in soils that are either impermeable or developing in low-lying sites. Many such soils are mottled grey and yellow-brown but persistently waterlogged soils are usually wholly grey or bluish grey. Agricultural soils that suffer from waterlogging are drained artificially by the use of land drains combined with secondary treatments such as subsoiling or mole-draining.

2.3 Soil formation in Wales

The soil cover of Wales contributes to the distinctiveness of Welsh landscapes, farming communities and habitats. Rudeforth *et al.,* (1984) report on how soil formation in Wales has been and continues to be strongly influenced in detail by a number of key factors:

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1. Almost *complete glaciation* ending around 12,000 years ago and leaving a fresh land surface for soil to re-develop. Welsh soils are young by world standards.
2. A *moist, cool climate* over much of its land. Low thermal energy translates into slow rates of chemical weathering but high rainfall drives strong leaching.
3. *Hard, mostly acid bedrock and superficial deposits* as soil parent materials that support a particular suite of soils. Ninety percent of soils are loamy; only three percent are calcareous.
4. *High relief* with steep slopes that often govern local patterns in soil development through their control of hydrology and climate.
5. *Extensive forms of agriculture* dominated by grass production, and a high percentage of *protected land managed for biodiversity and/or landscape.*

The exceptions to these generalities are almost all in the coastal and border fringes to the Principality where land is lower, warmer, drier, flatter and sometimes underlain by basic or even calcareous bedrock.

Soil in any area is constantly varying and soil science has devised systems of soil classification in an attempt to describe this variability and to map it on paper. The soil classification (Avery ,1980) used in the National Soil Map of Wales (Rudeforth *et al.*, 1983, 1984) is described in the following sections.

2.3.1 Present soil development in Wales

The above factors have combined to create a characteristic suite of soils over the majority of Wales that can mostly be encountered by walking a transect from valley floor to hill top. The majority are loamy in texture. Differences in clay content, stoniness and compactness combine with slope and position to determine the drainage regime of soils, particularly in the lowlands, but also in the uplands.

In the lowlands, *brown alluvial soils* (MG6 2%[1]) occupy the slightly higher land along river levees with *alluvial gley soils* (MG8 2%) on the lower backlands, where groundwater comes to the surface during winter and flooding is more frequent. Peat development occur in old oxbows and some larger western valleys and basins have been the focus for peat development, and are occupied by *raw peat soils* (MG10 3%) in raised bogs with *Sphagnum* moss.

The broad interfluves of the lowlands are swathed in loamy drift and covered by a combination of well drained *brown earths* (MG5 26%) and *stagnogley soils* (MG7 17%) characterised by seasonal surface waterlogging. The latter require artificial drainage if they are to be of productive use in agriculture.
With increased altitude and on the steeper slopes of the Welsh heartland, brown earths give way to *brown podzolic soils* (MG6 23%). They are characterised by very bright orange-brown subsoil that contains oxides of iron and aluminium. This is the 'ffridd' land and brown podzolic soils are associated with bracken and, on shallower west-facing slopes, gorse.

Table 2.1 Major soil groups.

Major soil group (MG)	Extent in Wales	Description
1 Terrestrial raw soils	<0.1	Very young soils with only a superficial organo-mineral layer
2 Raw gley soils	0.2	Unripened young soils of saltmarshes
3 Lithomorphic soils	2.2	Shallow soils without a weathered subsoil
4 Pelosols	0.1	Clayey 'cracking' soils
5 Brown soils	30.2	Loamy, permeable soils with weathered subsoil
6 Podzolic soils	32.3	Acid soils with brightly coloured iron-enriched subsoil
7 Surface-water gley soils	24.7	Loamy and clayey seasonally waterlogged soils with impermeable subsoil
8 Ground-water gley soils	3.4	Soils associated with high seasonal groundwater
9 Man-made soils	0.4	Restored soils of disturbed ground
10 Peat soils	3.4	Soils in deep peat
Unclassified land (urban)	3.0	

[1] The initial number relates each soil subgroup to its major soil group in Table 1 and the percentages given for each soil type refer to their extent of that soil subgroup as a lead soil in soil associations on the National Soil Map of Wales.

As slopes flatten out onto the crests of the Welsh Plateaux, brown podzolic soils pass into peaty-topped *stagnopodzols* (MG6 9%) that possess shallow ashen leached E horizons immediately above their ochreous, oxide-rich subsoil. Stagnopodzols support grass heath communities with patchy heather but lend themselves to ploughing and reseeding, a treatment that converts them to brown podzolic soils. The larger moorlands are characterised by patterns of stagnopodzols on crests and rises with *stagnohumic gley soils* (MG7 8%) in between. Past drainage practice has been to open ditch these soils. With increasing altitude, peat depth increases and *raw peat soils* (MG10 3%) are developed on the main ridge of the Cambrian Mountains and on the Migneint.

The above pattern, in broad terms, is repeated on all of the main sedimentary rock formations of Wales. The harder, mostly acid, volcanic rocks of the Rhinogs and Snowdonia are no exception, but the balance of soil development on the high land is biased toward raw peat soils and shallower *peaty rankers* (MG3 1%) at the expense of stagnopodzols and stagnohumic gley soils.

Figure 2.1 is a simplified version of the National Soil Map of Wales (Rudeforth *et al.*, 1983) indicating the distribution of 18 soil classes. Table 2.2 is the legend to the map.

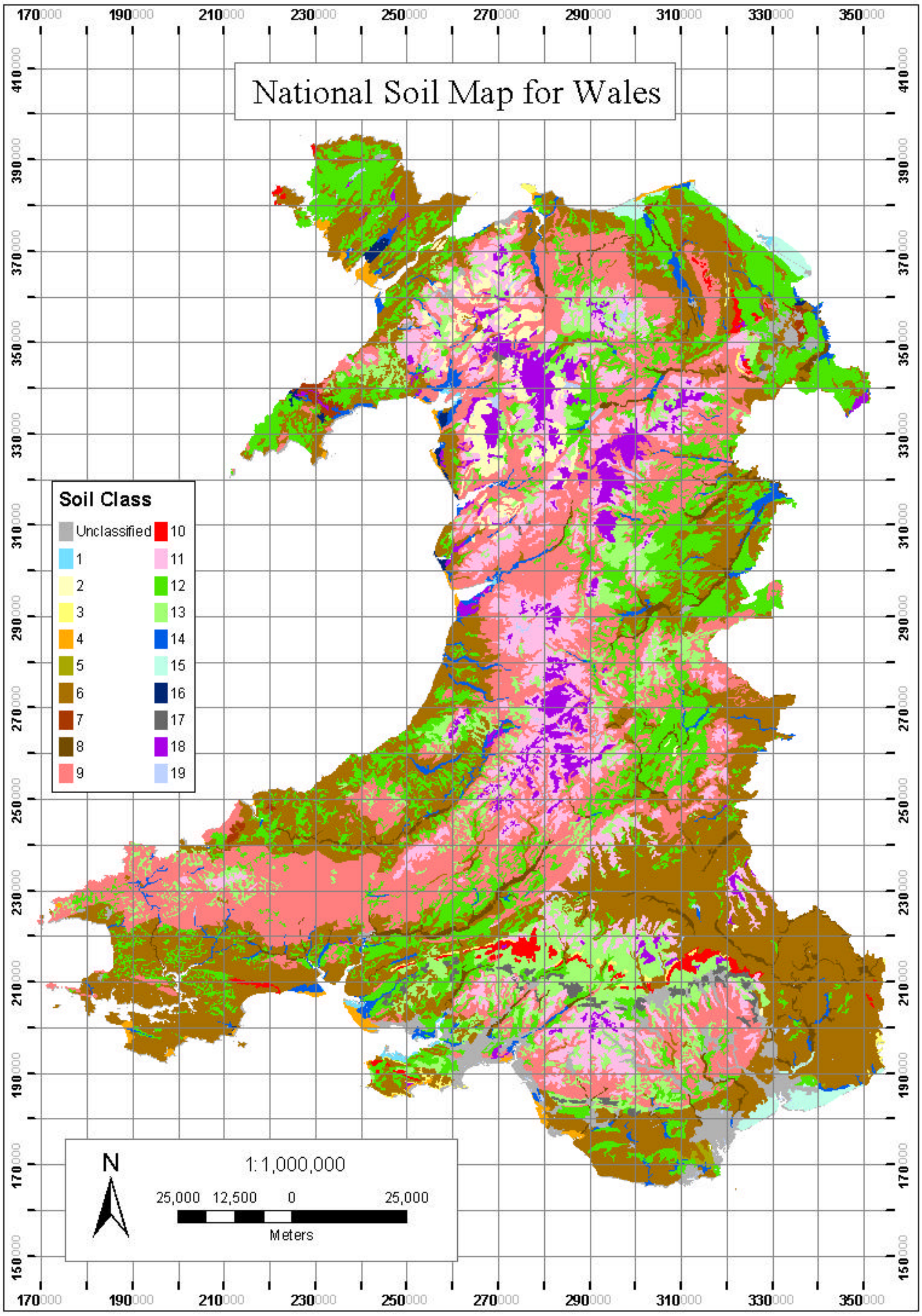

Figure 2.1 Simplified National Soil Map of Wales.

Table 2.2 Legend to the Simplified National Soil Map for Wales.

Map Unit	General description of soils	MG[1]	General land use and vegetation
1	Saltmarsh soils	2	Saltmarsh
2	Shallow acid peaty soils over rock	3	Heather, gorse and wet moorland
3	Shallow soils over limestone	3	Herb-rich grassland
4	Sand dune soils	3	Dune vegetation
5	Slowly permeable clayey soils over mudstone	4	Pasture
6	Well drained loamy soils	5	Pasture and mixed arable farming
7	Well drained sandy soils	5	Arable and mixed farming with root crops
8	Well drained soils in floodplains	5	Pasture, some mixed arable farming
9	Well drained acid loamy soils over rock	6	Steep rough grazing, woodland or forestry often with bracken; some improved pasture
10	Well drained very acid loamy and sandy soils	6	Heathland and coniferous forestry
11	Loamy acid permeable soils with a wet peaty surface	6	Wet grass moorland and coniferous forestry
12	Slowly permeable, seasonally wet, loamy and clayey soils	7	Pasture with mixed farming in the lowlands
13	Slowly permeable wet acid soils with a peaty surface	7	Wet grass moorland and coniferous forestry
14	Stoneless loamy and clayey soils with high groundwater	8	Pasture with mixed farming in the lowlands
15	Stoneless loamy and clayey coastal soils with high groundwater	8	Pasture; intensive arable and horticultural cropping in the north-east
16	Permeable sandy and loamy soils with naturally high groundwater	8	Cereals and root crops with drainage; some small wetlandsBlue
17	Restored soils	9	Grass
18	Deep acid peat soils	10	Mire vegetation, some improved land in the lowlands
	Unclassified soils, mostly built land		Urban and industrial land

[1] main Major Soil Group as identified in the text

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2.3.2 Man's influence on soil development

Soils develop slowly and it is easy to think of them as static and unchanging. In reality, soil is in a dynamic equilibrium with many factors, especially the direct management of land and the indirect effects of industrial emissions. Present-day soils also bear the imprint of history back to the earliest phase of human settlement in Wales.

Urbanisation: Some 3% of Wales is now covered by residential and industrial development (see Chapter 3). Within that area, a significant proportion of the soils is supporting parks, playing fields, verges and gardens. Many of these soils are significantly altered both physically and chemically, and many will have been disturbed. The road network represents a further source of soil disturbance and loss.

Forest clearance and agriculture: With significant changes in climate over the period of human settlement in Wales, it is not always possible to isolate land use impacts on soil. However, forest clearance and development of the agricultural landscape of Wales have had been a major influence on the direction of soil development over the last 6000 years.

Historically, man has influenced the soil indirectly by modifying native vegetation and, more directly, through agriculture. Study of preserved pollen in soil has shown that clearance of much upland deciduous forest by Neolithic man led to the development of heathland. Loss of woodland altered the microclimate, and broke the sequence of soil nutrient recycling favourable to brown earth formation. This led to acidification and podzolization and the invasion of heather. Once heather became established, acid humus and thin peat formed, encouraging further podzolization.

In the lowlands, and to a lesser extent in the uplands, ploughing, draining, marling and the use of lime, fertilizers and crop protection products have altered soil profile features, soil hydrology, soil biology and/or soil chemistry to varying depths. Cultivation not only destroys surface horizonation, it leaves soil vulnerable to creep down slope with the resultant formation of stepped hedgerows as topsoil accumulates on the downslope edge of the field at the expense of the upper part. Soil erosion is greater from cultivated land than from established grassland and woodland (see Chapter 5). In Wales, cereal crops only occupy 3 per cent but land is also cultivated for the reseeding of grassland. The stoneless fine alluvium that overlies deeper gravel in virtually all Welsh valleys can be attributed to the period since forest clearance. Some 20% of farmland soils in Wales have been artificially drained with tile or plastic pipes, gravel backfill and secondary subsoiling to 'open' compact subsoil. The hydrology of these soils and of the rivers they support is permanently changed.

Beneath the zone of direct human interaction, deposits of silt, organic matter and clay from overlying horizons has been attributed to the effects of forest clearance and subsequent cultivation (Bullock and Thompson, 1981). The use of inorganic fertilisers in farming peaked in the late 1990s and has resulted in enrichment of agricultural soils with phosphorus and potassium (see Chapter 8).

Afforestation: The initial cultivation and drainage of land prior to afforestation results in considerable soil disturbance, often to full soil depth. Wet peat soils on moorland are gripped with parallel ditches to aid drainage. Crops are often fertilised with phosphorus. The growing conifer crop attracts atmospheric pollutants through occult deposition and this, and the effect of acidic conifer exudates in throughfall, leads to further acidification of the soil, particularly in acid sensitive areas where soils are of low acid buffering capacity, and the release of aluminium (see Chapter 11). Traditional clear-felling has been associated with increased nitrate and phosphorus loadings to local rivers. Erosion and stream sediment loads are increased significantly at planting and harvesting, particularly if no soil conservation measures are taken. The introduction of Forest and Water Guidelines (Forestry Commission, 1988) and moves toward multi-functional forestry with mixed species and mixed-age crops as proposed by the strategy document "Woodlands for Wales" (NAW, 2000) are likely to lessen these effects on the soil and river system.

Mining and mineral extraction: The extraction of coal, slate, brick clay, limestone, roadstone, sand and gravel and metal ores have all had their impacts locally within Wales (see Chapters 4, 9 and 10). The transport and smelting of metal ores in South Wales and in north-east Wales has resulted in wider dissemination of heavy metals.

Waste to land: Nightsoiling, the practice of spreading town waste onto peri-urban agricultural land, continued into the 1950's in some areas. Its legacy is a suite of soils with deepened topsoils that contain the detritus of town life and enhanced levels of heavy metals such as zinc and lead. Livestock waste represents by far the largest category of waste that is spread to land. Livestock slurries from intensive stock-rearing units can contain a range of veterinary products and other feed additives such as metals. Dirty water from yards and dairies often contains significant amounts of disinfectant.

Industrial and other depositions from the atmosphere: All Welsh soils have been affected over a long period by the deposition of industrial emissions from within Wales and from mainland Europe and other parts of the UK (see Chapters 9 and 11). The impact on soil and on freshwaters of acid deposition has been intensively studied (Hornung and Skeffington, 1993) and is reported on elsewhere in this report (Chapter 11). Vehicle emissions are of increasing significance in terms of soil loadings of oxides of nitrogen and also contain residues from petroluem additives. The relatively high lead levels in the organic topsoils of the Welsh uplands is thought to reflect entrapment of particulates from historical smelting in the lowlands.

In conclusion, there is not a single soil in Wales that has not been influenced in some way by human activities. Some impacts, construction is the most obvious, are highly visible, others require an experienced eye. A further category, subtle changes to soil biology, microbiology and chemistry requires investigation and research, much of which is yet to be carried out.

2.4 Soil information for Wales

2.4.1 Soil survey in Wales

There has been no systematic soil survey in Wales since progressive closure of the three Soil Survey of England and Wales offices in 1985 to 1987. This section describes the extent of soil mapping that resulted from soil mapping over the period 1925 to 1984.

The history of systematic soil mapping in Wales is described by Clayden (1974) and began in the early part of the last century (Robinson, 1917) ahead of initiatives in other parts of the UK. The purpose of all soil survey work has been to provide data to inform debate and decisions about land use. At first, on a geological and textural (ie the mix of clay, silt and sand) basis, the concepts of the *soil series* and *soil types* used in the United States were adopted, with the *soil profile* as the unit of classification, in 1927. The soil series is the equivalent of a plant species in soil taxonomy. Progress Reports of the Soil Survey of Wales describe soil series under suites which are parent material groups (Robinson *et al*., 1930).

The initiation of soil survey in Bangor by Robinson explains the concentration of early 1:63,360 scale soil maps of the coast of north west Wales (Figure 2.2). The Soil Survey of England and Wales was formed in 1945 with its headquarters in Rothamsted. Offices were opened at Trawscoed, inland of Aberystwyth, then Swansea and in 1972 in Mold. Survey activity though the period 1950 – 1980 focused on publishing maps at 1:63,360 and 1:25,000. Publication of the National Soil Map for Wales in 1983 was followed by progressive closure of survey offices in Wales as MAFF funding for soil survey was withdrawn. Soil survey ceased in 1987 with closure of the Mold office.

Forest soils have been mapped by surveyors employed by the Forestry Commission and using a separate soil classification (Pyatt *et al*., 1969). Pyatt *et al*., (2001) have published a new ecologically-based classification for future forest land mapping and the Forestry Commission is committed to a five year programme of digitisation of its existing soil maps (Dutch, *pers. comm.*). Figure 2.3 details the extent of digital and hardcopy film and paper-based soil maps of forests along with the total forest area. Of the 1250 km^2 of forestry in Wales, some 850 have been surveyed.

A number of other surveys are worthy of mention. Ball *et al.*, (1969) mapped the soils of the Snowdonia National Nature Reserve while Jenkins and Owen (1995) published a soil survey of Skomer Island. Surveys of Agricultural Land Classification have been conducted of more than 88,000 of land principally in the areas of better agricultural land (Vale of Glamorgan, Gwent and Clwyd). The soil information collected in these surveys is limited to the factors required for land classification.

Table 2.3 lists the main soil survey publications covering Wales and Figure 2.2 indicates the extent of soil surveys for Wales. Table 4 has further information about some of the larger unpublished soil mapping exercises.

Table 2.3 Published soil surveys covering Wales.

Date	Survey details
1958	Pwllheli (Hughes and Roberts 1958): 1:63,360 scale map
	County of Anglesey (Roberts 1958): 1: 63,360 scale map
1960	District of Rhyl and Denbigh (Ball 1960): 1: 63,360 scale map
1963	Bangor and Beaumaris (Ball 1963): 1: 63,360 scale map
1969	Snowdonia NNR (Ball *et al* 1969): 1:25,000 scale map
1970	North Cardiganshire (Rudeforth 1970): 1: 63,360 scale map
	Grid survey and report on the hydrological properties of soil in the River Dee Catchment (Rudeforth and Thomasson 1970)
1972	Vale of Glamorgan (Crampton 1972): 1: 63,360 scale map
1974	Grid survey of West and Central Pembroke (Rudeforth and Bradley 1974)
	Llangendeirne (SN41) (Clayden and Evans 1974): 1:25,000 scale map
	Pembroke and Haverfordwest (SM90/91) (Rudeforth 1974): 1:25,000 scale map
1975	Caersws (SO09) (Lea 1975): 1:25,000 scale map
1976	Eglwyswrw (SN13) (Bradley 1976): 1:25,000 scale map
1978	Wrexham N (SJ35) (Lea and Thompson 1978): 1:25,000 scale map
	Holywell (SJ17) (Thompson 1978): 1:25,000 scale map
1980	Llechryd (SN24) (Bradley 1980): 1:25,000 scale map
	Llandeilo (SN62) (Wright 1980): 1:25,000 scale map
1981	Llangadog (SN72) (Wright 1981): 1:25,000 scale map
1982	Arddleen (SJ21) (Thompson 1982): 1:25,000 scale map
1983	Wales (Rudeforth *et al* 1983 and 1984): 1:250,000 scale map
1985	Lannelli North (SN50) (Wright 1985): 1:25,000 scale map
1988	Newtown (SO19) (Hartnup 1988): 1:25,000 scale map
1995	Island of Skomer (Jenkins and Owen 1995): 1:10,000 scale map

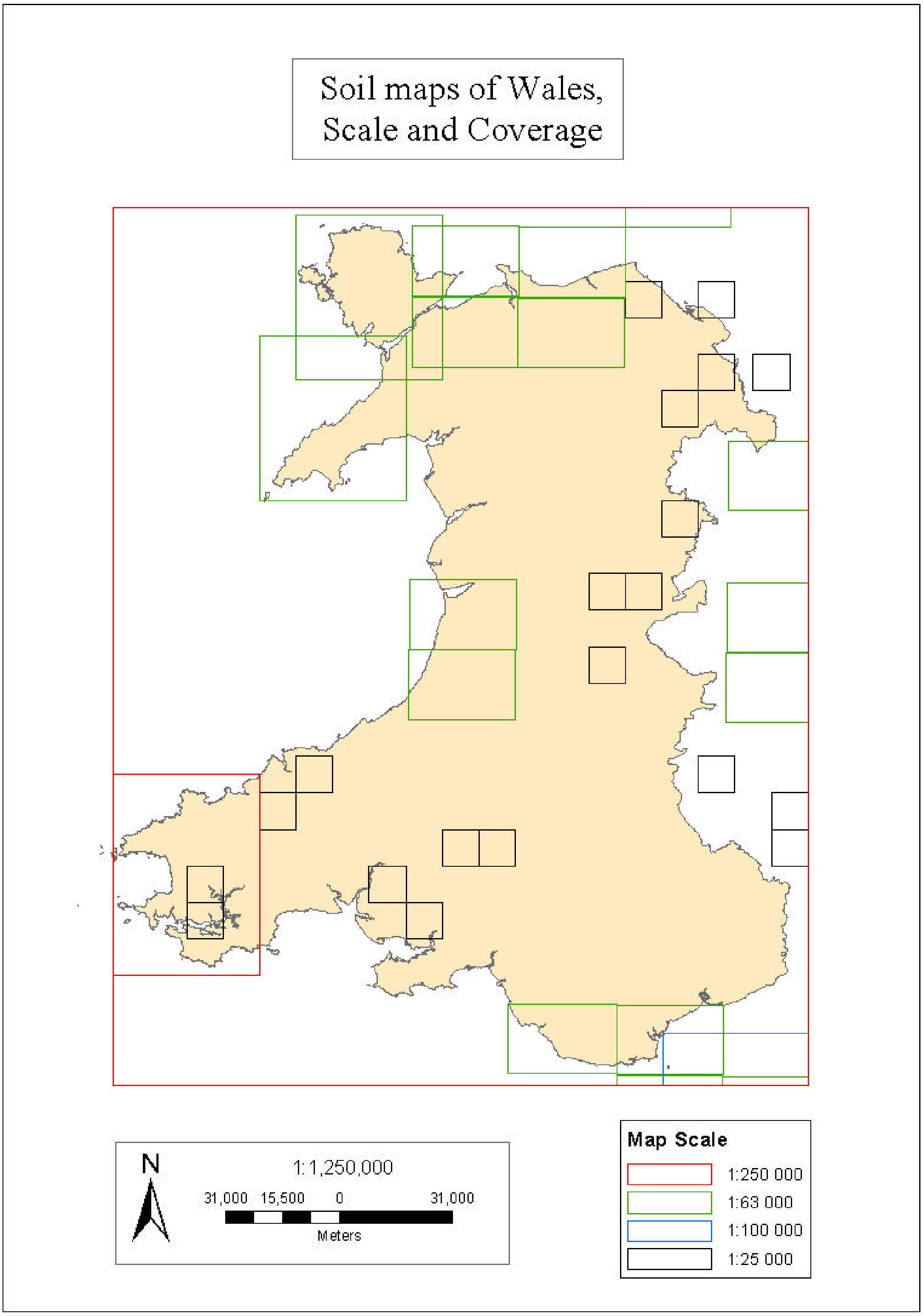

Figure 2.2 Soil surveys from the Soil Survey of England and Wales strategic mapping programme.

Table 2.4 Unpublished soil surveys in Wales.

Date	Survey details
Various	Soil surveys of the Forestry Commission forests (see Figure 2.3)
1936	The Soils of Glamorgan (Robinson and Hughes 1936)
	Survey of the soils of Glamorgan, Monmouth and Brecknock (Crampton, nd) reported in the Soil Survey of Great Britain reports for 1958 onwards
1962	Survey of three catchments near Aberedw, Glascwm and the Radnor Forest (Rudeforth 1962 reported in the Soil Survey of Great Britain report No 15 1962)
1964	Soil investigations at Brenig Catchment, Denbighshire, the Upper Wye and Severn catchments and Pant-y-dwr Field Laboratory (WPBS) ((Rudeforth 1962 reported in the Soil Survey of Great Britain report No 17 1964)
1971	Survey of the Trawscoed Experimental Husbandry Farm (Lea, reported in the Annual Report of the Soil Survey of England and Wales 1971)
1973	Survey of University Farm, Trefloyne, South Pembroke (Rudeforth reported in the Annual Report of the Soil Survey of England and Wales 1973)
1974	Survey of part of Pwllpeiran Experimental Husbandry Farm (Rudeforth reported in the Annual Report of the Soil Survey of England and Wales 1974)
1975 onward	Surveys of 1 km sample squares for the Countryside Survey (ITE and CEH 1975 onward)
1976	Survey of Llysfasi College of Agriculture, Vale of Clwyd (Lea reported in the Annual Report of the Soil Survey of England and Wales 1976)
	Survey of Teifi Marsh Nature Reserve (Bradley reported in the Annual Report of the Soil Survey of England and Wales 1976)
1979	Survey of Penllergaer Forest, West Glamorgan (Wright and Clayden reported in the Annual Report of the Soil Survey of England and Wales 1979)
1984	Surveys of selected 1km squares as part of a survey of rabbit populations in lowland England and Wales

In the conduct of these soil mapping projects, individual point observations have been made. For work prior to 1979, these data exist as paper records and most form part of the archive held at Silsoe by the National Soil Resources Institute. Post-1979, the Soil Survey and Land Research Centre adopted a standard computer compatible field recording card and these records are held digitally in the Land Information System, LandIS, at Silsoe. LandIS is an Oracle-based relational database that contains digital soil maps, soil descriptions, analytical data and soil series representative property data. In addition to field descriptions, modal profile descriptions and analytical data exist for all soil series identified during SSEW surveys. Those series described after 1970 are held digitally. Figure 2.4 indicates the location and numbers of modal soil profiles described within Wales and the nature of associated data held within the LandIS system. An unknown number of earlier profiles are present within the paper archive at Silsoe, some of which are published in the Memoirs and Records of surveys within Wales. Based on these analytical data, SSLRC staff created comprehensive property data sets for all soil series present on the National Soil Map. For the most extensive soil series, these are based on values from several sampled profiles. For the least extensive, they rely on interpolated values from similar but more extensive soil series. Particle size fractions, organic carbon, pH, moisture content at a range of tensions, bulk density and calculated hydraulic conductivities are the principal properties.

At the same time as the National Soil Map, SSEW sampled soils on a 5 km grid with intersects off-set 1 km north east of the zero lines. This National Soil Inventory (McGrath and Loveland, 1992) generated approximately 800 described profiles and sampled topsoils for Wales. For each of these points, there is a full site and profile description to rock or around a metre depth and a suite of topsoil inorganic analytical data from a bulked topsoil sample (Table 2.5). As a set, the National Soil Inventory data provide an unbiased, statistically representative sample of the Welsh soil resource. The entire inventory was sampled over the period 1978 – 1984 and partial resampling of arable (1 in 3) and grassland (1 in 2) sites was commissioned by MAFF in the mid nineties. Resampling of semi-natural sites is planned for this winter (1 in 3 of all England and Wales sites).

Following on from a survey of dioxins in topsoils on the 50 km grid sites of the National Soil Inventory, Liverpool University Environmental Research Centre are commissioned to sample and analyse soils and herbage in rural, urban and industrial sites. The rural sites coincide with the previous survey (11 sites in Wales) while the urban and industrial sites are being chosen subjectively. (3 urban and 14 industrial sites in Wales). At each site, topsoil pH, bulk density, organic carbon and texture will be analysed along with a rang eof dioxins, Polychlorinated biphenyls, Poly aromatic hydrocarbons and metals. Certain radiometric measurements will also be made (Crook, *pers. comm.*).

The ADAS Representative Soil Sampling Scheme provides a 5 year sampling cycle for arable and improved grassland soils with each site being sampled in three successive sampling years (years 0, 5 and 10). A third of sites drop out each sampling year to be replaced by a new set of replacement sites. Soil nutrients and pH are monitored.

Table 2.5 National Soil Inventory analytical data.

General determinands	
pH	
Organic carbon	
Clay, silt and sand	
Elemental determinands	
Aluminium	
Barium	
Cadmium	
Calcium	
Chromium	
Cobalt	
Copper	
Iron	
Lead	
Magnesium	
Manganese	
Nickel	
Phosphorus	
Potassium	
Sodium	
Strontium	
Zinc	
Mercury	Incomplete data set
Selenium	ditto
Vanadium	ditto
Arsenic	ditto
Molybdenum	ditto
Fluorine as fluoride	ditto

Elements in italics have total and EDTA extractable values

Table 2.6 summarises the main sources of information about the soils of Wales.

Table 2.6 Summary of soil information sources for Wales.

Classes of soil information	Format/medium		Information about		
	Hard copy	Electronic/digital	Soil extent	Soil diversity	Soil quality
Complete soil map coverage at 1:250,000 (hard copy and digital),	✓	✓	✓	✓	
More detailed SSEW soil mapping for selected areas,	✓			✓	
Detailed soil surveys of Forestry Commission land	✓	(✓)		✓	
A set of 800 National Soil Inventory sites with topsoil analytical data,		✓		✓	✓
A set of topsoil nutrient analytical data from the Representative Soil Sampling Scheme,		✓			✓
Point observations of soils,	✓	(✓)		✓	
A number of fully described and analysed soil profiles (chemical and physical data),	✓	(✓)			✓
Representative property values for all soil series present on the National Soil Map, based on data from 5) above but often interpolated for soil series of limited extent,		✓		✓	✓
Soil maps and some analytical data from a limited number of randomly selected 1 km squares (Countryside Survey and MAFF Lowland Rabbit Survey squares),	✓	(✓)			
The products of Agricultural Land Classification mapping,	✓	(✓)			
Random contract soil surveys of various land holdings.	✓				

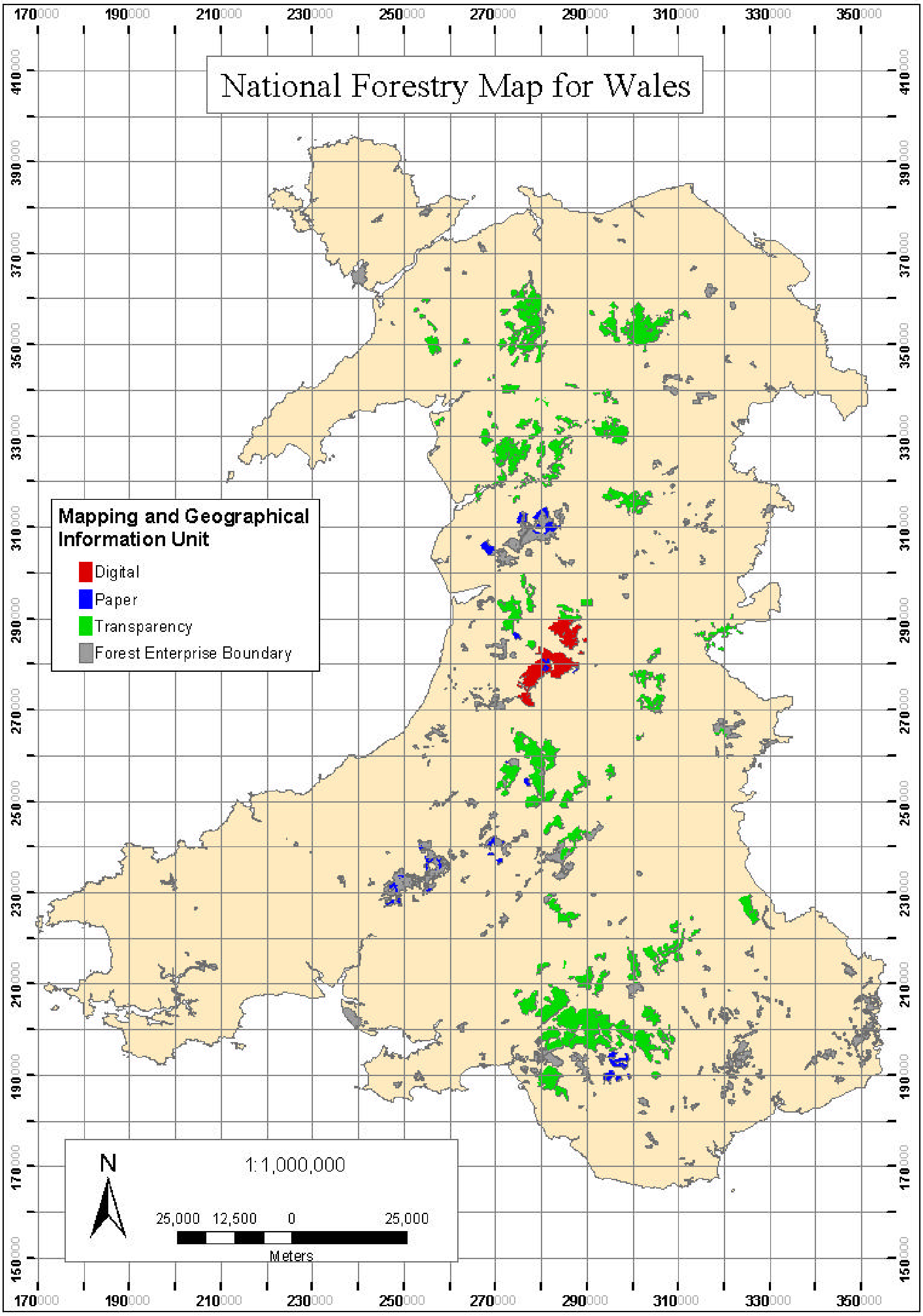

Figure 2.3 Forestry Commission soil survey maps.

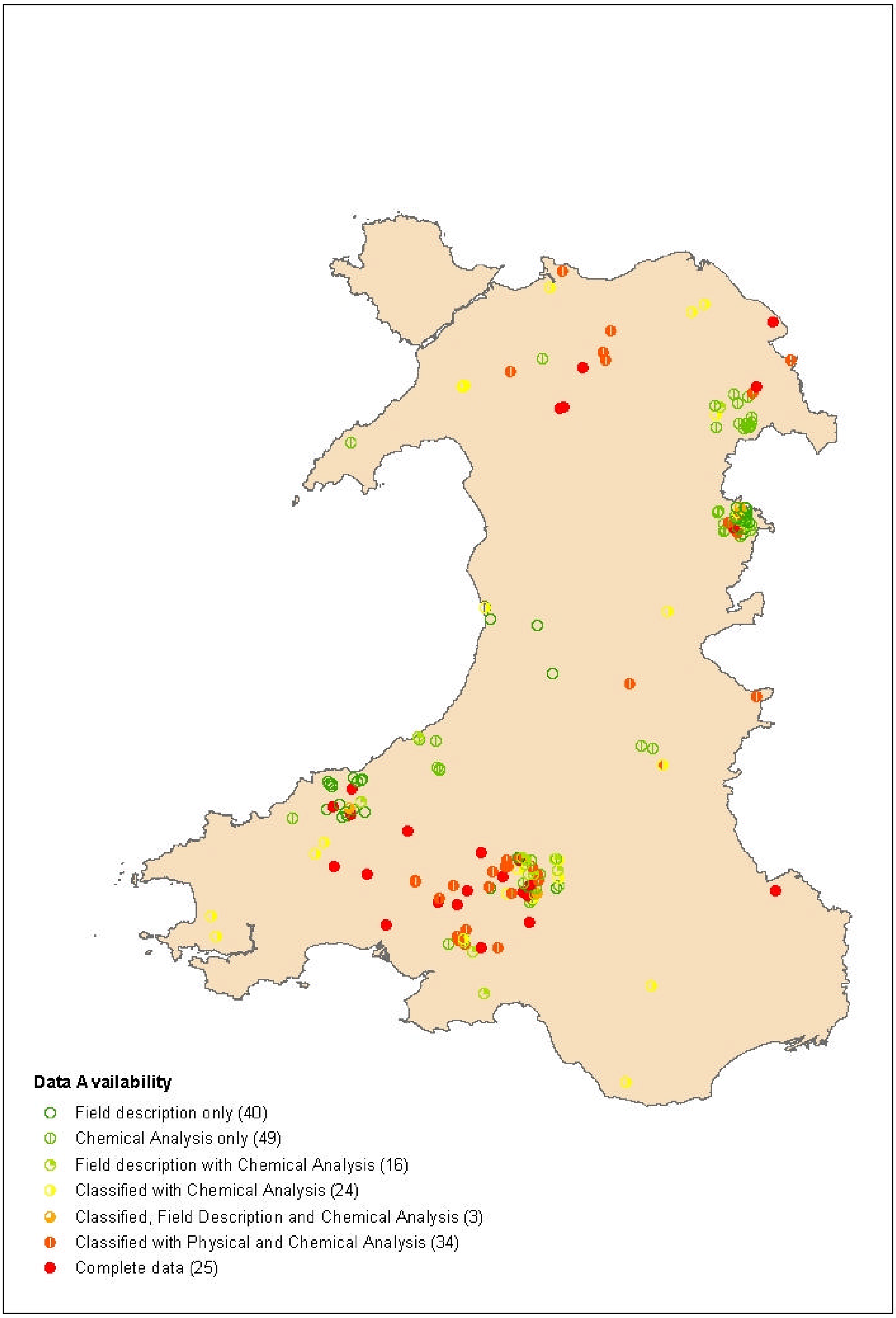

Figure 2.4 Modal soil profiles descriptions in LandIS with and without analytical data in Wales.

2.4.2 Computer-based soil information

At least some of the above information are held in digital form as components of soil or other information systems. The LandIS system managed by the National Soil Resources Institute with support from DEFRA contains a vector copy of the National Soil Map and simplified raster versions. It also holds the National Soil Inventory data sets and soil series property data.

The Forestry Commission is planning to digitise its own soil survey maps over the next five years.

The easy availability of powerful Geographical Information Systems software for spatial analysis mean that future users of soil information will require that information in digital form.

2.4.3 Soil information needs for policy, research, planning and land management

These are considered under a number of headings representing the principle activities for which soil information may be needed into the future. An inter-departmental working group with National Assembly for Wales representation has been considering future needs for soil information in England and Wales but has not as yet reported.

2.4.4 Spatial soil data/soil survey

For spatial data (i.e. soil survey) Avery (1987) discusses the relationships between scale, observation density, minimum land unit sizes for interpretation and cost. These considerations are based on traditional methods of field soil survey. Assessment of the accuracy of maps such as the National Soil Map is not straight forward and no such assessment has been carried out systematically. Mayr (2001) has researched methods that are much less resource-intensive and rely on the geostatistical interpretation of remotely sensed data and the analysis of landscape. These offer the possibility of more economic approaches to the spatial characterisation of soil variability in the medium term.

Current information exists for Wales to inform and direct national and sub-national scale policy development but not for local decision making (Figure 2.5). Only a small proportion of Wales has soil mapping at a scale greater than 1:63,360 that will support planning and management decisions at the natural catchment, National Park, Unitary Authority or more detailed level. Few, if any, detailed surveys actually cover entire authority or catchment areas. While the principal experimental farms and land holdings have been surveyed at 1:10,000 scale, few if any others have such information and therefore soil information does not exist to support land management decisions at land holding or management unit/field level.

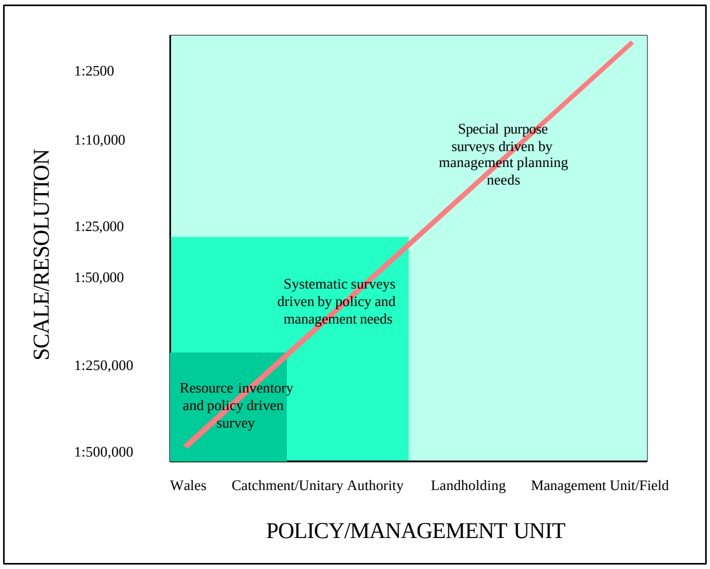

Figure 2.5 Scale, resolution and utility of soil survey information.

Interest has been expressed in having more detailed information on the soil resources of National Parks and National Nature Reserves in Wales (1:50,000 to 1:25,000 scale) in conjunction with information on the extent to which soil types and sequences are represented in the relatively undisturbed environments of 'protected' areas. Future agri-environmental schemes may require information about soils at farm and field level for planning more sustainable farming systems (at least 1:10,000 scale).

The Environment Agency (2001) is promoting a number of soil management 'Best Management Practices' as part of its strategy for the control of agricultural impacts on the water environment. To be effective, many require field scale information about the nature of soils across farmland, and the Environment Agency is embarking on a pilot web-based 'On your Farm' advisory service to farmers that will make use of soil map-based spatial information. It is anticipated that the Water Framework Directive and other water and land-related environmental legislation will focus attention on soil-controlled processes at catchment and sub-catchment scales and generate demands for soil spatial data appropriate to planning and management at that scale (ie 1:25,000 scale and possibly 1:10,000 scale).

2.5 *Monitoring of soil quality*

There is growing interest in, and justification for, a more systematic approach to soil monitoring (Huber *et al*., 2001; Commission of the European Communities, 2002). The CEC is likely to commission a Technical Working Group to advise it on the most appropriate structure for a Pan-European monitoring framework. This structure will then be sent to Member States. A network of sites for the monitoring of European forest soils has already been established on a rough 16 km grid in order to comply with CEC Regulation 1696/87 (Vanmechelen *et al.*, 1997). With French adoption of a similarly spaced network, there is growing support for adoption of this grid as the basis of a Pan-European Soil Monitoring Network. Few of the intersects of the National Soil Inventory coincide with 16 km intersects but it would be logical to ensure continuity between any future network and data collected to date.

At present, systematic representative data only exist for the inorganic composition of topsoils for Welsh soils. The NSI provides information on pH, organic matter, total and available nutrients, metals and fluorine; the RSSS nutrients and pH. Data on soil erosion rates (Harrod *et al*., 2000, McHugh, 2002) are based on the NSI grid. Analytical and biological data from sampling in the kilometre squares for the Countryside 2000 Survey are reported on by Black *et al*., (2002).Cawse sampled a 50km grid coincident with the NSI intersects and measured radionuclide concentrations in topsoils. Rural sites of the Environment Agency coordinated survey of dioxins, PCBs, PAHs and metals in soil and herbage is conincident with the NSI on a similar 50 km grid. Only one Environmental Change Network site exists in Wales and is located on the footslopes of Snowdon.

Initial thinking within Europe is that the Pan-European soil monitoring network should address, possibly selectively:

1. Fundamental soil attributes such as pH and organic matter,
2. Soil qualities such as biomass and biodiversity, erosion rates and physical condition,
3. Soil fertility,
4. Soil contamination with inorganic elements/compounds and radionuclides,
5. Soil contamination with organic compounds,
6. Soil contamination with pathogens.

Some, at least, of these attributes should be measured at more than one depth within the soil – i.e. not just topsoil. The temporal frequency and spatial density of sampling and many other issues remain undecided.

There is some data from Wales relating to 1) to 4) but none for 5) or 6).

2.6 *Modelling of land and environmental management*

The policy, research, regulatory and planning communities now use a range of more or less complex logical and mathematical models to predict the consequences of change, to assess risk and suitability and to test scenarios in land management. These models of the phyical and biological environment employ soil spatial and attribute data. Figure 6 indicates the scarcity of hard analytical data on soil properties for Wales.

There is current demand for a range of soil physical, chemical, hydrological and biological properties organised by soil type, to link them to spatial data, that do not exist. Demand will increase into the future as issues such as adaption to climate change and pressure on land resources are addressed. There are some archived data that could be made available by entry into databases such as LandIS but ultimately there is no substitute for a renewed programme of field soil sampling and laboratory analysis.

2.7 Overall information framework

Figure 2.6 illustrates how primary data, secondary information, soil and land classifications and interpretive models fit together to provide the user community with applicable information on the nature, capability and vulnerability of soil and land resources. While many of the components exist on paper or in digital form, there is no focus for bringing them together within Wales at present.

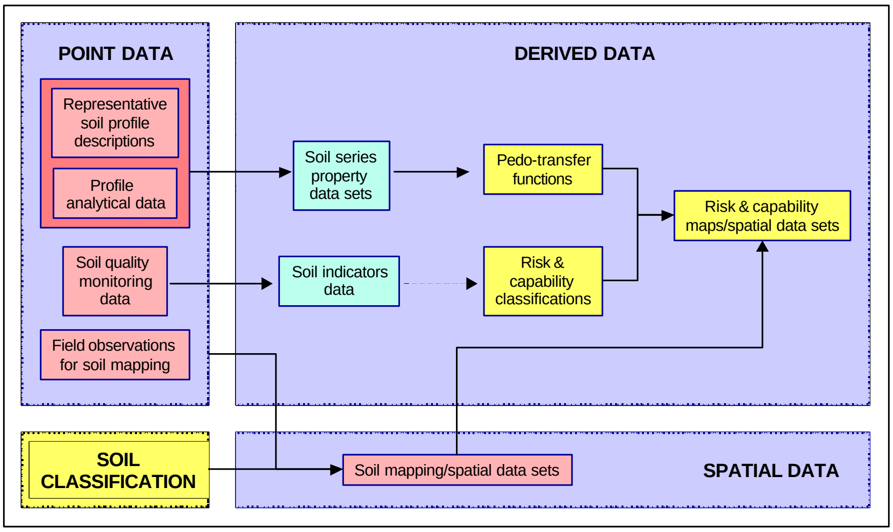

Figure 2.6 Soil information framework.

Soil is one of Wales's most valuable natural assets and much of the Welsh economy relies directly or indirectly on its functionality. The proposed Welsh National Policy for the Protection of Soil is intended to assist and support national Government, Local Government, the Government Agencies and the Archaeological Trusts in the achievement of sustainable development as laid out in 'A Sustainable Wales – Learning to Live Differently'. As a starting point, these organisations will wish to have information about:

- The current state of soil resources and any trends,
- The capability of Welsh soils to support relevant, sustainable forms of land use (different crops, forms of forestry, habitats, hard development) and the likely consequences of inappropriate forms of management (financial, soil, atmospheric, aquatic and biotic impacts),
- The vulnerability, critical capacity/load and resilience of Welsh soils to various pressures,

They will need such information universally resolved at national, local authority and natural area levels and for selected parts of Wales at subcatchment, designated area, landholding and management unit levels. Experienced soil scientists will also be needed to interpret and manipulate such data, and to act as an interface to the user community.

Illustrations

Plate 1 A typical soil of the Welsh lowlands.

Plate 2 A typical soil of the Welsh uplands.

Plate 3 Creation of urban soil.

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3. SOIL LOSS TO DEVELOPMENT

Summary

- Information on loss of land and soil to development is not collected at a national level in Wales. Some local authorities have collected information, but not to any consistent standard.
- UK wide sample based or satellite surveys of land cover are unlikely to deliver good estimates of land or soil loss, due to limited sampling in Wales or methodological changes over time
- Loss of soil to development eliminates most of soil's functions, although much remains in an amenity role
- Soil may continue to exercise an important hydrological role in urban locations, allowing rain to infiltrate slowly and reducing flood runoff.
- Soil is a valuable resource and should re-used as soon as possible after stripping.
- If original vegetation is unimproved or semi-improved, whole turfs should be translocated to ensure rapid re-establishment of flora and fauna. This procedure is not currently incorporated into planning guidance.
- Soil may contain a variety of materials and artefacts resulting from human activity. These will be destroyed as part of the soil removal or re-distribution process.
- Recent planning policy continues to provide greater protection of better quality agricultural land, unless there is an environmental or archaeological designation. Soils of lower quality agricultural land are likely to be at least as valuable ecologically, but appear not to be as adequately protected, if not designated for other reasons. Implementation of the uncultivated land and semi-natural areas provisions of the EC Environmental Impact Assessment Directive may provide additional protection.

3.1 Background

Compared to most of the pressures on soils discussed in this report, loss to development has the potential to completely destroy the existing soil cover. In reality, loss of soil to development does not necessarily equate exactly with loss of land to development. Prior to development, soil is usually stripped because it is a poor foundation for building upon. It is usually put to further use in landscaping once development is complete, or in amelioration of site conditions elsewhere such as brown field sites and other land restoration projects. In most new urban development areas, a significant proportion of the land area taken will not be built upon, and will remain as gardens, amenity areas, road verges etc., albeit with a very different function, and potential change in soil conditions through mixing and truncation. Loss of soil at landfill sites through burial can still be significant, although progressive restoration and re-use of soil lessens this loss.

3.2 Information sources

Statistics for loss of soil to development are not compiled. Furthermore, it is clear from Chapter 2 that little soil information is available at an appropriate scale for such an assessment to be made. However, despite the comments above, loss of land to development provides an indication of the loss of, and change in use, of soil. Unfortunately, in Wales, there is no integrated scheme whereby loss of land to development and infrastructure is compiled (personal communication, National Assembly for Wales Government, Statistical Directorate, 2002). We understand that some local authorities in Wales do collect this information, but there is no standardised methodology.

In England, the Ordnance Survey are contracted to provide DTLR with data on land use change that are observed during their regular re-mapping exercise (DTLR 2001). This exercise is repeated at six monthly intervals for 'category 1' change, which is housing, commercial, industrial, public-sector development and changes to the communication networks. Over the period 1985 to 1996, approximately 0.5% (70,350 hectares) of land changed from rural to urban uses in England (DTLR, 2001). Due to the scale of land use change in any one year, Ordnance Survey cannot record every change when it happens. Therefore, there is a lag between the change occurring and it being recorded by OS. Some changes remain unrecorded years after they occurred, but the majority are picked up after 5 years of OS surveying. (DTLR, 2001). Over the last few years, OS have intensified their surveying. The aim is to ensure that around 99 per cent of all existing 'major detail' are surveyed and available at any one time. This significantly reduces the lag in the process, although changes to uses other than Category 1, e.g. rural, are subject to longer lags.

Two possible sources of information on loss of land to development are the Countryside Survey 2000 (CS, 2000) (DETR, 2000) and Land Cover Map 2000 (LCM, 2000). CS 2000 measured change from 1990 to 1998 in the 'Built up and Gardens Broad Habitat', one of the broad habitats defined by the UK Biodiversity Action Plan (UK Biodiversity Steering Group, 1995). CS 2000 used a sampling framework of 1km x l km squares in which land use was mapped in both 1990 and 1998. Over this period, the area of this broad habitat increased by 57,000 hectares for England and Wales taken as a whole. Estimates for Wales alone have not so far been attempted, although the Wales Assembly Government (WAG) is currently commissioning a Wales-only report from CS2000 data and considering increasing the number of sample squares for future countryside surveys. LCM 2000 uses satellite technology to map land use, including a category 'Built up and gardens'. Estimates of area are available for Wales from LCM 2000, and from a similar exercise in 1990 (LCM, 1990). However, differences in the interpretation in the two maps prevent their use in estimating change over time.

3.3 The Current situation

3.3.1 Planning policy

Since the '1940s planning policy at both national and local levels has afforded a measure of protection to soils, not as a national resource of importance in its own right, but as a consequence of other policies. For example, the better quality agricultural lands, Grades 1, 2 and 3a, have been protected by and large from development. Much of the remaining poorer quality land forms the core of the large tracts of land in Wales that have been designated as National Parks, ESAs, Areas of Outstanding Natural Beauty, Sites of Special Scientific Interest, National Nature Reserves and Country Parks. However, there has been no specific national or local planning policy to protect soils for what they are, a natural resource containing seed stocks of plants of local provenance which once destroyed through pollution, movement or development are lost.

Until recently the planning policy framework for Wales was provided in 'Planning Guidance (Wales): Planning Policy' (PG(W)PP (National Assembly for Wales, 1999). The policy guidance included a number of statements relevant to soils. For example, the policy stated that the planning system should protect natural resources thereby contributing to sustainable development. It also contained objectives to protect the environment and stressed the important role of the planning system in maintaining biodiversity, an essential element of sustainable development. The policy stated that 'the countryside should be protected for the sake of its landscape, natural resources and its agricultural, ecological, geological, physiological, historical, archaeological and recreational value' but soils were not referred to specifically. Under the Town and Country Planning Act, an Environmental Impact Assessment (EIA) was required for certain types of mainly large-scale developments which included an evaluation of the impact of the development on natural resources. Soils were included in the information to be included in the EIA

In March 2001 DTLR announced an amendment to Planning Policy Guidance Note 7: The Countryside - Environmental Quality and Economic and Social Development to clarify the approach that local planning authorities should take towards best and most versatile (BMV) agricultural land (ALC grades 1, 2 and 3a). DTLR asked local authorities to consider agricultural quality alongside other sustainability and landscape factors, but they made clear this was not a new policy on agricultural land. The amendment was seen by some, however, as a watering down of the policy on BMV land. The revised DTLR/ODPM (Office of the Deputy Prime Minister) guidance states: "Development of…. the best and most versatile agricultural land…. Should not be permitted unless opportunities have been assessed for accommodating development on previously developed sites and on land within the boundaries of existing urban areas. Where development of agricultural land is unavoidable, local planning authorities should seek to use areas of poorer quality land in preference to that of higher quality except where other sustainability considerations suggest otherwise". Overall this revision amounts to a fairly subtle change to English policy on BMV land.

In Wales, BMV policy was also reviewed and it was concluded that guidance given in PG(W)PP was basically sound and policy changed little when the new planning framework for Wales, Planning Policy Wales (Wales Assembly Government, 2002) was introduced this year. The issue of BMV land is discussed further under the section 'The Future Situation'.

3.3.2 Development plans and the new Unitary Development Plans

In Wales, every local planning authority (county and county borough councils, National Parks) must prepare a unitary development plan (UDP) for its area (National Assembly for Wales, 2001a; 2001b). As in PGWPP all have policies that give a measure of general protection to natural resources but nothing specific relating to soils. There is one exception to that in the draft Conwy UDP that contains a specific policy relating to soils in the chapter on the Natural Environment under the subsection relating to Pollution. Policy E3 states: "Development will not be permitted where it would have an unacceptable effect on environmental quality in terms of:

- The quality, quantity and natural flow of surface and underground water and the quality of sea water;
- Emission of airborne pollutants;
- Vibration, odour light or noise pollution; and
- *The quality of soils.*

Unfortunately no reference to soils is made in the written explanation that follows the policy.

3.3.3 Development control

The development control (DC) process is one the primary ways in which policy is implemented through to the development of land. The imposition of conditions has traditionally been the key method by which the planning process has protected soils and soil quality. It has done this in a number of ways but primarily by the requirement to strip topsoil and subsoil prior to development and to store it in a satisfactory manner ready for reuse at the end of the development process. For example, as part of a landscaping scheme associated with housing or commercial development or for reclaiming land temporarily taken out of use for mineral extraction or other purposes.

3.3.4 LANDMAP

The LANDMAP Information System has been developed by CCW and is a GIS that records and makes available information about landscape qualities (CCW, 2001). The system contains information on a variety of aspects of landscape:

- earth science,
- biodiversity,
- visual and sensory,
- history and archaeology
- cultural

In this respect it provides a valuable single source of information for land management planning and LANDMAP is being implemented by local authorities throughout Wales. Unfortunately, there is little requirement for soil information in LANDMAP. The 'Earth Sciences' aspect allows for recording of 'components of pedological importance' within each area assessed, but there is no requirement for soil maps.

3.4 Impacts on soil functions

3.4.1 Biomass, food and fibre production

Loss to development prevents soil performing this function to any great extent. Perhaps the only exception is where domestic gardens are used for vegetable production.

3.4.2 Environmental interactions

Even where development has taken place, the proportion of the developed land, which retains a soil and vegetation cover, may be significant, i.e. as gardens, amenity areas, road verges etc. The soil in these situations will maintain many of the interactions of soil in non-developed land, but in a less 'productive' fashion. Perhaps one of their most important functions in this respect is to allow infiltration of rain, which would otherwise need to be channelled away. In this respect, the implementation of Sustainable Urban Drainage Systems (SUDS) is relevant. SUDS are designed to manage surface water runoff in a more sustainable way than traditional drainage systems. They provide more natural approaches to runoff management, by using the natural capacity of soils to help to prevent increases in flood or water pollution risk downstream of development. The area of sealed hard surfaces is minimised and local ponds and wetlands provide local storage of runoff water, which also provide amenity and ecological benefits.

Soil is a major repository for waste from a variety of sources, but in this context landfill of domestic, industrial, commercial and construction waste is the main issue. The Landfill Directive (EEC,1999) sets stringent requirements for landfilling of wastes which should reduce the amount of land required for landfill. In Wales, these requirements will be implemented through the Wales Waste Strategy (WAG, 2002) and a Planning Technical Advice Note on waste (NAW, 2001c)

3.4.3 Provision of a platform

Development effectively eliminates the possibility of using soil for productive purposes, but soils in developed situations take on an important amenity role, by supporting gardens, playing fields, verges and other open areas.

3.4.4 Support of ecosystems, habitats and biodiversity

Current and future planning systems should effectively prevent development on land with valuable habitats, and to a large extent sites of high biodiversity. Soil's ability to support these consequently should not be altered to any large extent. However, where soil is built over or covered, this function will clearly be terminated or suspended for extended periods until re-development or restoration occurs. Soil is a valuable natural resource, a habitat in its own right and with its own unique flora and fauna, so to build upon it is not environmentally acceptable. Soil should at least be carefully stored, but for as short a time as possible, or re-used immediately, complete with its own soil flora and fauna and associated vegetation. Translocation of soil with a comparatively simple vegetation such as improved grassland can be achieved with considerable success, (at least as far as the vegetation is concerned), but with mainly unknown effects on the soil microbial population and associated processes (see comments on soil stripping in the section on mineral extraction and peat). Translocation of soil and vegetation may not be so successful if this consists of agriculturally unimproved or semi-improved types. Here, many more plant species may occur and success of re-establishment is often poor. For example, Good *et al.* (1999) tested three methods of reinstating a species-rich meadow in South Wales, including translocation of whole turves with soil 10-20cm deep. Turves were moved to a receiver site in a single day, but 4 years after transfer, only 49% to 79% of the species originally present remained. Good *et al.* (1999) concluded that altered soil hydrology and nutrition combined with substitution of cutting for grazing were probably the main causes of the comparatively poor survival. This study emphasises the importance of identifying valuable habitats, and protecting them from development, because re-establishment elsewhere is unlikely to be entirely successful even under the carefully managed conditions possible in an experimental situation.

Ironically, soils of developed, and especially derelict land, may provide important 'hotspots' of biodiversity, especially for birds and plants not found in abundance in the wider countryside. Urban land provides a range of habitats not found in rural areas and supports species of plants and animals typical to it. Gardens also are important, not only for wildlife but also as the sites of the 'garden' soil. After many years of deep hand cultivation and fertilizer application, older garden soils are themselves of especial interest as examples of anthropogenic change to the profile and consequently are of cultural interest (see below).

In Chapter 13 of this report there is an extensive discussion of the issue of loss of rare soils, and how these might be protected from development or inappropriate agricultural activity through the system of designation of statutory sites. Soils are protected by default at sites designated for their wildlife and archaeological value, and by landscape and other countryside protection policies, but there is a good case for designating sites purely for their soil value. Soils in areas which are not designated (for their wildlife, archaeological, or potentially soil, value), are potentially at risk. This report does not recommend a prohibition on development on all soils, but simply states that all soils are a valuable resource that should be protected from destruction. In most development, soil can be re-used, albeit often with changed character, and not necessarily at the same site. Planning policy (see later) is moving towards recommending that all soils should be carefully handled and re-used, which is entirely desirable. There is scope however, for ensuring that the soil and vegetation of unimproved and semi-improved habitats should be even more carefully treated, to ensure the vegetation, soil flora and fauna, and the soil hydrological conditions are preserved if such soils need to be translocated.

3.4.5 Provision of raw materials

Soil stripped as a consequence of development is ideally re-used on site for landscaping and amenity areas. However, if extensive areas are to be covered with buildings, roads and other impermeable surfaces, substantial quantities of surplus soil will be available. This may be used in other development or re-development sites where topsoil is in short supply. Transport costs are likely to be high but wastage of soil by burial, or stacking for extended periods, is to be avoided.

3.4.6 Protection of cultural heritage

Soil may include a variety of materials and artefacts resulting from human activity. These can include anything from dumps and spreads of re-distributed natural soils, layers built up through human activity and deposition of refuse. Soil also includes evidence of past environments (e.g. in peat) and the effects of human activity on the environment. Soil may therefore be considered to incorporate all types of archaeological evidence and is fundamental to the presentation of evidence of past societies and the historical development of landscapes. Development can damage and destroy archaeological remains, as part of the soil removal or re-distribution process.

3.5 The future situation and policy responses

Both the National Assembly's Sustainable Development Scheme (National Assembly for Wales, 2000) and the UK vision of sustainable development (DETR, 1999) stress four objectives to be pursued in working towards sustainability:

- Social progress recognising the needs of everyone
- Effective protection of the environment
- Prudent use of natural resources
- Maintenance of high and stable levels of economic growth and employment

Furthermore, the recently published 'Planning Policy Wales' (PPW) (Welsh Assembly Government, 2002) lists key policy objectives which should be taken into consideration by local authorities in the preparation of Unitary Development Plans (UDP), and these include:

> "Promote resource-efficient settlement patterns that minimise land-take (and especially extensions to the area of impermeable surfaces) and urban sprawl, especially through preference for the re-use of suitable previously developed land and buildings, wherever possible avoiding development on greenfield sites."

However, 'Planning Policy Wales' recognises that some development on greenfield sites will be necessary. It states that in UDP policies and development control decisions, considerable weight should be given to protecting the best and most versatile land (grades 1, 2 and 3a in the Agricultural Land Classification (ALC) – MAFF, 1998), and this should be "conserved as a finite resource for the future". The ALC system uses soil, climate and site factors to define grade, and the map for Wales has been produced at scale of 1:250,000. This map is produced for use in strategic planning and provides only a generalised indication of the distribution of land quality. It may also be out of date. ALC maps for specific areas may also be available at larger scales from the former FRCA, Aberystwyth (now the National Assembly Agriculture and Rural Affairs Division, ARAD). Conducting a detailed ALS field survey is consequently the only way to provide an accurate assessment of the quality of agricultural land. It could therefore be argued that a detailed environmental assessment should be carried out which encompasses all aspects of land quality, including ecological quality.

'Planning Policy Wales' goes on to state that "The best and most versatile land should be conserved as a finite resource for the future. In UDP policies and DC decisions considerable weight should be given to protecting such land from development because of its special importance. Land in grades 1, 2 and 3a should only be developed if there is an overriding need for the development, and either sites previously developed land or land in lower agricultural grades in unavailable, or available lower grade land has an environmental value recognised by a landscape, wildlife, historic or archaeological designation which outweighs the agricultural considerations." This policy does not seem to protect habitats (and accompanying soil) if they are outside designated sites for wildlife, archaeology etc. Soils of lower grade agricultural land are quite likely to have an ecological value at least as high as those of higher grade land. If land with a low ALC rating has a conservation value, but not sufficient to trigger a wildlife or landscape designation, then the land is unlikely to be protected as adequately as land with higher ALC rating. This situation may well apply to a wide range of unimproved and semi-improved habitats. There would appear to be a good case for introducing an ecological land capability system (or a system which includes ecological quality) which would help protect habitats and their soils of sites with low ALC ratings

Indeed, Planning Division of WAG is involved in the ODPM/DTLR research currently underway on "Land Evaluation as an aid to Land Use Planning", which is investigating a more holistic approach to evaluating land which should widen land classification from purely agricultural quality to encompass wider features of the natural heritage.

Most adopted development plans in Wales have policies protecting BMV land and so BMV policy does influence planning decisions in Wales. However, weighed against other development plan policies, the BMV policy does not override other policies.

Wales has a much lower proportion of Grade 1, 2 and 3a land relative to England and much of this better quality agricultural land lies in development 'hot-spots' in north-east and south-east Wales. Since much greenfield land around towns in these areas is BMV, the policy in PPW for re-developing and re-using brownfield sites and redirecting development away from greenfield sites is relevant here. However, the BMV policy may result greenfield site development being directed to the remaining pockets of land which are un-designated, but still of ecological value, e.g unimproved an semi-improved grasslands.

Planning policy is guided by a series of Technical Advice Notes (TANs) covering specific aspects of development. The current TAN on Agricultural and Rural Development (NAW, 2000) is to be reviewed (together with all other TANs) following publication of 'Planning Policy Wales', but current guidance in this TAN refers only to the fact that ALC exists, and that once agricultural land is developed its return to agriculture is seldom possible. The Technical Advice Note on Nature Conservation and Planning, TAN 5, (NAW, 1996) makes no specific mention of soils and deals only with designated sites and other sites of known nature conservation importance. TAN 5 also recognises that Regionally Important Geological / Geomorphological Sites (RIGS) should be designated according to clear and strict criteria. Rare soils, or particularly good examples of certain soil types, could be protected under the RIGS system, but the planning system should also recognise that all soils have an intrinsic value that can readily be destroyed in the development process.

In contrast to mineral extraction where soils receive a high level of care, there appears to be the need for detailed guidance on handling, storage and re-use of soil from development sites to ensure its quality is maintained. We believe guidance is provided on an *ad hoc* basis by local authorities but a specific policy for soils stripped during development is required. This could take the form of the guidance provided in the consultation draft of the Minerals Technical Advice Note (Wales) – Aggregates (NAW, 2002), which includes a five page Annex specifically on soils and their re-use (see Chapter 3). Planning Policy Wales, and its associated TANs, do not provide adequate operational guidance for the handling, storage and re-use of soil at present. Much of the guidance in MTAN Aggregates could be recommended for inclusion in TANs currently under, or proposed for, revision. Both TAN 5 (Nature Conservation and Planning) and TAN 6 (Agricultural and Rural Development) are to be reviewed and revised with the help of Technical Advisory Groups. TAN 5 is likely to be widened into a Biodiversity TAN covering a wider span of issues than those covered in the current TAN and clearly the revision of these TANs should provide the opportunity to increase consideration of soil protection.

Planning Policy Wales details the requirements for Environmental Impact Assessments of certain types of development, and which are required by legislation, including the Town and Country Planning Regulations and the Habitats Directive. This legislation is designed to protect wildlife and habitats, and will obviously also protect the soils of these habitats. Further protection of soil should result through implementation of the uncultivated land and semi-natural areas provisions of the Environmental Impact Assessment Directive (Directive 85/337/EEC as amended by Directive 97/11/EC). Proposals for the implementation of this Directive in Wales were recently subject to public consultation, and once implemented, should help protect uncultivated land and semi-natural areas (and their soils) in Wales, especially from agricultural intensification and development. The Directive should also help protect uncultivated land and semi-natural habitats from industrial development, quarrying and open-cast mining and peat extraction.

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4. SOIL LOSS TO MINERAL AND PEAT EXTRACTION

Summary

- Wales has a diverse geology and a wide range of minerals has been mined and quarried. At present, coal, limestone, sandstone, hard rock aggregates, sand and gravel and slate are the main materials produced in Wales. Extraction of metalliferous ores, once widespread in Wales, has now virtually ceased. There is an extensive legacy of waste material from historic mineral extraction some of which has been restored or could form a valuable secondary product.
- Applications for mineral extraction are dealt with by mineral planning authorities (local authorities), who are guided by 'Minerals Planning Policy Wales (NAW, 2000) and a future series of minerals technical notes. These recognise the importance of soils with detailed guidance on soil stripping, storage and restoration.
- Planning guidance specifies that progressive restoration of mineral excavations should take place wherever possible, thus eliminating the need to store soil.
- Planning guidance does not specify whole-turf stripping and re-use in progressive restoration schemes. This is important where vegetation is unimproved or semi-improved.

- Peat covers 3-4% of Wales and is predominately acid upland blanket peat. Small areas of raised bog and fen peat are scattered throughout lowland Wales.
- Peat supports ecosystems of considerable biological interest, and provides a record of vegetation, land use and human cultural history.
- Peat extraction has recently been predominantly from lowland raised bogs and fens.
- Peat extraction in the uplands was once an extremely widespread and locally intensive activity, with whole communities being involved. Many of these sites are now designated because of their conservation interest and protected from further extraction. Restoration of damaged sites is ongoing and there is no extensive peat extraction currently occurring in Wales
- Proposals for extraction of peat should be considered by mineral planning authorities using guidance provided in 'Mineral Planning Policy Wales' (NAW, 2000), and should be allowed only under exceptional circumstances.
- Peat extraction of areas >150ha requires Environmental Impact Analysis under the Town and Country Planning 1999 regulations, but smaller proposals may require EIA if they would result in significant environmental impact
- Small scale agricultural peat extraction is unregulated, except on farms with agri-environment agreements, SSSI agreements etc., although conditions of these agreements are sometimes breached. Under the Whole Farm component of Tir Gofal, agreement holders are required to consult their Project Officer before undertaking any quarrying or excavations.

4.1 Background

Throughout this chapter, we have considered peat separately to the other minerals, since the issues relevant to peat quite distinct from those relevant to minerals. However, for planning purposes, peat is included within the definition of minerals and is subject to minerals policy and legislation.

4.1.1 Minerals

The diverse geological history of Wales ensures that a wide range of mineral materials is available in Wales. These include coal, slate, metal ores, sand and gravel, brick clay, limestone (for building, aggregates, cement and industry), and hard rock (for aggregate and building stone). Apart from metal ore extraction, which has virtually ceased in Wales, extraction of these materials continues, although in most cases at a much lower intensity than in previous decades.

The legacy of former mineral extraction is seen throughout Wales. Colliery tips are found in South Wales and near Wrexham, although many have now been removed, landscaped or restored to productive use or amenity areas. Virtually all metalliferous mine and quarry workings in Wales are now disused. However, evidence of extensive former activity remains throughout Wales in the form of spoil heaps and disused workings, especially in mid-Wales and Snowdonia. Lead, copper and zinc were the main metals of interest. In North Wales, slate quarrying is still an important employer locally, but in Gwynedd alone it is estimated there are 450-500 million tonnes of slate waste.

Details of production (in tonnes) of minerals for each country in the UK are given in Yearbooks of the British Geological Survey (e.g. British Geological Survey, 1999).

4.1.2 Peat

Peat is extensive in Wales, especially in the uplands, where acid blanket peat occupies large areas on plateaux and interfluves throughout Wales. In the lowlands, raised bog and fen peat occur in isolated patches in natural basin sites and river valleys. Many upland soils in Wales are described as 'peaty' (e.g. peaty gley, peaty podzol, although these terms are no longer used in the Soil Survey of England and Wales classification). 'Peaty' refers to the fact that soils have a peat surface layer over mineral soil, with the peat layer less than 20 inches (45cm) thick. True peat (which is what we are discussing here) has traditionally been defined as being more than 45cm deep, although there has been inconsistency in this definition, even in older publications of the Soil Survey of England and Wales. Other workers have used definitions of 0.5 and 1 metre. Most recently, Rudeforth et al., (1984), used the standard Soil Survey of England and Wales definition of 40cm of organic material in the upper 80 cm of soil, or 30cm of organic material over bedrock.

Peat was formerly used as fuel and was generally won domestically. Today peat usage is almost entirely in commercial horticulture and domestic gardens and is sourced from outside Wales. The lowland raised bogs and fens have been exploited most, mainly because of accessibility, but in the case of fen peat, because of its higher pH and fertility.

Much lowland peat has also been cultivated and drained for agriculture, although statistics on the area involved have not been compiled. Significant areas of upland blanket peat have been converted to forestry in Wales. Cannell *et al*., (1993) estimated 9,100 hectares of forest have been established on blanket peat (12-14% of the total area of blanket peat). Stevens *et al*., (2000) estimated 15,500 hectares of the blanket peat supported conifer, or 17% of the total. The discrepancy between these two studies is the result of using different sources for the areas of conifers and blanket peat.

Peat supports a range of habitats of high nature conservation interest and also preserves a detailed and irreplaceable record of human land-use and vegetation change in the form of biological remains and inorganic deposits. Many peatland sites are now protected by various forms of statutory designation, but this protection afforded to peatlands relates to their vegetation and habitats, and not directly to the peat itself.

As peatlands receive greater protection the use of imported peat and peat substitutes is consequently increasing to satisfy the growing demand.

4.2 Information sources and literature

4.2.1 Minerals

Detailed information on the location of mineral resources is available in an extensive set of maps and reports published by the British Geological Survey (BGS). These include:

- Mineral Reconnaissance Reports, undertaken between 1971 and 1997, which cover metaliferous minerals and bulk constructional and industrial minerals
- Mineral Assessment Reports, undertaken between 1971 and 1990, which cover sand and gravel, hard rock aggregates, limestone, conglomerate and celestite
- Minerals Programme Publications, which commenced in 1998 and covers a wide range of topics including minerals assessments for certain districts
- The British Geological Survey has also published small-scale maps for the UK of building stone, coal and industrial minerals.

In addition, Mineral Resource Information for Development Plans for South Wales were completed by BGS for DETR in 1997.

A very useful summary of mineral resources in Wales is provided in the recently published 'Minerals Planning Policy Wales' (National Assembly for Wales NAW, 2000). This describes the types of minerals found in Wales, their distribution, and planning issues associated with their exploitation. 'Minerals Planning Policy Wales' provides guidance on the main minerals which authorities in Wales are likely to have to consider extraction applications for. The list includes coal, aggregates for the construction industry, 'dimension' stone such as limestone, slate, clays and shales for making brick or fire clay, limestone for industrial purposes such as steel making, and silica sand. Resources of metalliferous minerals occur primarily in Mid and North Wales, but there are no current workings of any significance. The Environment Agency are currently consulting on a 'Metal Mine Strategy for Wales', which will consider the best environmental course of action for remediation of the fifty sites considered to have the greatest environmental impact (Environment Agency, 2002). Over 1,300 known non-ferrous metal mine sites are held on an Environment Agency database.

Details of production of minerals for each country in the UK are given in Yearbooks of the British Geological Survey (e.g. British Geological Survey, 1999).

4.2.2 Peat

Peat is widely distributed in Wales but estimates of the total extent vary with the definition of 'peat' (Yeo, 1997). Probably the best estimate of the extent of peat in Wales is that of the Soil Survey of England and Wales (Rudeforth *et al.,* 1984), who define 'peat' as having more than 40cm of organic material in the upper 80cm. Rudeforth *et al.*, 1984, estimate the total area of peat as 706 km^2, or between 3 and 4% of the area of Wales. Estimates of peat area which use a greater depth for the definition of peat should yield a smaller area, and Yeo, 1997, reports a figure of 285 km^2, based upon British Geological Survey maps. In this case 'peat' has to be at least 1m deep. Surprisingly, however, Taylor and Tucker (1968), using a depth of 0.91 m, estimate the total area of peat in Wales at 842 km^2, rather more than the estimate by Rudeforth *et al.*, 1984.

Peat and other 'peat' soils in Wales contain a significant store of terrestrial carbon. Typically the organic carbon content of the surface (0 – 15 cm) layer of these soils is 46 percent (see Chapter 7), but efforts to estimate the total are thwarted by the variability in carbon content within and between soil horizons, and because the depth of peat varies enormously. Only very crude estimates are possible and are currently being attempted by CEH Edinburgh, and separately for Wales by the School of Agricultural and Forest Sciences, UW Bangor, in collaboration with CEH Bangor.

The distribution of peat in Wales is shown on the 1:250,000 Soil Survey map which accompanies Rudeforth *et a*l., 1984. This map is at scale and provides the most comprehensive and consistent coverage for Wales. Mapping by the Soil Survey has also been carried out at a more detailed scale (1:63,360 and 1:25,000) but this is restricted in its coverage of Wales (see Chapter 2 for details of these areas).

Most of the 706 km^2 of peat in Wales is upland blanket mire (which includes some upland raised bogs which are difficult to distinguish from blanket peat), whereas there is only 24 km^2 of lowland fen peat and a small area of lowland raised bog (Rudeforth *et al*., 1984).

Two sources of information on the distribution of lowland peat in Wales are:

- Burton and Hodgson (1987) who mapped sites <200m O.D. at 1:1,000,000 scale, listed 36 sites in Wales and provided brief descriptions of many of them, and
- Lindsay and Immirzi (1996) who compiled an inventory of lowland raised bogs in Great Britain. Of the 1,045 sites listed for G.B., only 20 are in Wales.

4.3 The current situation

4.3.1 Minerals

Mineral extraction by quarrying and open cast mining will clearly require substantial disturbance of soil in order to reach the minerals beneath. The processes affecting soils are:

- Stripping and stockpiling or progressive restoration of topsoil and subsoil
- Burial under development and infrastructure associated with mining/quarrying
- Burial under mine/quarry waste

- Contamination by wastes/leachate/industrial oil and chemicals
- Changes in water flow patterns causing changes in soil hydrology

Mineral extraction is regulated under planning policy, which in Wales is covered by the recently issued 'Minerals Planning Policy Wales' (NAW, 2000). The emphasis of planning policy is to provide mineral resources in a sustainable way, by maximising use of secondary and recycled materials (e.g. slate waste, demolition waste), and by ensuring future primary-won material is essential and properly planned for. This policy is therefore intended to limit the amount of freshly-won mineral and this is clearly desirable. Use of secondary aggregates and other materials is promoted. Slate waste could be utilised in substantially greater quantities than at present (NAW, 2001), and Wales lags behind all regions of England in recycling construction and demolition waste, most of which is currently disposed of as landfill (DETR and Environment Agency, 2000).

Where applications are made for new mineral extraction, 'Minerals Planning Policy Wales' (NAW, 2000) states that unless the plans provide for satisfactory and suitable restoration, planning permission should be refused. 'Minerals Planning Policy Wales' is supported by a series of detailed technical guides ('Mineral Planning Guidance - MPG') which provide guidance on operational procedures for soil handling and restoration. MPGs were issued for England and Wales from 1988 to 1995 after which they were generally issued for England only. Some of these MPGs are still applicable in Wales although later revisions often only relate to England.

MPGs are to be replaced by a set of Minerals Technical Advice Notes (Wales) in which guidance is updated and expanded. The first of these, 'Minerals Technical Advice Note (Wales) Aggregates' (MTAN Aggregates) (NAW, 2002) is currently out for consultation (February, 2002). It includes a five page annex specifically on soils, which summarises a number of recent reports on soil stripping, storage and restoration. It states that progressive restoration is essential, and should reduce or eliminate the need for storing soil, which inevitably causes degradation – physically, chemically and biologically. It also states that 'every effort should be made to identify soil types and their quantity before soil stripping operations commence. A soil survey by suitably qualified personnel is usually necessary. Information should be obtained on the location of soil types, their extent, and of the thickness of topsoil and subsoil layers…..'. 'MTAN Aggregates also includes considerable detail in a further annex on subsequent replanting, seeding and aftercare.

Further Minerals Technical Advice Notes (MTANs) are planned, including that for coal in 2003 (personal communication, Sue Martin, Planning, NAW). Reclamation and soils issues will be included in each MTAN and soils advice in future will include advice similar to that in the aggregates MTAN, as appropriate.

The advice given in this MTAN shows a high level of care for soils. However, there is no advice given for situations where it is desirable to retain the entire soil/vegetation system in turves for immediate removal to receiver sites in progressive restoration schemes. Where the original vegetation is of conservation interest, as in unimproved or semi-improved grasslands and heaths, turf removal is extremely desirable, even though higher plant survival is not as great as one would wish (Good *et al*., 1999). Habitat re-creation may also be required by planning authorities where aggregate or other mineral material is quarried. For instance, the Penrhyn slate quarry has been given permission to extend their operations into an SSSI on the edge of the Snowdonia National Park. One of the conditions is that 70ha of dry heathland habitat destroyed during quarrying should be re-created on a backfilled area. One technique adopted successfully has been direct transfer of heathland turf. This technique, although expensive, has the advantages of retaining many of the soil's own flora and fauna, in addition to the advantage of instant vegetation cover.

Except in situations where soil and vegetation to be stripped is of conservation interest (which may preclude mineral extraction of the site anyway for this reason), the soil handling procedures given in MTAN Aggregates, if applied in full, should provide as high a level of protection of soil as can reasonably be expected, given that there is no means of avoiding removal and restoration of soil in this situation.

Technical guidance for soil handling other forms of mineral extraction has been available as Mineral Planning Guidance (MPG) for coal mining and colliery spoil disposal (MPG 3), reclamation of mineral workings (MPG 7) and provision of raw material for the cement industry (MPG 10). These will be superseded by relevant Minerals Technical Advice Notes (Wales). This detailed consideration of soil issues in the regulations covering mineral extraction contrasts sharply with the relatively limited approach in relation to land development (see Chapter 3).

4.3.2 Peat

Although there is little evidence of it today, peat extraction seems to have been a remarkably extensive (almost universal) activity, both in the uplands and lowlands leading to historic reductions in the soil organic carbon stocks (see Chapter 7). A majority of upland sites show at least some evidence of past extraction and many lowland sites have been subject to some degree of peat extraction, including several of the most important peat sites in Wales, such as Cors Fochno NNR and Fenns, Whixall and Bettisfield Mosses NNR which are currently undergoing restoration. Peat extraction continues on a small scale at a very limited number of sites (including Carmarthenshire and Glamorgan) and there remains a risk where potential sites have old extraction consents and are not SSSI (P.Jones, CCW peatland ecologist, personal communication). However, the emphasis at present in the statutory agencies and voluntary bodies is to protect remaining peat systems and to restore those that have been damaged.

4.4 Impact on soil functions

4.4.1 Bio-mass, food and fibre production

Minerals

Much of the land taken for mineral working is in agricultural use prior to mineral extraction operations, and up until the 1980s the majority of this land was returned to agriculture (NAW, 2002). The techniques for restoration of soils for agriculture are well researched and the more sensitive approaches to soil stripping and handling advised in NAW (2002) for aggregate extraction (if applied to all mineral extraction industries) should help protect the ecological function (and potentially the agricultural function) of soil more than in previous decades. Restoration to forestry or woodland has in recent years been regarded as an alternative option to agriculture, especially where the latter is unsuitable due to insufficient or unsuitable soil. Also, many Welsh soils, including the poorly draining, structurally unstable soils of many marginal upland pastures in South Wales, do not take kindly to stripping and restoration, and can become compacted and subject to surface erosion. There is a good case for woodland creation on these soils, even though tree growth may not be spectacular.

Soil stripping, storing and in some cases burial of soil associated with mineral extraction will clearly prevent soil from carrying out this function until restoration takes place. To keep this period as short as possible, and to reduce the risk of degradation of the soil, progressive, phased restoration should occur whenever possible, with the greatest care taken to ensure topsoil and subsoil are replaced in the correct order and storage kept to a minimum.

Peat

Extraction of peat changes the nature of a site dramatically, either through hydrological change, or through truncation of the profile from peat to mineral soil. Extraction of peat does not generally result in sites that have a high potential for biomass, food and fibre production.

Lowland peat soils in Wales are not extensive but have considerable potential, once drained and if not too acid, for intensive agricultural production.. The Lowland Raised Bog inventory of GB (Lindsay and Immirzi, 1996) suggests there may be as much as 2,200 ha of peat of raised bog origin which no longer supports semi-natural mire vegetation – most of this will have been converted to fairly intensive agriculture. Very often, this peat will be limed and fertilised, and will have high agricultural productivity. If peat such as this is removed to leave only a thin peat layer, most likely over clay, the resulting soil will be of much lower agricultural productivity and therefore removal of this ‘improved’ peat should be resisted. Quite apart from the agricultural aspects, there is a very persuasive case for regarding these archaic peatlands as a valuable potential nature conservation resource. Restoration technology has advanced to such an extent that even the most modified systems can be restored to something better.

Upland blanket peat is characterised by very low agricultural and forest productivity, although lodgepole pine and Sitka spruce will produce a moderate crop so long as drainage and nutrients are provided. Extraction of this type of peat does not occur to any extent in Wales at present.

4.4.2 Environmental interaction

Removal of peat may have a significant effect on hydrology, by reducing the capacity of the soil to store water, especially if impermeable clay-rich substrate is exposed, and water runoff is likely to be faster and more 'flashy'. From an agricultural point of view, there will be loss of the potential fertility of peat, because of truncation of the profile and inevitable compaction.

4.4.3 Provision of a platform

This function is effectively eliminated until restoration is completed.

4.4.4 Support of ecosystems, habitats and biodiversity

Unless great care is taken in ensuring rapid re-use of soil in progressive restoration, there is a considerable risk of damage or destruction of this function. The planning process should ensure that valued ecosystems and habitats are protected from mineral and peat extraction, and where mineral or peat extraction is allowed, that rigorous conditions are applied to soil storage and restoration schedules. Even so, habitat restoration and re-creation never exactly re-create the original, despite labour-intensive and expensive methods. This is a matter of concern where extraction is allowed on sites of conservation interest. Even under experimental conditions, only limited success in re-creating habitats is achieved (see Chapter 3 and Good *et al.,* 1999). The nature conservation agencies have provided advice at special sites for soil removal/storage and replacement with vegetation e.g. Cairngorm funicular railway.

Effects of mineral and peat extraction on soil biodiversity are largely unknown. Stock piling of soil has deleterious effects on soil hydrology and aeration, which will be detrimental to soil macro and meso-fauna. Stockpiling can result in accumulation of significant quantities of ammonium in the anaerobic cores of the mounds as nitrifying bacteria are inhibited, (Williamson and Johnson, 1994). Upon dismantling and land restoration, the ammonium is rapidly converted to nitrate, which is readily lost from newly restored soil ecosystems by leaching and denitrification.

Metalliferous mine waste may support a special flora tolerant of the high metal concentrations, e.g in the Ystwyth Valley and Gwydir forest. These sites therefore have an almost unique conservation importance

Lowland fens and raised bogs are rare soil types in Wales and have been damaged by peat extraction, agricultural improvement, and nutrient runoff from adjacent land. Restoration schemes are currently in place at a number of sites, but opportunities may arise for further restoration, including adjacent land, through the 'Voluntary Options' component of Tir Gofal.

4.4.5 Provision of raw materials

Mineral and peat extraction will have the following impacts on this function:

- Peat extraction is, in itself, a supplier of raw materials for use as a soil elsewhere
- Soil buried under mine and quarry waste tips is effectively prevented from providing this function
- Soil stripping and progressive restoration, with little or no stockpiling is the best option for preserving the soil (as a raw material)

4.4.6 Protection of cultural heritage

Mineral and peat extraction may potentially have very damaging effects on the cultural heritage, through direct destruction of features of archaeological value held within the soil. Peat may also provide a valuable record (in the form of preserved pollen and other remnants) of vegetational and environmental change, e.g. as at Cors y Llyn NNR in mid-Wales (Moore and Beckett, 1971).

A register of Historic Landscapes has been produce by CCW for Wales and several of these incorporate elements of historical mining or quarrying activities, with tips and buildings regarded as characteristic features. Examples are the Nantlle valley, Amlwch and Parys Mountain and Blaenau Ffestiniog.

4.5 The future situation

Wales has substantial reserves of minerals such as coal, slate, limestone, sandstone and hard rock. The emphasis of planning policy is to provide mineral resources in a sustainable way, by maximising use of secondary and recycled materials, and by ensuring future primary-won material is essential and properly planned for. It is clear, therefore, that mineral extraction will continue in Wales, and that displaced soil needs to be carefully and properly handled and re-used in accordance with current planning policy documents.

Demand for peat and peat-based composts remain substantial. Total peat use increased from 2.542 m^3 to 3.162 m^3 from 1993 to 1997, mainly through increased usage by amateur gardeners who account for almost 70% of all peat used (DETR, 1999). Further increases in the potential usage of peat and peat alternatives seem likely, with demand supplied by increased acceptance of alternatives (29% of total substrate was alternatives in 1997 - DETR, 1999) and imports.

4.6 Policy responses – present and future

4.6.1 Present

For mineral extraction, the recently issued Minerals Planning Policy Wales (NAW, 2000) and its associated MTANs and MGCs give extensive recognition to soil conservation and restoratoin issues. For peat, the DETR Working Group on Peat Extraction and Related Matters (DETR, 1999) reported that there is 'no commercial peat extraction from bogs in Wales' and 'no [planning] guidance has been issued there'. It is not clear from this statement whether it includes all types of peat (i.e including fens), but planning guidance in Wales has now been issued. Proposals for peat extraction are included in 'Minerals Planning Policy Wales' (NAW, 2000), which states that 'peat bogs are of significant nature conservation interest and are frequently important for archaeological interest, and these areas should be protected and conserved for future generations. Future peat extraction should be limited therefore to exceptional circumstances in areas which have already been damaged significantly by human activity where restoration towards wetland habitats could improve the nature conservation importance of a worked out bog. The Countryside Council for Wales should be consulted on proposals for peat extraction.' However, Minerals Planning Policy Wales also states that 'There continue to be market demands for peat which could be met by limited peat extraction in Wales in the interests of economic growth and maintaining employment provided that the environmental impacts are acceptable.'

At the local level, proposals for peat extraction will be dealt with by mineral planning authorities (local authorities, National Parks) who are expected to have strategic policies in regard to peat extraction. Peat extraction needs to be considered in the light of the Town and Country Planning Regulations (1999), which dictates that environmental impact assessment is required under these regulations if the proposed site covers more than 150 hectares or if there are likely to be significant effects on the environment. Any peat extraction which might affect environmentally sensitive areas (in the widest sense) should be referred to CCW.

These regulations appear to provide protection of most peat soils in Wales because to remove them would have adverse environmental consequences. It is not clear however to what extent smaller areas of peat, which may be of moderate or low conservation importance fare in this system. Neither is it clear how degraded upland blanket peats which are not covered by existing or proposed SSSI/SAC/SPA designation would be handled by the planning process.

Additional influences on the future protection of peat include recognition of blanket bog as a priority habitat within the UK Biodiversity Action Plan (UKBAP, 2002): in Wales, some 15,700 ha of blanket mire vegetation occur within SSSIs. Action Plan targets include maintaining the current extent of blanket mire in favourable condition, and to introduce management regimes to improve a substantial area of degraded blanket mire.

The Action Plan for blanket bog also states that the potential threat from climate change could over-ride many of the other factors which influence blanket mire, such as grazing, pollution etc. Peat is a major repository for carbon, and any process which alters the role of peat from a net accumulator of C to a net source of C is extremely undesirable. The role of soil organic matter in the carbon cycle is dealt with in greater detail in Chapter12 Climate Change.

4.6.2 Future

The mineral planning authorities (the local authorities) are required to adopt a strategic approach to mineral and peat extraction, and to examine vigorously all applications for extraction. Planning policy in Wales has undergone significant revision recently, and soil is now expected to be treated in a much more sympathetic manner than previously. There are still some concerns, however, over the lack of a requirement for whole-turf transplantation where the original vegetation is of an unimproved or semi-natural nature.

Several respondents to the questionnaire thought that peat extraction was an issue in Wales. It seems clear that peat extraction has been important locally in Wales, but there is currently only very limited extraction. The planning process should protect remaining areas of peat where these have significant nature conservation value, but there remains a risk of extraction:

- where peat has undergone agricultural improvement,
- in smaller sites where extraction or drainage can occur without the knowledge of planning authorities, or
- where upland blanket peat has undergone degradation to the point where designation for conservation purposes is not appropriate.
- by agricultural operations in SSSI. Although CCW adopt a ‘zero-tolerance’ attitude to damage in SSSI, it cannot guarantee damage will not occur (CCW, 1999), especially as sites may be visited only once every 6 years. In practice, most sites are visited far more regularly than this. Six years is the reporting cycle for the Habitats Directive and under Common Standards Monitoring CCW are required to report on the condition of all SSSI features every six years; the next reporting deadline being 2005/06. This does not necessarily mean that a feature is only monitored once during this period however.

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5. SOIL LOSS BY EROSION

Summary

- Soil erosion is taken to include all water and wind-driven forms of accelerated soil loss and the issues associated with the resulting sediment. The transport of soil particles as water-borne sediment is intimately associated with possible changes in river flow regimes that are the consequence of the same set of land practices. Based on a single national survey and a number of local studies, it can be concluded that soil erosion is occurring throughout Wales as a result of land use and management practices.
- Footpath restoration and maintenance in response to path erosion is a major cost to the countryside management industry. The problem of erosion is now a recognised management issue in the forestry and construction industries which have developed codes of practice to counter the threat. Farming is another major cause of soil erosion but the industry has yet to recognise the environmental and economic costs of its actions in this context, despite campaigns by various Government agencies.
- The impact of soil erosion from enclosed farmland and open moorland is perceived to be greatest off-site, in the river network and lakes of Wales, where there are thought to be effects on river ecology and game fisheries. However the link between land and water has only recently been more widely recognised. The aesthetic impacts of accelerated soil erosion are also significant.
- The current policy response to soil erosion is inadequate. Better education and extension programmes are needed. Soil conservation and erosion control should become components of agri-environmental programmes such as Tir Gofal and minimum standards of soil husbandry should be required of farmers receiving other subsidies. More monitoring of soil erosion and of sediment movement is urgently required.

5.1 Introduction

The gradual erosion of soil is a fundamental process in landscape formation. However accelerated erosion is an unwelcome consequence of some forms of land management (Evans, 1995; Imeson, 1974). While recognised as widespread in southern Europe, erosion in the UK has been considered to be of only local significance (RCEP, 1996) partly because the off-site impacts of sediment have not been recognised. Its impact and importance in the management of the environment are now more widely acknowledged (Environment Agency, 2000). Soil erosion represents more than the simple loss of soil as there are off-site impacts from the sediment that is generated. Ecosystems and habitats, which are significant in the Welsh landscape, rivers, lakes and fisheries and the palaeoecological and archaeological information stored within soils are all at risk.

Soil erosion is here taken to include all forms of water- and wind-driven particulate loss from soil and all issues associated with the resulting sediment. The accelerated loss of soil through erosion is influenced by both natural and human factors. The environment influences vulnerability of the soil to erosion and determines the degree to which erosion, once initiated, develops. External factors, such as humans and grazing animals,) initiate and increase soil loss by damaging or reducing the vegetation cover of soil. The fcators determining the vulnerability of soils to erosion and the key processes are reviewed in Appendix V.

5.2 *Erosion in Wales*

5.2.1 Soil erosion in Wales

Much of the data on soil erosion in Wales cited below derives from national-scale assessments of the extent of erosion on a range of lowland, permanent grassland and upland field sites completed by NSRI Cranfield University (Harrod, 1998; Harrod *et al.*, 2000; McHugh, 2000; McHugh *et al.*, 2002a). Field sites were objectively located at the National Soil Inventory 5km grid intersects, and hence represent the range of landscapes within Wales. Although it is generally accepted that further information on soil erosion is necessary (RCEP, 1996), current sources of objective, large-scale data are limited (DOE, 1995). To date, information on the rate of soil loss from these sites does not exist, although ongoing research is seeking to redress this (McHugh, 2002a).

5.2.2 Upland erosion

The most comprehensive data on erosion in Wales pertains to degradation of soils within the upland habitat. As definition of the uplands is difficult using any single attribute (Bunce, 1997), the term upland refers to any area vegetated principally by upland plant species, including *Eriophorum*, *Sphagnum*, *Molinia*, *Agrostis* species, *Calluna* and *Nardus*.

Soil hydrology is an important factor in erosion, as soils with increased moisture content have reduced shear strength (Morgan, 1995). Vulnerability to erosion also varies with slope because of the gravitational energy of eroded sediment, the inherent instability of steep slopes and the difficulties of regeneration and recovery once steep slopes are damaged (McHugh, 2000; Morgan, 1995; Evans, 1996).

The data cited here were derived from DEFRA-funded research into upland erosion extent, rates and causes (Harrod *et al*., 2000; McHugh, 2002 a and b), in which the extent of erosion was assessed at 155 field sites located across Wales. Of these, 66 (42.6%) field sites, less than the 59% of eroded English field sites, contained eroded soil. In terms of the pattern of distribution, however, upland erosion in Wales was similar to that for England (McHugh, 2000). Erosion was greatest on concave field sites, at altitudes up to 600m and on slopes with angles up to 7° and of greater than 25°. Whilst most eroded field sites were on grassland and heath vegetation, the scale of erosion was greatest on bog vegetation. Similarly, more erosion was measured on peat soils, with decreasing extents of erosion on wet peaty mineral soils, wet mineral soils and on dry mineral soils.

Eroded field sites in the uplands were not concentrated within individual regions of Wales but were scattered throughout the uplands. Although it was not quantified, increased erosion on field sites between 1997 and 1999 was primarily due to the actions of humans and grazing animals (McHugh, 2000). Subsequent research has also shown that grazing animals and humans were together responsible for the initiation of erosion at 75% of field sites and for the maintenance of bare soil at 77% of field sites (McHugh, 2002b). In the longer term, aerial photographs have shown that erosion caused by both humans and animals (principally sheep) has increased over the period since 1946, and that erosion of peat and mineral soils has stabilised or started to recover, through revegetation, across Wales (Harrod *et al*., 2000; McHugh, 2002 a and b).

In further studies in the uplands of Wales, erosion losses have been assessed in the headwaters of the Wye and Severn on Plynlimon by the former Institute of Hydrology and Centre for Ecology and Hydrology since 1973. The Wye is predominantly unimproved grassland, grazed by sheep and cattle, whereas the Severn is predominantly commercial conifer plantations, established on former acid grassland. Bedload is measured in river-bed traps in two catchments, one in each of the Wye and Severn. Suspended sediments are regularly sampled in five streams, one of which is in the Wye, and four in the Severn. These data do not necessarily measure ‘extensive’ soil erosion, since casual observations in the catchments reveal that much of the eroded material in the grassland catchment is from channel bank erosion, channel deepening and flush bursting, and in the forest from drainage channels and road construction or maintenance. Rather, these studies indicate how medium to large-scale land management practices affect overall erosion processes. In this case, ditching and drainage associated with the forest establishment resulted in substantially greater sediment and bedload in the Severn catchment.

Further studies at Plynlimon by Collins *et al*., (1997) have adopted a chemical and radiometric finger printing technique to distinguish between eroding surface soils and channel banks. Eroding surface soils were the most important source of contemporary suspended sediment loads at Plynlimon, and at Abermule on the Severn floodplain with erosion of forest soils, associated with autumn and winter activities, particularly evident. Collins *et al*., (1997) also examined a sediment core from the floodplain at Abermule, which demonstrated the significance of recent phases of afforestation and deforestation for accelerated soil erosion.

Recording of bedload and suspended sediment at Plynlimon continues (Naden and Smith, CEH Wallingford, personal communication, 2002), with three broad objectives:

- Modelling sediment delivery from small forested upland catchments
- Sediment related processes associated with current forestry practices

- Upscaling sediment delivery to broad upland areas

The Plynlimon data will also be invaluable as a baseline against which the impacts of climate change, which are predicted to include more severe and prolonged rain events, may be judged.

Many areas of blanket peat on upland plateaux in Wales are subject to peat 'hagging', with associated aprons of bare, eroding peat. The factors responsible for initiation of hagging remain uncertain, despite concentrated research effort in other afflicted areas such as the south Pennines (Tallis *et al*., 1997). Erosion of blanket peat has been studied on Plynlimon, where it was concluded that, once started, erosion of peat faces and aprons progresses under the actions of drying and rain impact (Francis, 1990). Dry summers caused extreme desiccation and heavy autumn and winter rain resulted in the greatest peat sediment delivery at that time of year. Needle ice formation in winter may also dislodge significant quantities of peat.

From the 1940s until the 1980s, upland blanket peat was subject to extensive conifer afforestation, for which pre-afforestation drainage work was essential. On the Llanbrynmair moors in mid-Wales, stream water concentrations of suspended peat increased 2.5 times after afforestation ploughing, despite the ploughing strategy being designed to minimise sediment loss (Francis and Taylor, 1989). It was concluded that summer desiccation prepared the sediment for transport from the plough furrow sides and autumn rains removed the loosened sediment, such that stream concentrations were also highest in autumn. Fortunately, it is unlikely that afforestation of peats, using this type of pre-afforestation cultivation, will take place in future.

5.2.3 Lowland arable erosion

Because the risk of soil erosion is greatest when there is little or no protection provided by a cover of vegetation, arable land is more at risk than established grassland or undamaged semi-natural vegetation such as heathland (Harrod, 1998). The vulnerability of arable soils to erosion is influenced by topsoil texture (topsoil textures dominated by sand and silt are more vulnerable to soil loss than those with a high clay content (Morgan, 1995; Evans, 1990)) and slope (erosion vulnerability increases with gradient (Fraser *et al*., 2000)). Erosivity is also influenced by the presence of calcareous material in the topsoil, which confers greater aggregate stability to the soil structure (Harrod, 1998).

In a study on lowland arable erosion, the criteria for selection of field sites, which included a minimum distance of 5km between field sites, effectively excluded arable fields in Wales where arable cultivations are generally of smaller scale than in England (Harrod, 1998). Nonetheless, the principal areas of arable cultivation in Wales, including Dyfed and Pembrokeshire, are likely to be subject to similar erosion pressures and patterns as those in England. Harrod (1998) found that channelled erosion, particularly rilling, was the principal form of erosion on lowland arable fields and that erosion occurred most frequently on autumn-sown crops of winter wheat and barley. The number of eroded field sites increased as drilling date approached the year end, possibly due to poorer crop growth or because farmers tended to delay sowing the lighter, more erosive soils that are workable for longer periods. There was no significant difference between the erosion caused by conventional (powered harrows and/or combination drills after ploughing) and traditional (ploughing and harrowing before drilling) cultivations but the proportion of eroded sites was substantially reduced with both minimum cultivation and with drilling following ploughing and pressing. These limited results, and the absence of quantitative data for Wales, emphasise the need for a sustained policy of arable erosion monitoring and assessment.

Little is known of the extent of lowland wind erosion beyond the very obvious 'blow outs' seen on almost all coastal dune systems. Anecdotal evidence suggests that it is restricted to light sandy soils in the Wrexham and Maelor areas of the north and caused by drying spring winds on spring-sown fields.

5.2.4 Lowland grassland erosion

Although not usually considered to be susceptible to soil erosion (Morgan, 1995; Evans, 1990), lowland grassland soils can suffer structural degradation following poaching (trampling) by livestock or by untimely vehicle movements (McHugh *et al*., 2002). The chance of erosion developing is greatest in the early stages of grassland establishment, when the ground behaves much as it does during arable use, but once the sward is established susceptibility is reduced (Harrod, 1998).

Soil hydrological properties and land management determine the pathways and proportions of excess water movement in grassland soils. Ill-timed landuse (cultivation, traffic or grazing) under unfavourable weather conditions can seriously damage soil structure and alter the balance, storage, and transmission of water. During the growing/grazing season livestock require continuous access to pastures and it is inevitable that some grazing occurs under wet soil conditions. Out-wintering of both sheep and cattle results in soil damage from general poaching and from concentrated degradation around feeding sites, where rutting and slurrying of the soil by vehicle traffic exacerbates soil degradation (Harrod, 1998).

Erosion extent, evidence of poaching and structural degradation were assessed on 28 lowland grassland field sites in Wales in 1997 (Harrod, 1998). Results indicated that soil erosion was not a significant process on established, enclosed grassland. Eroded soil was recorded within only five of the sites visited and the total volume of erosion measured was $0.16m^3$. Whilst some erosion was attributed to restricted soil infiltration capacity or to soil saturation, livestock and land management practices (including forestry and drainage) caused damage on individual sites.

In a separate study, Ford (2000) investigated bare ground features in the Llafar catchment (north of Llyn Tegid), which is dominated by seasonally waterlogged surface water gley soils that are susceptible to poaching. The catchment is stocked by large numbers of sheep and some cattle. Bare ground was confined to the enclosed grassland of the lower catchment and accounted for 1% of the grassland area (Table 5.1). Poached fields need to be added to this figure but significantly 75% of all features were within 40m of the nearest member of the extended river network. Rowan and Carling (1999) report that sedimentation in Llyn Tegid has risen from 0.076 g cm^{-2} yr^{-1} in the first half of the last century before gradually increasing through to 1980 and then rising dramatically to 0.14 – 0.34 g cm^{-2} yr^{-1}. Phosphorus inputs to the lake match this pattern. The principle source of sediment is predicted to be enclosed grassland soils.

Table 5.1 Erosion features in the Llafar catchment (after Ford, 2000).

Bare ground feature	No of features	As % of total bare ground present in catchment
Gateways	177	36
Field and boundary poaching	85	24
Stock feeders and troughs	61	9
Vehicle ruts	42	13
Yards and muck heaps	26	14
Erosion scars and terracettes	3	<1
Quarries	1	1
Bare soil (reseeding)	1	3

5.3 *Impact on soil functions*

5.3.1 Biomass, food and fibre production

The effects of erosion on arable crop production are less pronounced in Wales than in other regions of the UK. Similarly, upland erosion is not usually associated with reduced productivity because of the extensive nature of upland agriculture. Phillips *et al.,* (1981) determined that the effect of erosion on sheep in the Peak District, based on the reduction of grazing ground, was negligible and it is likely this effect would be similar in Wales. Erosion also depletes soil nutrients, including nitrogen and phosphorus, and therefore represents a threat to productivity, a financial loss to the farmer and a eutrophication danger to the water environment. More insidious soil loss, such as sheet erosion, slowly depletes soil nutrients over long periods and therefore also threatens soil productivity (Van der Post *et al*., 1997).

5.3.2 Environmental interactions

An important function of soils, particularly upland soils, is to intercept, store and subsequently release rainfall thus regulating river flows. Erosion is associated with reduced infiltration and increased runoff (Cooperrider and Hendricks, 1937). Flooding is more frequent (DOE, 1995) and, where they occur, aquifers are not recharged to the same extent (Biot and Lu, 1995) and summer river flows can be lower (Nicholls *et al*., 1995).

The degradation and erosion of the highly organic peat soils found across Wales also represents the loss of a significant carbon sink and the release of previously sequestered carbon into the atmosphere. Negative impacts of these changes include further acceleration of the impacts of climate change, as described in (Chapter 13).

The increased siltation of watercourses and reservoirs (FAO, 1993) and nutrient loading associated with increased sediment loads results in eutrophication, reduced river oxygen content, fish productivity (Phillips *et al.*, 1981) and fish stocks (Theurer *et al.*, 1998) through the clogging of spawning gravels. Eroded soil redeposited on roads and within private homes also has severe financial and infrastructural impacts.

5.3.3 Ecosystems, habitats and biodiversity

Soil erosion in the uplands is symptomatic, if not the direct cause, of loss of quality of upland ecosystems and habitats.

Movement of soil to watercourses as sediment attenuates light in the river, reduces plant growth and affects the growth, behaviour and survival of invertebrates and fish. Hynes and Yadav (1985) report that increased rates of sediment accretion in Llyn Tegid is associated with a gradual change in the diatom flora of the lake indicating more eutrophic conditions associated with higher phosphorus levels.

5.3.4 Provision of a platform

Mass soil movement is rare but the increased flood response of catchments that goes in train with increased erosion and sediment yield puts a greater area of land and population at risk from flooding (Holman *et al.*, 2001).

Soil erosion resulting from the recreational use of the uplands has resulted in the implementation of engineering solutions to footpath management in areas such as Snowdonia. Some footpaths may have been temporarily closed or diverted as a result.

5.3.5 Protection of cultural heritage

Erosion reduces the aesthetic appeal of important cultural landmarks, such as Offa's Dyke, and it compromises the ecological value of ancient woodlands. It also represents a threat to ancient monuments when vegetation and soil removal result in the exposure of vulnerable foundations. In addition, soils around ancient monuments are a valuable resource for identifying past agricultural practices (Usal, 2001) or re-creating past environments (Manning *et al.*, 1997).

5.3.6 Costs of erosion

The overall financial cost of upland erosion is difficult to estimate, because many of the impacts are not directly financial. The greatest economic losses are incurred by water authorities who may need to replace or dredge reduced-capacity reservoirs but National Park Authorities also divert significant proportions of their budgets to erosion, particularly footpath, repair and prevention.

Few studies have directly examined visitor opinion on erosion, but ongoing research in SW England indicate that visitors avoid areas of footpath degradation and eroded landscapes (S. Rodway-Dyer, personal communication, 2002). In addition, research on the Pennine Way indicate that visitor numbers doubled when footpaths were resurfaced, suggesting visitor avoidance of eroded areas (Pearcehiggins and Yalden, 1997). Severe erosion may be sufficient to dissuade visitors entirely, which would impact negatively on local economies.

Using Retail Price Indices (from Nix, 1992), Evans (1996) estimated the total long and short term costs of erosion in the UK were between £23m and £50m per annum, with loss of riparian land in Wales alone costed at £3.5 - 4.2m per annum.

Research has shown that financial allocations to erosion control are limited by budget rather than demand (S. Rodway-Dyer, personal communication, 2002). In 1999, the Lake District NPA estimated that 180 footpaths needed repair involving 41,690 man days of work and a cost of over £4.5 m. During 1995 and 1996 repair undertaken on 450m of path cost £43,000. Similarly, footpath repair work on the Pembrokeshire Coast Path cost £48,000 per mile in 1992 and averaged £50 per metre at Beinn Eighe (Scotland: Gordon, 1992). Severe footpath erosion has been reported from all three National Parks in Wales, requiring extensive, ongoing restoration works. This has been described as a multi-million pound problem (Gritten, Snowdonia National Park ecologist, personal communication, 2002). On Snowdon, where over half a million people use the six paths to the summit each year, degradation has led to a continuous programme of footpath repair and maintenance since 1970. Pardoe and Thomas (1992) estimated that £200 000 was spent annually on footpath repair alone in Snowdon. Nationwide, this translates to millions of pounds invested in repairs to extensively damaged footpaths that have eroded in less than thirty years (Evans, 1996).

5.4 Response to soil erosion, current and future

5.4.1 Current responses

Because soil erosion has only been regarded as of local significance and because erosion is not linked with its off-site impacts, responses have been *ad hoc* and varied.

In countryside management the focus is on responsive engineering solutions. The National Parks and other authorities have intensive programs of erosion control, especially on footpaths. Walkers are encouraged to keep to constructed footpaths and to avoid unprotected soil to prevent exacerbating erosion.

In agriculture, the response is inadequate and does not reflect the severity of the off-site impacts. MAFF incorporated a small amount of soil conservation advice in the Code of Good Agricultural Practice for the Protection of Soil (MAFF and Welsh Office Agriculture Department, 1993). There is a set of leaflets for lowland farmers to assess erosion risk in different crops (MAFF, 1999). Farmers are entitled to a single day of free soil conservation advice but very few have taken up this opportunity. For the uplands, a MAFF/WOAD leaflet on grazing management makes no mention of the impact of over-grazing on soil erosion, although the recently published “Controlling Soil Erosion” leaflet does advise on how to minimise disruption to soils and vegetation. The Maize Growers Association, with assistance from the Environment Agency, has published an advisory leaflet on erosion control for its members. The Environment Agency (2001) presents a set of Best Farming Practices, several of which address the forms and causes of soil erosion and a copy of which is to be sent to every farmer in England and Wales.

In addition to these voluntary codes of practices, there are numerous sources of advice on the sustainable management of soil resources, many of which include the prevention of erosion. For example, the FWAG Golden Rules of arable farming encourages farmers to avoid cultivating steep slopes, which in turn helps to reduce the risk of erosion (FWAG, 2002).

In forestry, the Forests and Soil Conservation Guidelines (Forestry Commission, 1998) provides advice to commercial foresters on the minimisation of soil degradation. In construction, CIRIA (Coventry and Wolveridge, 1999) has published a Code of Environmental Good Practice on Site, which includes various recommendations for the containment of sediment on construction sites.

In heritage conservation, there is recognition of the damage that erosion is causing and general advice is being prepared for DEFRA by contractors. For England, English Heritage is seeking better methods of risk assessment in order to target at risk monuments.

5.4.2 Future potential action

Encouraging better soil conservation practice

Farming is the most extensive land use in Wales and has been least attentive to the need to control soil erosion. A number of actions over and above the current leaflets and free advice service are offered for consideration.

- Awareness of the environmental and economic costs of soil erosion from farmland should be raised among the farming community.
- Minimum standards of soil conservation should be obligatory conditions under all agri-environment and other support schemes of the Common Agricultural Policy.
- In particular, soil erosion risk assessment and conservation should form part of Tir Gofal. This will require training for the Tir Gofal officers of CCW in soil erosion risk assessment and soil conservation.
- An appropriate selection of soil conservation Best Management Practices should be eligible for support under Tir Gofal and other agri-environmental schemes on a targeted basis.

The significance of soil erosion on the quality of landscape, habitats, rivers, lakes, estuaries and fisheries of the Welsh environment must be better understood. A response and prosecution policy should be developed for examples of soil mismanagement resulting in environmental damage. This may require changes to legislation – soil and sediment may need to be identified as 'polluting substances' in the context of water pollution. Already, English Nature include silt in their list of pollutants of freshwaters from diffuse agricultural sources (English Nature, 2002). Farming Connect, which aims to help farming businesses make informed decisions about the future of their business, may become an important medium for advising large numbers of farmers about issues of soil management.

Restoring eroded soils and protecting those at risk

Bare soil needs to be revegetated. Site-specific measures include:

- Fencing off of eroded areas to exclude humans and grazing animals and to prevent further soil disturbance and loss and allow seedlings to grow and achieve maturity,
- Use of hardstanding around stock feeders and in gateways,
- Fencing off of ditch and river margins to prevent stock poaching and degrading banks. Buffer strips will not intercept all fine sediment from fields and should be used in conjunction with other on-field measures,
- Replanting shrubs, trees and grasses (Morgan, 1995)
- Applying seed and fertiliser (Anderson *et al*., 1997)
- Using mats and geotextiles where appropriate to maintain soil cover and prevent movement
- Restoring footpaths through use of hard materials (wood, concrete, stones etc) (Davies *et al*., 1996; Pearcehiggins and Yalden, 1997).

Holistic approaches to management are the only permanent solution to erosion and its negative effects on the environment. Erosion control should not limit activities such as afforestation but should consider soil and landscape (Carling *et al*., 1997) whilst balancing economic, environmental and social goals. Funded programmes will be needed to restore eroded soil in some landscapes.

5.5 Gaps in existing information on soil erosion in Wales

The extent and frequency of erosion in Wales is poorly documented.

1) Information on the extent of erosion within specific landscapes and soil associations in Wales is inadequate. Current knowledge is based on national sampling schemes with recording sites on a 5km grid and on local studies. A comprehensive survey of erosion of Welsh soils is required with detailed local surveys in the full range of landscapes.

2) Information on the rates of soil erosion within Wales is inadequate or non-existent. Ongoing surveys (NSRI) are attempting to assess changes in erosion over a period of years but, in conjunction with (1) above, regular and systematic surveys of the soils would allow comprehensive information on the rates and causes of erosion to be identified. This may form part of a Pan-European soil monitoring network to which Member States will be required to contribute.

3) To date, there has been no Wales-wide attempt to summarise erosion control measures currently in use in the country. Such fundamental information would allow future erosion control or remediation works to be effectively and economically focussed.

4) Recent EA research to develop a risk assessment tool assessing the scale of movement of eroded sediment from hillslopes to watercourses has gone some way towards characterising the risk of sedimentation within rivers and streams (McHugh *et al.*, 2002b). However, further research is required to validate the output, to fully characterise complex catchment erosion and deposition patterns and to understand the roles of adventitious effects, including roads and drains, on the movement of soil and water.

The complexities of the soil erosion issue in Wales, as well as its important and far-reaching impacts, warrant its inclusion in a Wales-wide monitoring scheme as, only once it is fully understood, can necessary steps be taken to ensure the conservation and the sustainable use of the vital soil resource.

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6. SOIL STRUCTURE

Summary

- The soil's physical structure is important to its functional performance. It affects productivity in the agricultural context, is a factor in soil biodiversity and influences soil hydrology.
- The degradation of soil structure is most likely to be an issue in agricultural soils. However virtually no data exist on the structural condition of Welsh soils and no reliable conclusions can be drawn as to whether action is required.
- Anecdotal information, largely from England, suggests that soils may be becoming less permeable through a combination of surface capping of arable soils, poaching of grassland soils and topsoil compaction in both.
- The acquisition of information on Welsh soil structural condition is the primary recommendation. Advisory leaflets on soil management exist but mechanisms are required that will encourage farmers to adopt better practice, if monitoring proves that this is needed. The inclusion of soil management obligations in Tir Gofal is identified as one option.

6.1 Background

The structure of soil is one of the attributes that defines and distinguishes it from underlying geological materials. It is the internal organisation and architecture of the soil that allows it to separate into discrete crumbs or blocks when dug up. Soil structure evolves through the incorporation of a complex of organic materials with mineral particles. While physical wetting and drying cycles encourage the development of vertical fissures deep into soil, the activities of soil biota have the greatest influence on the development of structure, particularly that of the topsoil. While soils are 'structured' at scales ranging from the whole profile through to the microscopic, most concern has been voiced over the maintenance of structure at the scale of the whole profile. Well-developed soil structure contributes to the fertility of soil by allowing the development of deep and extensive rooting systems that enable growing plants to exploit the soil's nutrient and moisture reserves. Soil structure also allows the soil to drain while retaining water for plant uptake in the soil pore space that commonly accounts for 40 – 50 per cent of topsoil by volume.

While the structure of soils can be degraded by a range of activities – housing and industrial development (see Chapter 3), the reclamation of mineral workings and spoil heaps (see Chapter 4), engineering works such as pipeline installation, and forest management – the principal concern is with agricultural land management simply because of its position as the dominant land use in Wales (around 80 per cent). The impact of land use practices, in particular arable farming, has been the subject of debate ever since the Strutt report of 1970 (Agricultural Advisory Council on Soil Structure and Soil Fertility, 1970). Latterly, the debate has focused on the relationship between the loss of soil organic matter and soil aggregate stability in tilled soils, i.e. the strength of individual soil structural units (Ministry of Agriculture, Fisheries and Food, 2000a). Recent monitoring of National Soil Inventory sites indicates a drop in topsoil organic carbon in grassland soils over the past twenty years as well as arable (Ministry of Agriculture, Fisheries and Food, 2000b and Chapter 7). Effects such as surface capping, where the bare surface of a soil develops a thin but impermeable crust, topsoil compaction, the development of a plough pan and the poaching of grassland by stock can change the hydrology of the soil. Untimely cultivation or stocking, when the soil is too wet, is normally most damaging, but large, heavy machinery and high stocking densities compound the problem.

Degradation of soil structure was of concern initially because of its impact on crop performance. That is still the case. Yield maps of arable crops indicate the yield penalties imposed by soil compaction and plough base smearing along field headlands. Environmental concerns have been added to these agronomic impacts. Degraded soil structure reduces the infiltration of rainfall and, if of sufficient extent within a catchment, these effects can alter the hydrology of whole rivers. There is anecdotal evidence that the response of rivers to rainfall events is becoming more intense as a result of agricultural soil management practices. Impaired drainage also promotes the processes responsible for the production of N_2O, an important greenhouse gas (Chapter 13).

Advise to farmers on good agricultural practice provides guidance on the management of soil structure (Ministry of Agriculture, Fisheries and Food 1993, Environment Agency 2001, National Soil Resources Institute 2001).

6.2 Information sources and literature

Rudeforth *et al*., (1984) report on the nature of soil structure in Welsh soils. There is literature on the characteristics of soil structure, tillage effects on soil structure, and the influence of soil composition on structure, some of which is from the UK but there is very little of specific relevance to Wales. Young and Ritz (2000) reviews the literature on biological controls on soil structure. The Agricultural Advisory Council on Soil Structure and Soil Fertility (1970) reports on structural problems in Welsh soils. Through the 1970s there was work on the effects of minimum tillage and direct drilling techniques principally in England (Cannell *et al*., 1979, Soane and Ball 1998). Patto *et al*., (1978) report on the diffculty of separating the effects on crop yield of compaction from those of poaching. However Kellett (1978) estimates yield losses of 25 – 40 per cent as a result of poaching with some half of that due to the impact on subsequent sward productivity.

Bradley and Thompson (1998) and Ford (2000) report on stock-related soil structural degradation on slowly permeable soils within the catchment of Llyn Tegid. Holman *et al*., (2000) investigated soil structural conditions in the Severn catchment down stream of Welshpool as part of a wider study of the impacts of land management on flooding.

6.3 The current situation

Most soils in Wales are naturally structured. The exceptions are raw soils of saltmarshes and the wettest blanket and mire peats of the uplands where soil biological activity is very low and soil development therefore largely suppressed. The natural structural configuration of Welsh soils varies with soil type (Rudeforth *et al* 1984). Of the principal lowland soils, the well drained soils of the Denbigh and Manod associations tend to have fine, crumb and subangular blocky structure while those of the Cegin and Brickfield associations, with dense, slowly permeable subsoils, have coarse aggregates and columnar subsoil structure.

There have been no systematic surveys or studies of the state of soil structure in Wales, and little is therefore known about the extent of compaction, surface capping or other forms of structural degradation. Agricultural Advisory Council on Soil Structure and Soil Fertility (1970) use an eleven class soil map of Wales to describe a number of soil structural problems (presumably in farmed soils). These are:

1. Silty soils (their soil classes 2, 5, 7, 9 and 10 which almost account for the whole of Wales) are described as 'prone to instability and slaking [i.e. surface capping] in the presence of water, and require careful management to avoid structural problems'.
2. Three types of farming are identified as giving rise to soil structure problems – early potato cropping in Pembrokeshire, continuous cereal growing and the intensification of livestock farming. The acreages affected are, however, described as being small.

Concern over periodic algal blooms in Llyn Tegid led to a brief study of the potential impact of farming practices in the catchment. Thompson *et al*., (1998), Bradley and Thompson (1998) and Ford (2000) report on the extent and causes of bare soil in catchments that are dominated by poorly-drained soils. The out-wintering of sheep, particularly on re-seeded pastures, and the practice of ranging stock over a number of fields connected by gateways, is resulting in severe poaching (see also Chapter 5). The Welsh sheep flock has increased from eight million in 1980 to over eleven million in 2000. Holman *et al*., (2000) carried out field inspections of soil structural conditions in areas covered by detailed soil surveys following the winter 2000 floods in the Severn and other catchments. The 10 x 10 km square SJ21 (Arddleen) was the only one in Wales. They concluded that there appears to be a broad link between land use and structural condition.

- Land used for cereals and oilseed rape tends to have coarser structural units or compaction at the base of the ploughed layer and into the top of the subsoil. Where recently cultivated, this is emphasised by the loose ploughed layer.

- Potatoes and sugar beet land often exhibits compaction at the surface after harvest. This is less in the middle to lower part of the ploughed layer with compaction again at the base of the ploughed layer and into the upper part of the topsoil. Harvested potato ground occasionally has a structureless topsoil that is wet and 'pudding' like.
- Grassland appears to have a compacted or smeared surface that retains water on the soil surface. Below the surface the soil is usually at or below field capacity with compaction noted only in very young leys that have topsoil structure typical of continuously cultivated soils.
- At present no specific structural distribution within the topsoils of vegetable and maize growing land has been recognised. Maize land, however, appears to have characteristics similar to that of cereals. The variability of vegetable types and the different management associated with them is unlikely to provide a clear-cut structural picture.

Samuel (2002) has drafted a review of the impacts of agricultural and forestry practices on flooding. No new data were collected as part of the exercise.

To conclude, there is insufficient information on the structural condition of Welsh soils to know whether there is any issue to be addressed. Where there is information however, it implies that a proportion of soils are now less permeable than they were, or could be, due to degradation of their topsoil structure. Soil structure influences soil hydrology, productivity and biology but no real evidence is available to assess soil quality in this respect.

6.4 The future situation

There is little that can be said about future trends in the structural state of Welsh soils. If, as can be inferred, the loss of structure in grassland soils is related to the reseeding of pastures combined with the out-wintering of increased numbers of stock, any continued increase in sheep numbers may be damaging. Any increase in the extent of maize production will have a similarly damaging impact unless it is associated with improved harvesting practices. The future direction of agriculture, in particular the structure of support payments for the livestock sector, will be influential. Other agronomic solutions to structural degradation include the growing of white clover, which has been shown to improve structure.

Loss of structure and permeability in soils will impact on the water environment through increased nutrient and sediment transport to rivers and lakes and, potentially, the exacerbation of flooding risk.

6.5 Impact on soil functions

The following sections assume that there is an, as yet unquantified, degradation of the structure of Welsh soils.

6.5.1 Biomass, food and fibre production

Capping of arable soils can prevent seed emergence and necessitate re-seeding. Compaction of topsoils results in reduced yields of all crops due to the inhibition of rooting. There may be animal health implications, such as foot rot, from severe poaching which also has a large impact on sward structure and quality.

6.5.2 Environmental interactions

There are potential impacts on the infiltration of rain water which may translate into increased sediment in and eutrophication of rivers and lakes through the transfer of nutrients. Lower infiltration rates may also increase flood peaks and winter flows and decrease summer flows in rivers.

6.5.3 Provision of a platform

No effect

6.5.4 Support of ecosystems, habitats and biodiversity

No evidence is available of compaction in soils supporting semi-natural vegetation, and the chief impacts are therefore on the biota of agricultural soils. The interactions between soil conditions and the composition of soil biological communities is complex. Young and Ritz (2000) review the impact of tillage. Compaction reduces pore space which impacts on gas exchange and the ability of roots and soil organisms to travel through soil. Compact topsoil is often anaerobic and this will have a major impact on the nature and size of communities and nitrogen cycling processes.

6.5.5 Provision of raw materials

No effect

6.5.6 Protection of cultural heritage

English Heritage (Corfield *pers. comm.*) have a concern about the distorting effects of ground compaction in urban soils and subsoils on the integrity of archaeological layers and soft artifacts. However no concern has been expressed over the shallow compaction found in agricultural soils.

6.6 Policy responses – present and future

Technically there are three separate issues associated with the structure of agricultural soils. Surface capping is a distinct and separate issue from compaction in the topsoil and immediate subsoil and from the poaching of grassland. The remediation of soil compaction is a straightforward matter and simply requires the breaking up of the compact layer by normal inversion tillage and/or subsoiling. Capping can be countered by minimum tillage or other practices that leave surface litter to protect the soil surface from raindrop impacts. However minimum tillage equipment will not be available to all small or mixed farms, and is not necessarily suitable for the cultivation of all soils. While soils are compacted and arable fields are capped and grasslands poached, the environment is at risk from the site effects of increased run-off and of sediment flows to rivers and lakes. Impacts on yields and on soil biodiversity are additional factors and ideally soil management practices should seek to avoid capping and compaction rather than rely on eventual and repeated remediation.

6.6.1 Good practice guidance

The Code of Good Agricultural Practice for the Protection of Soil (Ministry of Agriculture, Fisheries and Food and Welsh Office Agriculture Department (1998) contains advice to farmers on the avoidance and remediation of soil compaction. More recently the National Soil Resources Institute (2001) has produced a Guide to Better Soil Structure with DEFRA funding. The Environment Agency (2001) identifies the management of soil structure as one of its 12 Best Farming Practices. Soil structure is also identified as one of the issues to be considered in the LEAF Audit scheme.

For forestry, the Forestry Commission (1998) has provided Forests and Soil Conservation Guidelines.

6.6.2 Agri-environment schemes

Soil management has yet to be included in any formal agri-environment scheme but the Policy Commission on the Future of Farming and Food (2002) includes a recommendation for a 'broad and shallow' single stewardship scheme that would include the protection (and management) of natural resources. This could include soil management, especially with the undeniable links to water quality and biodiversity. There are implications for Tir Gofal and the inclusion of targeted good soil management in Tir Gofal should be considered.

6.6.3 Demonstration farms

The Policy Commission on the Future of Farming and Food (2002) also recommends the creation of a network of demonstration farms. The value of such a network with representatives on the major Welsh soils would be considerable. Such farms could be linked into the Tir Gofal scheme.

6.6.4 Research and Monitoring

The lack of systematic information on the structural condition of Welsh soils is a concern and a survey is needed in order that the future soil strategy and related programmes of action are based on hard information.

Further research into the link between agricultural soil management and river flooding is justified.

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7. SOIL ORGANIC MATTER

Summary

- The absolute organic matter content of soils in Wales is not known with any certainty. However, we have calculated that the 0-15 cm layer of the soils of Wales (the only national data set available) contains at least 37 million tonnes (37Mt) of organic carbon (approximately 64 Mt of soil organic matter). Field observation of soils in Wales leads us to believe that this estimate is at the lower end of the scale.
- There are insufficient data to make a reliable estimate of the soil organic carbon below the 0-15cm depth, as few measured soil carbon data are available for subsoils representative of the range of soils, climate and land-use in Wales.
- The mean organic carbon content of the 0-15cm layer for all soils of Wales is 10.8 per cent (18.6 per cent organic matter).
- This mean value is strongly influenced by the high carbon content of the extensive peat and bog land (mean carbon content 46 percent; 79 per cent organic matter). This contrasts with the much smaller carbon contents of arable soils (mean value 3.5 per cent carbon; 6 per cent organic matter) and permanent grassland soils (mean value 4.9 per cent carbon; 8.4 per cent organic matter).
- Between 1980 and 1996, the mean organic carbon content of the upper 15 cm of Welsh soils under arable and permanent grassland declined by about 0.5 per cent.
- Loss of organic carbon has implications for the ability of Welsh soils to assist in meeting the nation's obligations under the Kyoto Protocol. It also has implications for a potential increase in the erodibility of soils, a concomitant increase in the amount of sediment transported to surface waters and into the built environment, a decline in the soil's ability to adsorb a range of potential contaminants (both organic chemicals and metals) and, possibly, effects on soil biodiversity
- Efforts to increase the amount of organic carbon in the soils of Wales have implications for the intensity of land use.
- It is clear from the analysis used to prepare this report that the data on the soils of Wales is inadequate for estimating their current quality in detail or for predicting their future behaviour. There is an urgent need for more detailed information and for a robust monitoring programme to assess change.

7.1 Background

This report takes the conventional view that the overwhelming proportion of organic matter (SOM) in the soils of Wales has derived from biological processes within the soil, and not from extraneous sources such as industrial wastes. It is soil organic carbon (SOC) that is actually determined in the laboratory and it is, therefore, this phrase that is used throughout the bulk of this section of the report. The convention is to convert such carbon concentrations into SOM by multiplying them by a factor of 1.724. We have not done this in reporting the data we have, as there is a considerable body of evidence that this factor is very much an oversimplification (see, for example, Howard and Howard, 1990).

The concentration of organic carbon (OC) in the soil is affected by a number of processes:

- vegetation type (forestry, grassland, tillage crops);
- cultivation practices (depth and frequency of ploughing, 'minimum' tillage, removal or retention of crop residues, length of grassland break within a rotation, intensity of grazing/stocking density, number of silage cuts, amount and frequency of applied fertilisers, control of soil acidity, forest stand age and clearance policy);
- biological activity (of both larger fauna, e.g. worms, beetles, and at the micro-scale, e.g. bacteria and fungi);
- application of wastes (animal slurries, 'dirty water', sewage sludge, industrial wastes).
- climate (temperature, rainfall)

In *very general* terms, SOM will decompose more rapidly in warmer areas, with an adequate supply of moisture. As temperatures fall and moisture increases, then decomposition rates fall and organic matter is likely to accumulate. This is illustrated by the well-known relationship between rainfall and the accumulation of highly organic surface layers of soil (Pearsall, 1950). The less a soil is disturbed and the longer it is left under a permanent or semi-permanent crop, e.g. long-term grassland, trees, semi-natural vegetation, then the more carbon will be added to the system and soil carbon content will increase. Most of the increase occurs in the upper part of the soil but, with time, carbon will accumulate in the subsoil, albeit more slowly and to a lesser extent. Even where there is a positive budget of this kind, accumulation of carbon is a slow process, measured in decades to achieve a substantial increase.

Where the soil is disturbed, e.g. by ploughing, by erosion, by clear felling of forest stands, then decomposition of carbon is rapid and build up of carbon achieved over decades can disappear in much less than a decade. Generally, the more frequent the disturbance, e.g. annual cultivation, the more rapid the loss of stored carbon from the soil. The amount of carbon varies enormously with soil type. For example, 1 per cent by weight of organic carbon in 1 hectare of the topsoil layer of an average mineral (i.e. a non-peat) soil is about 20 tonnes. In a peat soil, however, which is almost 50 per cent carbon, the amount of carbon in this layer is nearer to 250 tonnes (Note that peat soils are only about one-quarter as dense as mineral soils).

These figures illustrate the difficulty of managing soils to change their carbon contents substantially simply because the amounts of material involved are so large. It also has to be recognised that much of any organic material added to a soil, e.g. animal slurry, sewage sludge, compost, will decompose relatively rapidly. The costs of transporting substantial amounts of organic matter around the landscape are themselves significant. From the opposite perspective, the potential loss of carbon from soils is enormous, should they be managed in a way that encourages decomposition of the carbon they do contain. In the case of peat soils, this can be as simple as draining them. This lets oxygen from the atmosphere deeper into the peat soil and loss of carbon can then be rapid.

SOM is implicated in a number of soil mediated processes. Its decomposition is effected by a very wide range of soil organisms from the macro- to the micro-scale; thus it is a food-source and the quality and amount of it could affect biodiversity. SOM affects soil structural (aggregate) stability, ease of cultivation, nutrient supply and flux (nitrogen, phosphorus, sulphur, micronutrients), mobility of (organic) agrochemicals and potentially toxic elements (the so-called heavy metals), source/sink processes for greenhouse gases, bulk density, water holding capacity at low suctions, porosity and warming in spring.

7.2 Information sources and literature

The principal source of information about SOM in the soils of Wales *as a whole* is the Land Information System (LandIS) held by NSRI (Hallett *et al*., 1996). Some of these data have been collated by Rudeforth *et al*. (1984) in their general description of the soils of Wales. More detailed reports are given by Ball (1960, 1963), Ball *et al*., (1969), Bradley (1976, 1980), Clayden and Evans (1974), Crampton (1972), Hartnup (1987, 1988), Hughes and Roberts (1958), Jenkins and Owen (1995), Lea (1975, 1985), Lea and Thompson (1978), Roberts (1958), Rudeforth (1970, 1974), Rudeforth and Bradley (1974), Rudeforth and Thomasson (1970), Thompson (1978, 1982), and Wright (1980, 1981, 1984). Although these publications give some data on SOC in soil profiles for Wales, not all are available within the national database.

More useful, in a national context, are the data from the National Soil Inventory (NSI) (Loveland, 1990), many of which are reported in McGrath and Loveland (1992). Their maps show the overall distribution of organic matter in the 0-15 cm layer in soils in Wales, but do not summarise the data for Wales separately from those for England and Wales as a whole. This separation has, however, been made for the purposes of this report. There was limited re-sampling of the sites reported by McGrath & Loveland (*loc. cit.*) between 1995 and 1997, the data for which are given in this report, but are otherwise unpublished. Figure 7.1 shows the locations of the original NSI sites and Figure 7.2 the locations of the re-sampled sites. The re-sampling scheme is described more fully below.

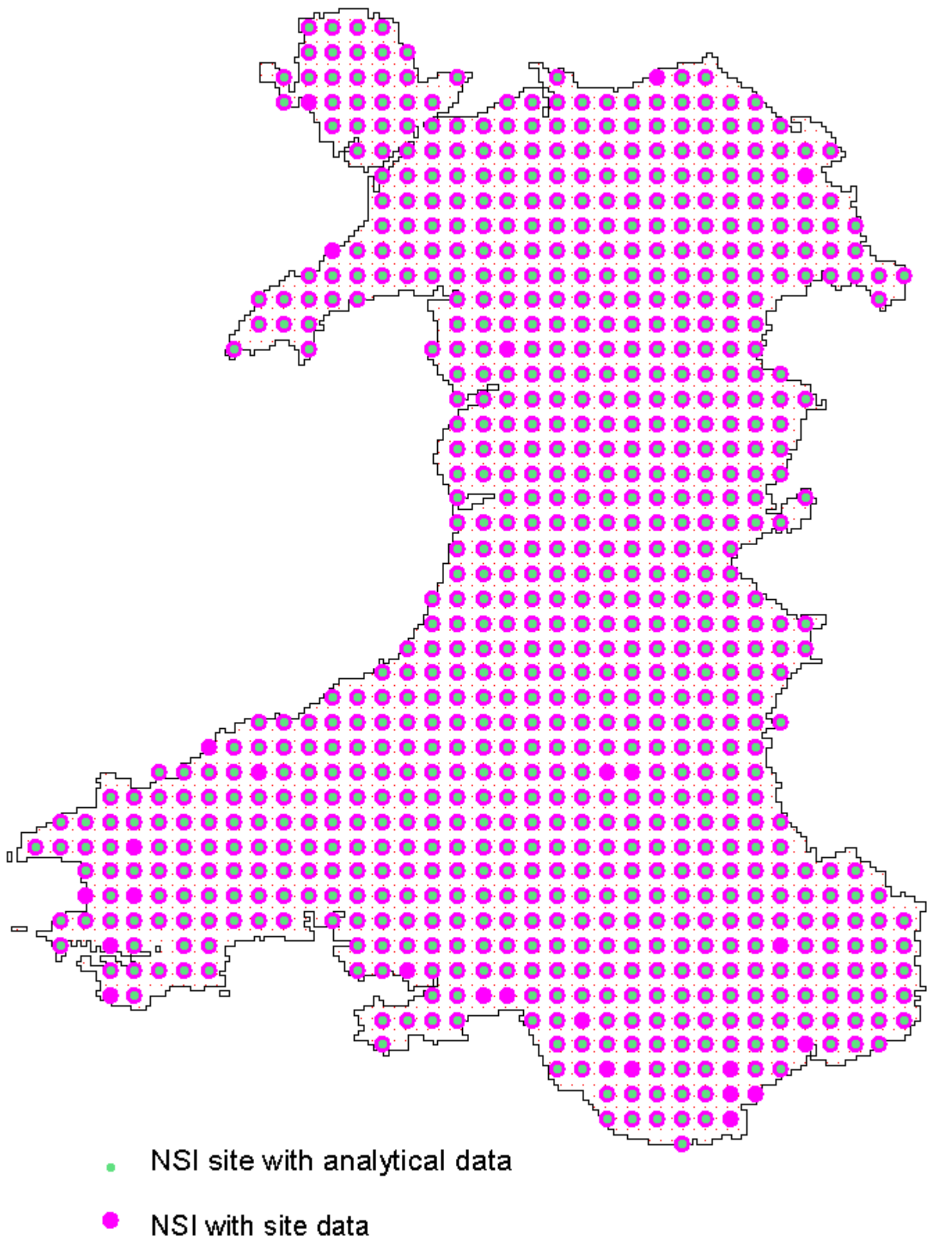

Figure 7.1 The National Soil Inventory 5 km X 5 km grid for Wales, showing locations of sites from which soils were sampled and those for which no samples are available (access refused, e.g. firing range; no soil present, e.g. urban or solid rock to surface).

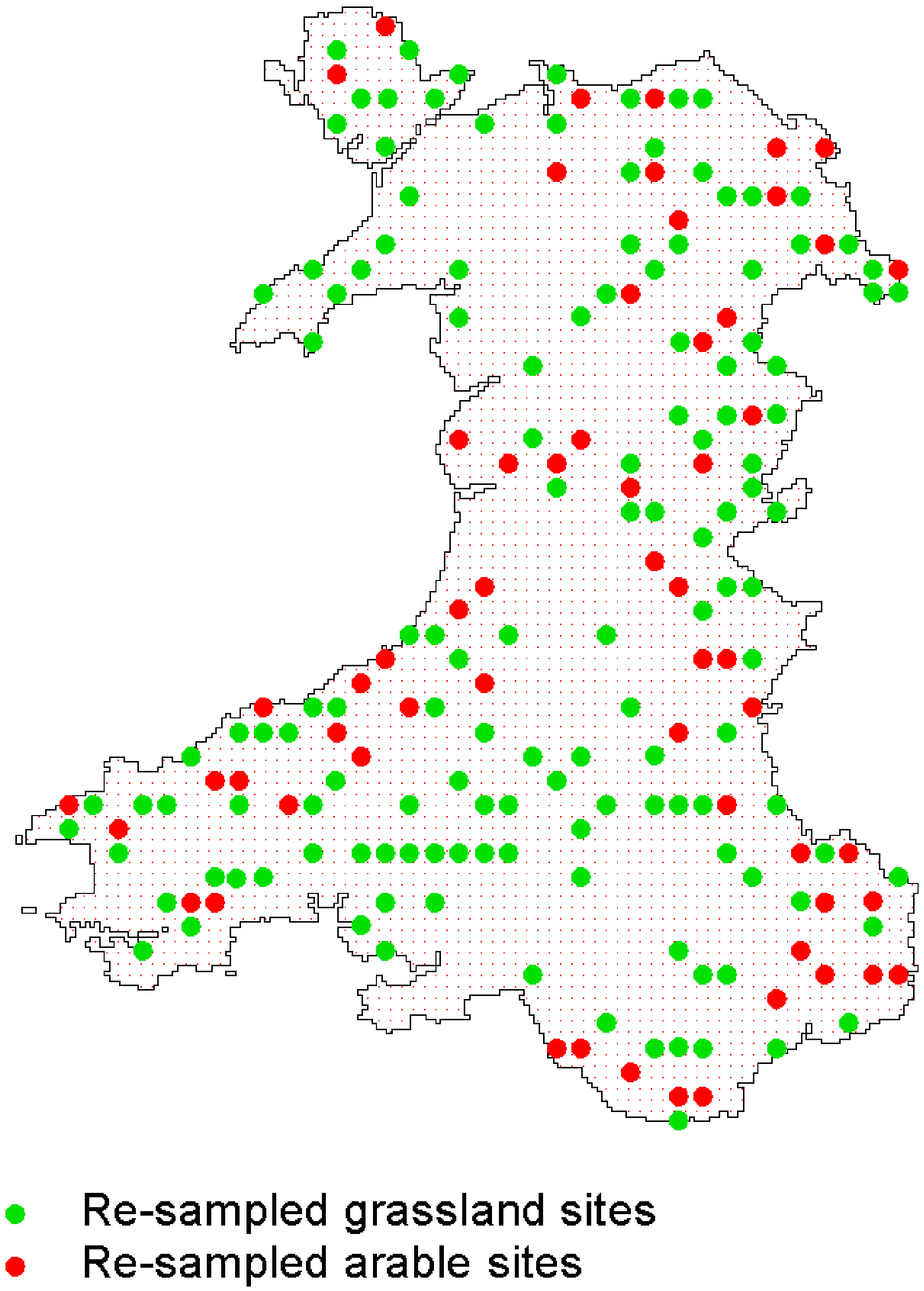

Figure 7.2 The distribution of the re-sampled NSI sites in Wales (the '1996' data).

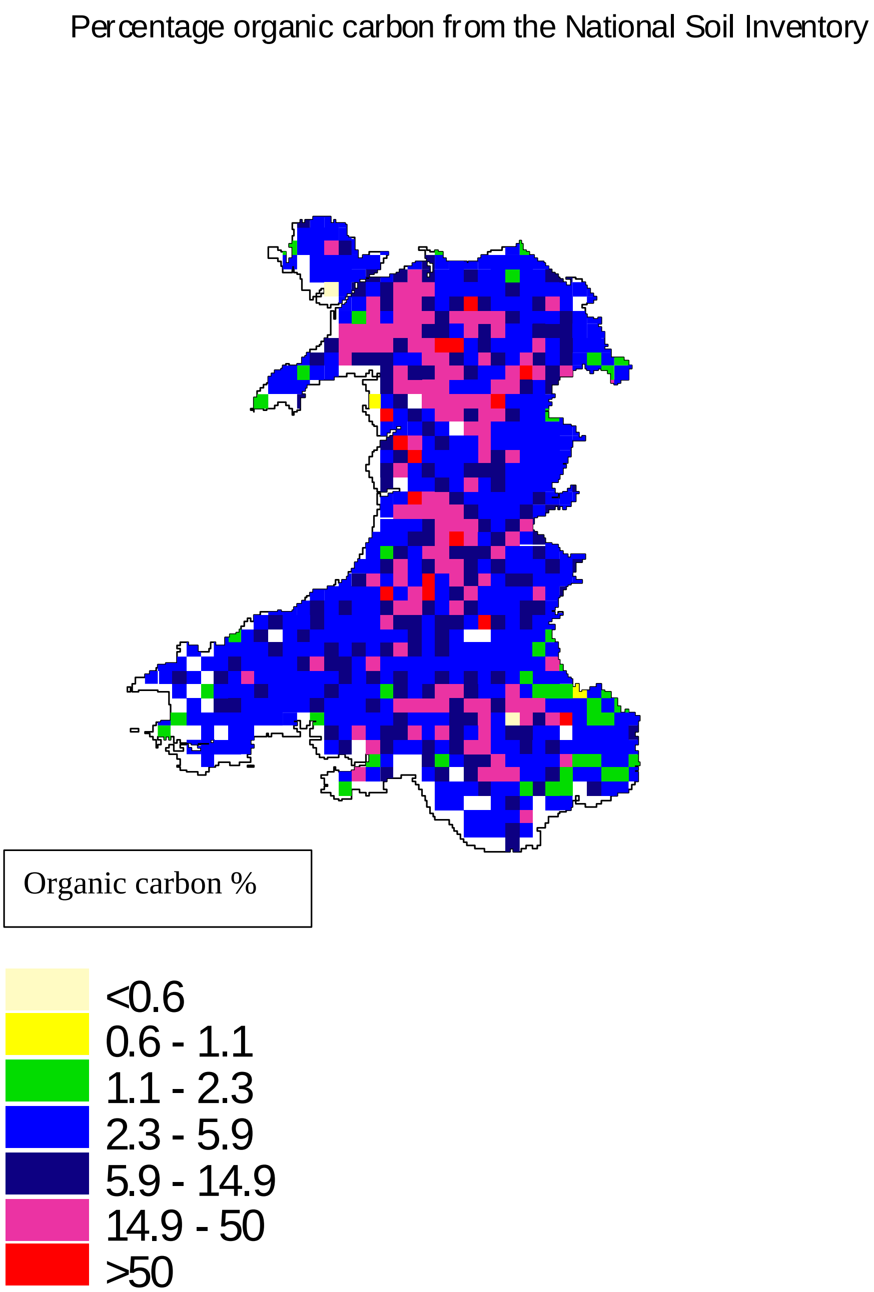

Figure 7.3 The organic carbon content of the 0-15 cm layer of the soils of Wales (National Soil Inventory; 1980 data).

7.3 The current situation

Figure 7.3 shows the distribution of OC in the 0-15 cm layer of the soils of Wales. These data are from the National Soil Inventory that was carried out between 1978 and 1983, with the bulk of Wales being sampled between 1979 and 1981 (referred to hereafter as the '1980' data). This is the only dataset giving complete coverage for Wales and, although the data are about 20 years old, they represent the best assessment we have of the 'current situation'. Based on these data, Table 1 (Appendix VI) gives summary statistics from all of these sites. The mean carbon content is large at 10.8 per cent and this is a reflection of the very large amounts of carbon stored in the soils of Wales in organic soils (peats) and organic soil layers. This is further illustrated by Figure 7.4.

These data have been further stratified by the major land uses, by major soil type, and by major land use X major soil type. The data are reported here only for those strata containing at least 10 observations, the minimum from which we deem it sensible to draw any conclusions, and these data are summarised in Figure 7. 5 and Tables 2 and 3 in Appendix VI.

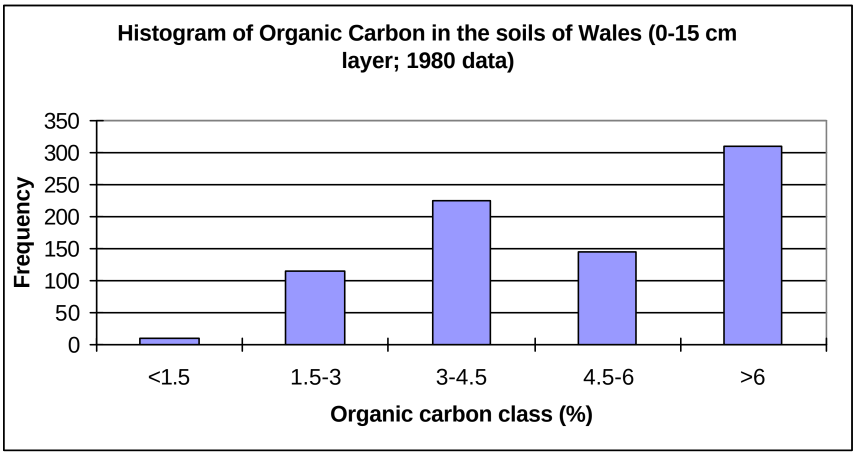

Figure 7.4 The distribution of organic carbon in the soils of Wales (NSI: 1980 data).

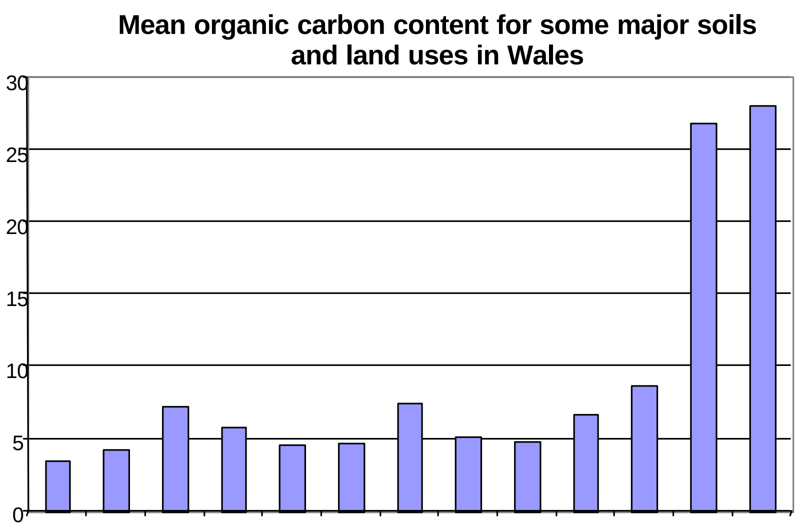

Figure 7.5 The mean OC content of the major soil types of Wales according to major land uses (NSI: 1980 data). LG = ley grassland, PG = permanent grassland, UG = upland grassland, RG = rough grazing.

We have used the 1980 data to calculate an approximate soil carbon stock for the 0-15 cm layer of the soils of Wales of 37 million tons (37 Mt SOC; *ca* 64 Mt SOM). This calculation takes no note of soil carbon stored below 15 cm depth. This is particularly important in deeper organic soils, where the amount of SOC stored could be very large indeed. At the time of writing, the data to derive a value for carbon held in these deeper layers are inadequate. In the LandIS database, there are subsoil carbon data to a greater or lesser degree for only about 80 points in the landscape of Wales. Further, and unlike the NSI points, these observations are not distributed in a way that gives information at a reasonably uniform spatial scale; many of the points are extremely close together and large areas have no measured data at all (Chapter 2; Figure 2.4). This is an inadequate basis on which to attempt to estimate the subsoil carbon stocks of Wales, so we have not done so.

7.4 The future situation

We are not aware of any existing quantitative attempt to estimate the future state of SOM in Wales, although such a project is in progress and is expected to report in 2003 (Bradley, pers. comm.). However, an indication of what can happen, over a relatively short time-scale, is given by the unpublished data that came from a re-sampling of a limited number of National Soil Inventory arable/ley grassland sites and permanent (managed) grassland sites between 1995 and 1997 (called the '1996' data).

The re-sampling design was based on the requirement to detect a change of 0.2 per cent in the mean value of SOC for the 1980 data for the two land use classes, based on the data for England and Wales. The number of samples was split between each of the then ADAS Regions in proportion to the original numbers of samples from that region. For Wales, this gave 56 sites for arable/ley grassland and 106 sites for permanent (managed) grassland. No other land uses were sampled at the time. The number of sites to be re-sampled is strongly affected by the range of the SOC values about the mean; the wider the range, the more samples you need to detect a given change in the mean at a stated level of confidence. If one recalculates the target population using only the 1980 data for Wales, with its relatively large numbers of sites of greater SOC concentration than in England, then the minimum numbers of sites to be re-sampled would have been 139 for arable/ley grassland and 208 for permanent grassland. Thus, the data available from the smaller numbers of sites can only be regarded as indicative and a fuller survey might paint a different picture. Figure 7.2 shows the locations of the re-sampled sites. Table 4 (Appendix VI) gives summary statistics for the original and re-sampled sites for the two land uses. Because of the limited number of sites, we did not stratify the data further. However, it can be seen that the mean SOC content has declined by about 0.5 per cent under both land uses.

The data are presented graphically in Figures 7.6 and 7.7, from which it can be seen that the decline in SOC is largely attributable to loss of carbon from the soils with large concentrations in 1980. This is not so surprising for arable soils, as cultivation is known to promote loss of SOC. It is more surprising in grassland soils as the conventional wisdom is that grass stores organic carbon. The reasons for the decline are not known. It is possible that more frequent cutting for silage, increased use of nitrogen (Chapter 8), increased stocking densities and a succession of warm years between 1980 and 1995 (Chapter 13), have all played their part.

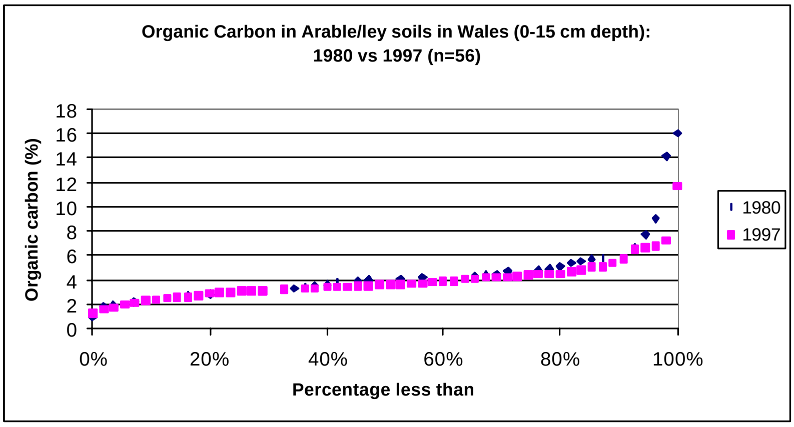

Figure 7.6 Soil organic carbon content of the 0-15 cm layer of arable/ley NSI sites in Wales sampled in 1980 and 1996.

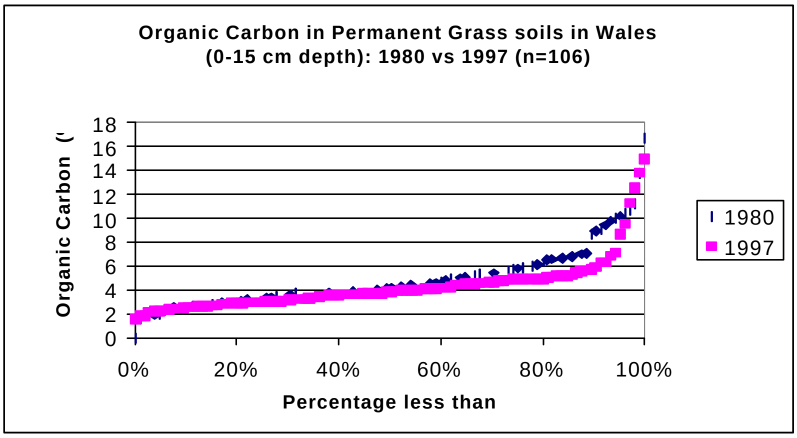

Figure 7.7 Soil organic carbon contents of the 0-15 cm layer of NSI permanent (managed) grassland sites in Wales sampled in 1980 and 1996.

One problem highlighted during the writing of this report is the inadequacy of current mathematical models of soil carbon behaviour. In particular, there are no reliable models for such behaviour in peat soils, in peat layers over mineral soils, in very wet soils, in highly organic layers under forestry, or for subsoils. All of these factors are highly relevant to predictions of the behaviour of SOM in the soil of Wales in the longer-term.

7.5 Impact on soil functions

7.5.1 Biomass, food and fibre production

There is little firm evidence that a change in SOM content has a measurable effect on biomass production (in terms of the yield of food crops or fibres) until one reaches levels of about 1 per cent SOC (1.5 to 2 per cent SOM). This finding is based on a very limited number of studies of winter wheat and decline in yield, if any, is attributed to the fall in the amount of N derived from the decomposition of SOM (Shepherd *et al*., 1996). Conversely, there is little evidence that yields of food crops, grass or fibre increase as SOC contents increase above this level. From this perspective, therefore, the limited evidence available suggests that the soils of Wales have adequate stocks of SOC to maintain biomass, food and fibre production.

It is possible that further research into organic farming systems might change this view. There is little doubt, however, that organic residues added to soil can substitute, to some extent, for applications of mineral fertilisers, as well as conferring other benefits on soil physical and biological properties. It should be remembered, however, that 1 ha of soil with 3 per cent of SOC to 15 cm depth (the 'typical' rooting depth of much of the managed grassland in Wales) will contain about 60t of OC. Even additions of substantial amounts of organic wastes, in which a significant - but variable - proportion of the OC is readily oxidised by soil microbial processes or as a result of soil management practices, will increase the SOC content only slowly.

7.5.2 Environmental interaction

Loss of SOM may affect the following aspect of soil functions:

- there could be a significant change in the ability of the soil to immobilise the movement of chemicals through the soil (see Chapters 9 and 10). Some metals bind more or less strongly to SOM so, in theory, a decline in the latter coupled with an increase in the load of the former, might exceed the soil's immobilisation or 'buffering' capacity. This could lead to an increase in diffuse pollution of waters. Similarly, the behaviour of many organic chemicals, especially their partitioning between adsorption on the surfaces of soil particles and their solubility in the soil solution, are strongly affected by the amount of SOC. In general terms, a decline in the latter would imply greater solubility in the soil water and thus a higher risk of transport to surface and ground waters. However, this partitioning effect is a substance specific property and would require investigation on a case-by-case basis.
- As SOC content declines so soil aggregates become more unstable (see Chapters 5 and 6). Again, there is some evidence that serious instability occurs at around 1.5 per cent OC across a range of soils. Although few soils in Wales have such low SOC contents at the moment, it is possible that continued decline in SOC could occur under climate change and aggregate instability could become more of a problem. The net result could be an increase in the transport of soil particles to surface waters, along with any attached pollutants and, possibly, an increase in slaking of the soil surface leading to enhanced run-off. There is some evidence from limited field studies in southern England that catchments whose soils suffer such surface deterioration are implicated in increased severity of flooding. Ironically, the evidence also suggests that soils whose surfaces slake, suffer from moisture deficits in the deeper parts of the soil.
- Most losses of SOM occur through microbially-mediated oxidation to produce carbon dioxide or, in very wet soils, reduction processes that produce methane. There is also concomitant production of nitrous oxide from the nitrogen associated with the soil carbon. All three are so-called 'greenhouse gases'. Thus loss of SOM will contribute to global warming and will make it more difficult to meet Wales's potential obligations to international policies such as the Kyoto Agreement (see Chapter 12).
- A proportion of SOM can also be lost from the soil in solution. Usually the amount of this dissolved organic carbon (DOC) is very small. Where such amounts are large, the water can be discoloured - so-called 'dark water'. There have been a few reports of an increase in the occurrence of dark water, which is usually unacceptable to consumers, and these have been attributed to a combination of very warm periods in the Summer followed by a very wet initial period in the Autumn. It is possible that such circumstances might become more common under global warming and there is already evidence from the Acid Waters Monitoring Network that stream water DOC concentrations have been rising, possibly as a result of climate change (pers comm., Chris Evans, CEH Bangor and Chapter 12)
- **The crucial point for Wales is that it's soils contain very large amounts of carbon and that climate change and / or intensification of land use and /or change of land use could lead to substantial losses of this carbon as Green House Gases. Such changes could be the extension of tillage land, the intensification of the use of pasture land, change in the proportion of forest land versus other land and / or more rapid turnover of tree crops.**

7.5.3 Provision of a platform

In the sense of forming a physical base for the utilisation of the soil, we see little evidence that there would be much change resulting from a decline in SOM.

7.5.4 Support of ecosystems, habitats and biodiversity

The effects of SOM on factors such as soil aggregation, nutrient supply and soil water have already been mentioned. SOM is also a feedstock for a very large number of soil macro- and micro-fauna and flora. There is also a complex and poorly understood relationship between this ecological diversity and the kind of SOM as well as its absolute quantity. Thus, some parts of the soil biological community rely on supplies of recently produced SOM, such as root exudates, fresh litter (both surface and buried), whilst others rely on older, more decomposed material through to relatively inert forms such as the lignified remains of woody material. SOM does not act alone in terms of its effects on these ecosystems; there are also complex interactions with factors such as soil acidity and the proportions of sand, silt and clay in the soil. The latter can have profound effects on soil moisture content and this too is a factor. Quantitative relationships between these factors and biodiversity are little known, because the range of systems is so diverse. In very general terms, it is known that systems with more SOM, with a ready supply of organic residues, of moderate or less acidity (pH ≈ 5 or more), and with little or no long term water-logging, have the greatest degree of biological activity, diversity and biomass. However, it is not necessarily true that this means that these systems are 'better'. If the full range of ecosystems and allied biodiversity is to be maintained, then a range of habitats needs to be maintained also, i.e. with a range of SOM contents and other soil properties. In principle, loss of SOM is likely to lessen such diversity as well as biomass and an increase in SOM could increase these aspects of soils. However, there is not a straightforward relationship whereby X per cent of SOM equates with Y amount of biodiversity or Z tonnes per hectare of biomass.

7.5.5 Provision of raw materials

We believe that change in SOM contents is unlikely to affect the supply or quality of most raw materials, other than water quality. This has been dealt with under 'dark water', above.

7.5.6 Protection of cultural heritage

We see the main problem arising from loss of SOM as the potential increase in soil erodibility (Chapter 5). Thus, over time, cultural features at shallow depth will face increasing risk of exposure and, ultimately, destruction. Should SOM contents increase, then erodibility will be reduced. It is possible that SOM might increase in some areas as a result of increase in precipitation as a function of climate change. Increase in SOM and higher precipitation can result in increased acidity. This might pose a threat to certain classes of buried materials, such as bone and metal. Wood, cloth, leather and similar organic remains might be better preserved in a more acid environment as biological activity is commonly reduced under wetter and more acid conditions.

7.6 Policy responses - present and future

The loss of SOM has the potential, on balance, to lead to deterioration in the quality of the soils of Wales and to compromise some of their functions. The most obvious effects relate to erosion, water quality, biodiversity and cultural heritage. Loss of SOM from soils will also make it more difficult for Wales to meet its obligations under the Kyoto protocol. It is, however, difficult to predict the magnitude of, and speed at which, changes in SOM content will occur and within what limits, both quantitative and geographic. As a general principle, the conservation of SOM is likely to require less intensive land use. It could be that an increase in 'organic farming' in Wales could mitigate against carbon loss. The effects of less-intensive land use and / or organic farming on the rural economy of Wales and, therefore on pressures to change the SOM status of Welsh soils, is beyond the scope of this report. However, the evidence available points to the fact the substantial storage of carbon in soils is a slow business, requiring a commitment over decades.

There is also a clear need for more data, of more recent origin, about the organic carbon stocks of the soils of Wales. Most of the data available are 20 years old or more. The more recent data are barely adequate to support firm conclusions about possible trends. The data themselves do not permit sufficiently detailed linkage to soil processes at an acceptable geographic scale and thus make it extremely difficult to link change on SOM status to soil function at a practical level. Behind this need for more data is the requirement for them to be collected in a systematic manner through a rational soil monitoring programme.

In summary, however, the soils of Wales contain a lot of carbon. Soil response to change, whether imposed by man in the shape of changed land-use, or by nature in the form of climate change, has the potential to release large amounts of this carbon over a much shorter timescale than usually applies when trying to put carbon back into soils. Discussion of climate change impacts on soils is examined further in Chapter 12.

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8. SOIL NUTRIENT ISSUES

Summary

- In Wales, in terms of land area, the predominant type of agriculture is extensive sheep and livestock farming, but there are also some areas of more intensive dairy production are potentially of concern.
- Some issues of soil fertility are not of national concern, although sulphur deficiency in some areas is a problem with a decline in atmospheric deposition.
- Soils in the uplands, prevalent in Wales, are particularly fragile because both increases and losses of soil nutrients can damage them.
- Most current and future issues for nutrients in Welsh soils are associated with nutrients as environmentally active agents, particularly those of N and P when transferred to water.
- The EC Nitrates Directive and Water Framework Directive are policies that will determine the future issues, and particularly pertinent and topical is the Welsh Assembly Government Consultation on Nitrate Vulnerable Zones.
- Wales benefits from less intensive land use than other parts of the UK and has the 'best' water quality with respect to N and P contents in the UK and benefits from fast flowing rivers that have potential to 'dilute' issues in rivers.
- Emissions of N gases to the atmosphere are also of concern in intensively managed regions, such as dairying in Pembrokeshire and poultry farming on Anglesey.

8.1 Background

There are two issues associated with nutrients in Welsh Soils; those associated with their deficiency and thus loss of soil fertility and those with the excess of the nutrients and their potential damage as environmentally active agents. The two main nutrients of concern are N and P, but there are other nutrients that are also significant, for example sulphur (S) and potassium (K), amongst others.

8.1.1 Role of nutrients in soil fertility

All plants require adequate amounts of water, light, carbon dioxide and nutrients in order to allow them to grow to their maximum potential (MAFF, 2000). A shortage of nutrients can cause serious restrictions to crop growth. There is a wide range of essential plant nutrients. Many nutrients such as N, P, K, magnesium (Mg), S, and calcium (Ca) are required in relatively large quantities (MAFF, 2000) and are all applied to varying degrees in agricultural soils.

Nitrogen is essential for plant growth and thus cause problems when it is deficient (Russell, 1973). It is generally taken up by plants as ammonium (NH_4^+) or nitrate (NO_3^-) ions, but is then reduced in the plant and, when synthesised with carbohydrates, converted to amino acids mainly in the green leaf itself. Hence, as the extra level of N supply increases compared to other nutrients the extra protein produced allows the plant leaves to grow larger and to have a larger surface area for photosynthesis. Thus, for many crops, the amount of leaf area available for photosynthesis is roughly proportional to the amount of N supplied. In agricultural systems, N usually has a larger effect on crop growth, yield and crop quality than any other nutrient.

Phosphorus plays an essential role in agriculture and for all forms of life: respiration, photosynthesis in green leaves, microbial turnover and decomposing litter all require adequate levels of P in specialised forms (Cole *et al*., 1977). In agricultural cropping systems, adequate supplies of P are essential for seed formation, root formation, crop quality and strength of straw in cereals and the accumulation and release of energy during cellular metabolism (Finkl jr and Simonson, 1979). Phosphorus in natural ecosystems is, like N, usually a scarce resource and is fairly efficiently recycled: in contrast, in agricultural systems, P is removed in the crop or animal product. This means that P in fertilizers and animal fodders/concentrates are imported to the agricultural system in order to sustain productivity, but only 5-10% of fertilizer P which is added to soil is taken up by crops (Loehr, 1974).

Sulphur is required for all biological systems. Sulphate (SO_4^{2-}) is the main form absorbed by plants but it is not the predominant form in most soils, which explains why S-deficiencies are a common phenomenon (Pierzynski *et al*., 2000). S is an essential element in several amino acids that are part of plant animal and human proteins. Sulphur plays an active role in plant structural composition and metabolic processes and it is also crucial to animals further down the food chain as it performs several structure, metabolic and regulator functions.

8.1.2 Role of nutrients as environmentally active agents

Biodiversity and nature conservation

In extensively managed land, where biodiversity and species richness is a priority, the abundance of soil nutrients, often as a legacy of intensive farming history where crop productivity used to dominate, can reduce the floristic qualities of meadows (Vickery *et al*., 2001). High soil N and P is a key factor limiting increase in botanical diversity of many extensively managed grasslands after the conversion from intensive agricultural management (Tallowin and Smith, 2001) or where atmospheric deposition occurs on upland. Specifically, for example, Goodwin (1998) has shown that high soil P levels are negatively correlated with species diversity.

Nutrient cycles in the wider environment

Nutrients also cause considerable environmental problems when they 'leak' from productive agricultural systems. Problems can occur both in water bodies (water quality) and the atmosphere (air quality) (Table 8.1). Nitrogen is cycled from the large atmospheric pools as dinitrogen gas into the soil ecosystem, resulting either through biological fixation by leguminous plants or by chemical fixation to produce N fertiliser (De Clercq *et al*., 2001). In Wales, the latter is more important in agricultural systems. In the soil, the largest pool of N is in the organic matter as nitrogenous compounds arising from decomposition of plant material and micro-organisms and added organic matter (manure in agricultural systems). The soil macro fauna plays an important role in making available organic N through mineralisation and ammonification, resulting in the release of NH_4^+. The available N that is converted into the microbial biomass is known as immobilisation. Thus the rates of mineralisation/immobilisation play an important role in controlling the soil N cycle and thus governing the leakage of N to the wider environment. The NH_4^+ produced during the mineralisation process is converted to NO_3^- by nitrification and involves oxidation of NH_4^+ to nitrite (NO_2^-) and then to NO_3^-, which as a highly mobile ion forms the basis upon which leakage to the atmosphere or water can potentially occur.

Nitrogen emissions to air

Under anaerobic soil conditions some micro-organisms are capable of using the oxygen from NO_2^-, NO_3^- and N_2O in the place of elemental oxygen and this processes is called denitrification with gaseous end products of N_2O, dinitrogen (N_2) and NO_x. In some soils, chemical denitrification can also occur. Most denitrification takes place in the upper layer of the soil and the gases produced are released to the atmosphere and the rate of denitrification depends on soil characteristics, soil moisture and aeration, the supply of carbon, temperature and substrate (NO_2^- and NO_3^-) supply. It is most likely to occur in poorly drained, fine textured soil and in situations with high with high water tables where anaerobic conditions are most likely to be present (De Clercq *et al*., 2001). A separate process by which N is released to the atmosphere is volatilisation. Ammonia can be volatilised from soils, added fertiliser, excreta and manure (Pain and Jarvis, 1999). With excreta and manure, the main source of NH_3 is urea, a major nitrogenous constituent of animal urine and some inorganic fertilisers, that are especially prevalent in the aqueous phase. Therefore the application of liquid based animal manures or inorganic fertilisers will increase the potential for volatilisation depending on the land application method. High soil pH, dry soils and high temperatures increase the potential for the NH_3 volatilisation to occur.

Nitrogen leaching to water

Leaching can be a major means of N loss from the soil ecosystem (De Clercq *et al*., 2001; Jarvis, 2000; Wilson and Ball, 1999). Because it is negatively charged, NO_3^- is not readily adsorbed to soil colloids in Welsh soils and thus it is present in soil solution and easily leached. Some NH_4^+ and organic N compounds are also easily leached but not to same extent as NO_3^-. Leaching potential is governed by soil type and structure (higher potential in easily drained soils), rainfall patterns and the supply of easily leached N. Higher levels of mineralisation that occurs in autumn after dry summer periods can result in substantial quantities of N for leaching as the assimilative capacities of crops decline.

Phosphorus transfer to water

Unlike N, the P cycle does not have a significant atmospheric component and therefore it is transfer to water that is the single dominant issue (Haygarth and Jarvis, 1999). There are three mechanisms of P transfer from land to water: solubilisation, detachment and incidental. The term 'solubilisation' refers to the release of molecules or macromolecules of P from soil surfaces and soil biota into soil water, for potential transfer, away from the point of source. Solubilisation reflects long-term management history and there is strong evidence that solubilisation potential increases with increased soil P status. Heckrath *et al*. (1995) used Olsen-P measurements to define a 'change point' value of 60-mg kg^{-1} soil in an arable soil, above which there was a much-enhanced tendency to release P to land drains. Detachment of soil particles with P attached, often associated with soil erosion, is a physical mechanism for mobilising P from soil into waters (Kronvang, 1990; Sharpley and Smith, 1990). Soil erosion *per se* has been described many times (Burnham and Pitman, 1986; Elliot *et al*., 1991; Evans, 1990; Heathwaite and Burt, 1992; MAFF, 1997; Morgan, 1980; Quinton, 1997) as has the role of particle transfer in P loss (Catt *et al*., 1994; Kronvang, 1990; Sharpley and Smith, 1990; Zobisch *et al*., 1994). More recently, the role of small colloids in detachment and transport of P has also been described (Haygarth *et al*., 1997). Incidental transfers are the circumstances when applications of manure or fertilizer coincide with conditions favouring fast discharges of excess water in overland or preferential flow (Haygarth and Jarvis, 1999).

Impacts of nutrients on waters

When nutrients leak into waterways, they play a role in the ecology of freshwater environments, through acidification and eutrophication. Acidified waters are generally characterised by low pH, high SO_4^{2-} and NO_3^- and both acidification and eutrophication result in major changes in the species composition in biotic communities, with generally a reduction in diversity and changes in productivity (Foy and Withers, 1995; Haygarth *et al*., 2000a; Hornung, 1999; Vollenweider, 1968; Vollenweider and Krekes, 1982). Redfield (1934) reported that marine biomass tends to a constant atomic ratio of 105:15:1 C:N:P and this is also applicable for fresh water systems (Uhlmann and Albrecht, 1968) and the implication is that adding P to a waterbody, therefore, has a much greater effect than adding either N or C (Hudson *et al*., 2000; Redfield, 1934; Uhlmann and Albrecht, 1968). Numerous definitions of eutrophication have been used in the literature and the legislation, covering a range of complexities. The simplest definition refers to eutrophication as the 'process of nutrient enrichment' as this is easily understood by most audiences, emphasising that eutrophication is a process that affects all points at low to high nutrient status. However, this simplified phrase does not refer to the biological symptoms and the undesirable effects. There appears to be a broad consensus that the definition should include cause (nutrients), process (enrichment) and effect (which can be on the ecology, chemistry or uses). The definitions used in the regulatory framework for phosphorus are varied. The definition given in the UWWTD (91/271/EEC) is:
'….the enrichment of water by nutrients, especially compounds of nitrogen and/or phosphorus, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned' (Foy and Withers, 1995; Haygarth *et al*., 2000a; Hornung, 1999; Hudson *et al*., 2000; 1934; Uhlmann and Albrecht, 1968; Vollenweider, 1968; Vollenweider and Krekes, 1982) and similarly in the Nitrates Directive (91/676/EEC):'*….the enrichment of water by nitrogen compounds, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned'*

However, these definitions can be restrictive, as eutrophication does not necessarily lead to accelerated algal growth, but may have other effects, such as changes in species composition and detrimental effects on conservation value. They also fail to address oligotrophic and mesotrophic waters at risk of deterioration, taking into account the eutrophication as a 'process' and not just waters that are 'eutrophic' (the 'state'). The Environment Agency has thus adopted the following definition of eutrophication, taking into account the terms used in OECD (Vollenweider and Krekes, 1982), OSPAR (1998) and EC Directive texts.
'The enrichment of water by nutrients, stimulating an array of symptomatic changes including increased production of algae and/or higher plants, which can adversely affect the diversity of the biological system, the quality of the water and the uses to which the water may be put.'

As well as problems with eutrophication, NO_3^- is also allegedly associated with methaemoglobinaemia in very young infants and is also associated with stomach cancer, but there is some controversy over the extent of this (Addiscott, 1999). Other problems exist in water as S can contribute to eutrophication and NO_2^- is known to contribute to stomach cancer and is toxic to fish especially salmonids.

Table 8.1 Key environmental concerns from arising from nutrient transfers (after Carton and Jarvis (2001)).

Environmental concern/issue	Environmental and other impacts	Scale of agricultural contribution	On-farm sources	Scale of impact
Nitrate (NO_3^-)	Water quality - eutrophication - health Economic loss - loss to farmers	Major source	Intensively managed land (inputs from fertiliser, manures, slurry, legumes and feeds)	Local : on-farm surface waters Regional: surface waters; catchment; aquifers. National/international: maritime waters
Nitrite (NO_2^-)	Water quality - fish stocks and health	Major source	Managed land	Local: on-farm surface waters. Regional: surface waters and wells
Ammonia (NH_3)	'Acid rain' - acidification of soils - eutrophication of natural systems Direct toxicity	Major source (> 85%)	Fertilisers (urea), Excreta, Manures and slurry	Local: "on farm" deposition Regional: deposition into natural ecosystems National/international: cross boundary transfer of NH_3 and deposition
Nitrous oxide (N_2O)	Greenhouse gas - global warming Ozone interactions	Substantial (likely to increase in importance as other sources decrease)	N fertilisers, Excreta	Global
Nitric oxide (NO)	Tropospheric ozone precursor	'minor?'	Combustion, fertilisers, Manures and slurry	Global
Phosphorus (P)	Water quality - eutrophication Health - toxins from algal bloom Economic - cost of removal	Substantial - increasing as industrial point sources decrease	Fertilisers, Manures, slurry P – enriched soils	Local: on-farm surface waters Regional: surface waters, catchments National/international: maritime waters (cross boundary transfer)
Methane (CH_4)	Greenhouse gas global warming	Substantial	Ruminants, Manures, slurry, rice	Global

Impacts of nutrients on the atmosphere

Ammonia is a reactive gas that has both effects on atmospheric chemistry and on terrestrial and aquatic ecosystems (Pain and Jarvis, 1999). After reaction with acidic compounds in the atmosphere, deposition of NH_3 to land as a gas or as ammonium salts can add N to nutrient poor soils (e.g. heathlands) and change the types of plants and thus the biodiversity. Ammonium salts can also be transported over long distances in the atmosphere and contribute to acid rain effects (see Chapter 11).

It is estimated that N_2O has contributed ca. 5% to the total greenhouse effect and more than 50% of the total atmospheric N_2O emission to the UK arises from agriculture (Brown and Jarvis, 2001). Greenhouse gases trap heat in the lower atmosphere, reflecting infra-red energy back to the surface, partly responsible for global warming (see Chapter 12).

Many upland soils in Wales are naturally low in nutrients and are therefore particularly sensitive to enrichment by, for example atmospheric inputs of N or inputs of fertiliser.

8.2 Information sources and literature

Many of the sources of information are already cited elsewhere in this document and much fundamental scientific information cited is generic i.e. not peculiar to Wales *per se* (Davies, 2000; Goulding, 2000; Jarvis, 2000). There are some specific sources of information that exist in the research Institutes sited within Wales, particularly the Institute of Grassland and Environmental Research on sheep farming (Cuttle *et al*., 1996; Cuttle and James, 1995; Cuttle *et al*., 1998), the Centre for Ecology and Hydrology (Reynolds *et al*., 1998) and the Universities. The Welsh Soils Discussion Group was once a rich source of information in the 1960s and 1970s (Adams, 1974; Colbourne, 1986/7; Hornung, 1971; Jenkins, 1967; Munro, 1972; Troughton, 1965) although much of this information is now rather dated. There are many other examples of nutrient research conducted on Welsh soils that have not been reported elsewhere in the document and could be perused should the reader require additional specific information (Adams and Kassim, 1984; Bennion *et al*., 1996; Davies and Munro, 1974; Emmett *et al*., 1991a; Emmett *et al*., 1991b; Emmett *et al*., 1995; Emmett *et al*., 1998; Harrison *et al*., 1995; Henriksen *et al*., 1998; Hornung *et al*., 1986; Hughes *et al*., 1999; Munro *et al*., 1973; Muscutt and Withers, 1996; Neal *et al*., 2001; Neal *et al*., 1998; Rees *et al*., 1991; Reynolds *et al*., 1988; Reynolds and Stevens, 1998; Reynolds *et al*., 2000; Skinner and Todd, 1998; Stevens *et al*., 1993; Webb *et al*., 2001).

Data on biodiversity and effects of nutrients in ESAs are provided by CS2000 and a MAFF funded ADAS project (Chambers *et al*., 2000)

Data from the National Soil Inventory (NSI) (Loveland. 1990), many of which are reported in McGrath and Loveland (1990). Their maps show the nutrients (P, K, Mg and Ca) in the 0-15 cm layer in soils in Wales, but do not summarise the data for Wales separately from those for England and Wales as a whole. This separation has, however, been made for the purposes of this report. There was limited re-sampling of the sites reported by Bellamy & Loveland (*loc. cit.*) between 1995 and 1997, the data for which are given in this report, but are otherwise unpublished. The re-sampling scheme and the NSI in general is described more fully in Chapter 7 on soil organic matter.

8.3 The current situation

8.3.1 State of agricultural land use in relation to soil nutrients in Wales

Agricultural land use and farm type can be used to give some indication of nutrient usage, knowing the levels of productivity, and hence fertiliser usage, that are associated. Agricultural land use in Wales

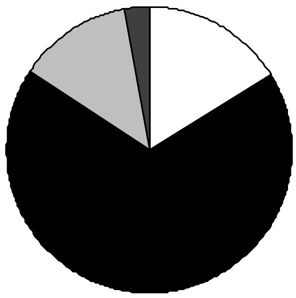

Figure 8.1 Pie chart illustrating agricultural land use in Wales by land area type – as percent of 1.5 million ha (Government Statistical Service, 1999).

gives strong insight into the current situation (Government Statistical Service, 1999) which supplies information from the June census 1997.

In 1997 the total agricultural land area in Wales was 1,477,447 hectares, comprising 27,937 holdings. By farm type most of this (70%) is sheep and cattle – see Figure 8.1.

- By region, as a percent of the total agricultural area of Wales, 14.4% of is in North East Wales, 25% is in Powys, 12.7% is in South Wales, 16.7% is in North West Wales, 9.7% in Ceredigion, 8.7% in Pembrokeshire and 11.9% in Carmarthenshire.
- In all regions, the dominant farm type is cattle and sheep (with over 85% in North West Wales 85.8%) except in Pembrokeshire, where dairying dominates.
- Sixty three percent of sheep holdings have 1000 sheep or more. Holdings of dairy herds are dominated (26.4%) by 100-<200 sized herds. There are 280,452 cows 1,314,820 cattle and calves and 10,824,529 sheep.
- Between 1992 and 1997, the total sheep and lambs in Wales has remained approximately similar with 10 915 100 in 1997, but this is an overall increased of about 10% since 1987.
- Between 1987 and 1997, the total cattle and calves in Wales remained approximately similar with 1323 000 in 1997.

Clearly livestock farming dominates agricultural land use of Welsh soils and, in terms of animal numbers and land area, this is mostly extensive sheep farming. Compared to those in England, Scotland or Northern Ireland, Welsh soils have the greatest number of sheep. A nutrient budget for typical lowland dairy and sheep farms has indicated that surpluses of P exist in both systems, although the threat of P transfer to the wider environment is greatest in the more in intensive dairy system (Haygarth *et al*., 1998).

8.3.2 Trends in nutrient use on Welsh soil

Information relating to trends in fertiliser practice can be gleaned from the British Survey of Fertiliser Practice 1999 (Heather, 2000), but these statistics relate to the whole of Great Britain in which statistics from Wales are included. A summary is presented in Table 8.2.

Table 8.2 Fertiliser use in Great Britain in 1999.

a. For all types of agricultural land use: Grass is most relevant to Wales.

	Total nitrogen kg ha^{-1}	Total phosphate kg ha^{-1}	Total potash kg ha^{-1}
All crops and grass	125	32	42
Tillage Crops	141	45	57
Grass	110	40	28

b. For grassland: Grazed grassland is most relevant to Wales.

	Total nitrogen kg ha^{-1}	**Total phosphate kg ha^{-1}**	**Total potash kg ha^{-1}**	**Total sulphate kg ha^{-1}**
Grazed Grassland	108	20	27	55
Silage	168	27	51	62
Hay	72	16	20	34

- The average field application rate for dairy farms in Great Britain in 1999 was 253 kg N ha^{-1} and 49 kg phosphate ha^{-1} on grass under 5 years and 191 kg N ha^{-1} and 33 kg P ha^{-1} for grass 5 years and over.
- The average field application rate for cattle and sheep farms in Great Britain in 1999 was 161 kg N ha^{-1} and 42 kg phosphate ha^{-1} on grass under 5 years and 93 kg N ha^{-1} and 28 kg P ha^{-1} for grass 5 years and over.
- The average field application rate for livestock/mixed farms in Great Britain in 1999 was 177 kg N ha^{-1} and 41 kg phosphate ha^{-1} on grass under 5 years and 121 kg N ha^{-1} and 42 kg P ha^{-1} for grass 5 years and over.

8.3.3 Other related environmental statistics *(Swallow et al., 2001)*

- The proportion of river lengths with concentrations greater than 100 ìg P L^{-1} in Wales in 2000 (average 1998-2000) was 8%. This is better than Northern Ireland (27%) and England (60%) but this figure will also include effects of point sources and thus will also reflect population densities rather than soil *per se*.
- River lengths with concentrations of NO_3^- greater than 30 mg L^{-1} in Wales in 2000 were 2% of the total.
- For chemical river quality in Wales, for 4,560 km of river length classified, 93% was classified as 'good', 5% 'fair' and 1% 'poor/bad' during 1990-2000 (Swallow *et al*., 2001). This pattern is similar to that found in Scotland and largely reflects the situation over the last ten years, whereas there have been much greater fluctuations in water quality in England and Northern Ireland. The status of chemical river quality in Wales is the best in the United Kingdom.
- Biological river quality in Wales is based on monitoring of invertebrates such as ….. that live in or on the beds of rivers or canals. They are good integrative indicators of long-term water pollution. Of 4,400 km of river lengths classified, 76% were classified as 'good', 22% 'fair' and 2% 'poor/bad' during 1990-2000 (Swallow *et al*., 2001).

The percentage of river lengths with concentrations greater than 100 ìg P L^{-1} in Wales has been reduced from 26 in 1990 to 10 in 1995 to 8 in 2000 (Swallow *et al*., 2001). However, this will reflect cleaning up of point sources rather than a decline in agricultural sources. It will become increasingly difficult to reduce this further without greater controls on agricultural land.

8.3.4 Case studies

A nutrient budget for Anglesey (Reynolds et al., 1998)

There is concern over observed eutrophication of shallow lakes on Anglesey as analysis of sediment cores has identified a steady rise in total P over time with an accelerated increase during the early 1970s. These changes are most likely to be due to increased agricultural intensification within the catchments. The contribution and fate of farm waste products from intensive poultry units on the island are of particular concern, because in 1994 there were 2.4 million poultry accounting for 37% of the Welsh total.

- For N, grassland fertiliser applications and N fixation comprise the largest contribution to external inputs accounting for 90% of the total. Losses from sheep and cattle grazing dominate, accounting for nearly 60% of the N leached.
- Grassland fertiliser inputs dominate the P budget accounting for 83% of the external input.
- The estimated annual P accumulation rate in Anglesey soil is 9 kg P ha^{-1} per year, similar to 10 P ha^{-1} per year estimated for GB and Northern Ireland.
- The N accumulation rate is 128 ha^{-1} per year, similar to estimates made in other agricultural systems.

Llyn Tegid, Wales (Environment Agency Wales,1999; Haygarth et al., 2000a)

Llyn Tegid is the largest natural lake in Wales and is located in the upper reaches of the River Dee catchment. The lake is a site of national conservation importance and has been designated a Site of Special Scientific Interest (SSSI) since 1997. Activities in the lake and its catchment over the last 20 years have had a detrimental impact on water quality, with blue-green algal blooms reported regularly in Llyn Tegid since 1995. In response to environmental concerns, the Environment Agency Wales initiated a project to investigate causes of the blooms and to consider options for management of the lake and its catchment. An assessment of the amount and sources of nutrients entering the lake via inflowing rivers showed that 8% was derived from human sewage, 2% from detergents, 11% from septic tanks and the remainder coming from diffuse sources, mainly forestry and farming (Environment Agency, unpublished data). The total P loading to the lake, particularly from diffuse sources, can be attributed to increases in improved pasture and coniferous forestry (identified from satellite imagery), as the soils in the catchment are vulnerable to erosion during overwintering of stock. The analysis of algal remains preserved in the sediment showed significant changes in the types of algae present, again suggesting an increase in the amount of nutrients available to algae. A catchment management strategy and action plan to ensure the sustainable use of Llyn Tegid was developed by the Environment Agency Wales in 1999, in consultation with other organisations with an interest in this area. The plan includes an objective 'To reduce the incidence of algal blooms by controlling the level of sediments and reducing phosphorus entering the lake to the target level by the year 2005' with associated actions to identify, develop and disseminate best management practices for land use to reduce sediment loss and nutrient release.

Botanical composition of grasslands in Welsh Environmentally Sensitive Areas (Chambers et al., 2000)

Soils and botanical data were analysed in a MAFF project conducted by ADAS (Chambers *et al*., 2000) from all six ESAs in Wales. The majority of mesotrophic grasslands were the semi-improved (*Lolium perenne – Cynosurus cristatus*) community. This community generally had higher soil P and lower total N levels than the unimproved grasslands and other vegetation types, as did other grasslands that had been subjected to agricultural improvement. The most common mire community was the (*Juncus effusus/acutiflorus – Galium palustre*) rush pasture. Lowland mire communities and those characterised by purple moor-grass (*Molinia caerulea*) were distinct from upland mire and wet heath communities, in having higher soil pH values and more variable OM and total N contents. Upland calcareous grassland communities had soil properties (pH and organic matter) that were similar to the acidic grasslands, rather than the lowland calcareous grasslands which had higher soil pH values. Heath communities had low soil pH (mean 4.7) and relatively high OM (mean 13.4%) and total N (mean 1.1%) contents, compared with the mesotrophic grasslands. Maritime cliff communities were not well differentiated from one another by their soil properties, or from other vegetation types, except that they tended to have higher soil Mg levels. Over all the ESA samples, vegetation of high botanical value was associated with the full range of soil pH values, but botanical value tended to show a negative relationship with soil extractable P levels.

Nitrogen deposition and biodiversity in the uplands: CS2000

The Countryside Survey 2000 (CS 2000) carried out by the Centre for Ecology and Hydrology was designed to provide detailed information about the habitats and landscape features that are important elements of the countryside (Haines-Young *et al.,* 2000). Using information from previous surveys in 1978, 1990 and 1998, the change in condition of habitats has also been assessed and includes an indirect method of assessing nutrient enrichment or eutrophication. This is based on changes in abundance of plant species that are known to be indicators of different levels of nutrient availability as indicated by their different Ellenberg values (Hill *et al.,* 1999, Ellenberg *et al.,* 1991). In the analysis of CS2000 data, evidence of nutrient enrichment was observed in roadside verges and dwarf shrub heath and bog. In the heaths and bogs this was associated with increased presence of plant species more typical of lowland grasslands (Haines-Young *et al.,* 2000). As a direct measure of the change in condition of soil, CS2000 included resampling of areas sampled in 1978. Analysis of these soils is still in progress but is to include determination of pH (See Chapter 11), nutrient levels, organic matter content, heavy metals and soil biota.

8.4 Impact on soil functions

8.4.1 Biomass, food and fibre production

Loss of atmospheric S deposition will have an effect on biomass, food and fibre production if it is not replaced (Brown *et al*., 2000; MAFF, 2000). General nutrient deficiencies in upland soils will also undermine production. For sustained levels of production, replacement policies for P and K need to be maintained

8.4.2 Environmental interaction

The extent of environmental interaction is potentially high in terms of 'leakages' of nutrients undermining water and atmospheric quality especially in high input systems.

8.4.3 Provision of a platform

Nutrients will not have a direct short-term effect on soil ability to provide a platform.

8.4.4 Support of ecosystems, habitats and biodiversity

Excess of nutrients in soils will seriously undermine biodiversity both in terrestrial and aquatic systems.

8.4.5 Provision of raw materials

Nutrients do not affect the provision of raw materials.

8.4.6 Protection of cultural heritage

Nutrients are essential in supplying soil fertility and a basis of agriculture and particularly sheep farming in Wales and thus the maintenance of current rural structures. However, there are longer-term concerns with nutrients that will undermine the cleanliness and quality of Welsh water. Nutrients do not directly affect buried items of historic interest

8.5 The future situation

Some information relating to the future can be gleaned from assessing the long-term trends in fertiliser use (Heather, 2000).

- The long term trends in application rates show that overall total N use since 1983 has declined on both tillage crops and grassland. In the longer term, since 1969 there is however a net increase.
- The use of P has declined gradually on tillage crops but apart from lower rates in 1998-99, has been relatively stable on grassland.
- Potassium use has tended to decline on tillage crops, despite some apparent recovery in application rate in 1997 and 1998. Overall rates on grassland, most relevant to Wales, have decreased slightly.

The average application rate of SO_4^{2-} to all grass in Great Britain has increased from 34 kg ha^{-1} in 1995 to 56 kg ha^{-1} in 1999, reflecting concerns over S deficiency due to a decline in atmospheric depositions.

The resulting trends in the nutrients according to the National Soil Inventory are shown in Table 8.3 and this largely reflects the fertiliser use statistics.

Table 8.3 Trends in Nutrients on Welsh soils from permanent Grassland Sites 0-15 cm. Totals reflect an aqua regia digest in mg kg^{-1} and available in mg L^{-1} soil by McGrath & Loveland (1992) and Bellamy and Loveland (*loc. cit*.).

	1979-1983 - Sample Wales			**1995-1996 Sample - England and Wales**		
Variable	**N**	**Mean**	**Median**	**N**	**Mean**	**Median**
Total P	772	921	828	770	666	599
Avail. P	761	23	16	771	24	18
Total Mg	772	4276	3491.5	772	3494	2667
Avail. Mg	762	168	121	772	210	150
Total K	772	5495	5118.5	759	3586	2784
Avail. K	762	152	114.5	772	217	162
Total Ca	772	8032	3264	772	6898	488

Between the two samplings total soil P, Ca and K have all declined. Available (Olsen's bicarbonate extractable P) has remained similar and available Ca and Mg have risen.

8.6 Policy responses – present and future

8.6.1 Policy drivers: Standards

- The EU has set standards for NO_2^- concentrations in water as 3 ìg L^{-1} for salmonids and 9 ìg L^{-1} for coarse fish.
- The EU has set a limit of 83 mg SO_4^{2-}-S L^{-1} in water intended for potable use (Brown *et al*., 2000; Council of The European Communities, 1989).
- The EU has set standards for NO_3^- concentrations in water as 11.3 mg NO_3^- -N L^{-1}.
- The Environment agency (Environment Agency, 2000) has proposed interim standards for P according to standing and running freshwaters – with eutrophication thresholds proposed as 85 and 200 µg TP l^{-1} respectively. This 'two phase' system is highly relevant to the upland dominated Welsh landscape where fast running rivers are a major component of the landscape.

8.6.2 Nitrates Directive and Nitrate Vulnerable Zones

An excellent review of the role of the Nitrates Directive (91/676/EEC) and other relevant EU policy is provided in De Clercq et al. (2001) and a consultancy document describing issues pertinent to Wales is available (Welsh Assembly Government, 2002a). The main objective of the directive is to 'reduce water pollution caused or induced by caused or induced by nitrates from agricultural sources and prevent further such pollution'. To undertake this, member states must:

- Designate vulnerable zones i.e. areas of land that are known to contribute to NO_3^- pollution. See Welsh Assembly Government (2002a) for full description of how this may affect Welsh farmers.
- Action programmes and suitable monitoring programmes need to be established with respect to designated areas.
- A code of good agricultural practices needs to be established.

8.6.3 Water Framework Directive

This is a new Directive that establishes a framework of protection of inland surface waters, coastal waters, and groundwater (De Clercq *et al*., 2001; European Union, 2000) at the catchment or river basin scale and which:

- Prevents further deterioration and protects and enhances the status of aquatic ecosystems.
- Promotes sustainable water use based on long term protection of available water resources.
- Aims at enhanced protection and improvement of the aquatic environment.
- Ensures the progressive reduction of pollution of groundwater and prevents its further pollution.
- Contributes to mitigating the effects of flooding and drought.

The extent to which this relatively new Directive will influence management of nutrients in Welsh soils over and beyond the next decade is unknown, but, given that Wales has largely good water quality the influence of the Directive is likely to be targeted.

8.6.4 EU Air Quality Policy

European Council Directive 1999/30/EC of 22 April 1999 is relevant to limiting values for nitrogen dioxide and other oxides of N (De Clercq *et al*., 2001). The 1990 emission levels for the UK was 2673 thousand tonnes of NO_2 per year and the percent reduction target for 2010 is -56%. The 1990 emission levels for the UK was 2673 thousand tonnes of NH_3 per year and the percent reduction target for 2010 is –11%.

8.6.5 Biodiversity

The Soil Association has produced a briefing paper on Soil Biodiversity that outlines the importance of related issues.

8.6.6 Agenda 2000

This is an action programme that was launched in 1999 (De Clercq *et al*., 2001) and aims to reform the common agricultural policy (CAP) and this will have secondary effects on the nature of agricultural intensification and nutrient usage.

8.6.7 The Paris Convention (PARCOM) and the Oslo and Paris Conventions (OSPAR)

PARCOM recommendation 88/2 on the reduction of inputs of nutrients to the North East Atlantic to achieve a 'substantial reduction (of in the order of 50%) of P and N'. PARCOM recommendation 92/7 involves the agreement to reduce

- NH_3 volatilisation
- Leaching of N, mainly NO_3^-
- Leaching, runoff and erosion losses of P, and;
- Farm water discharges.

The Oslo and Paris Conventions ceased to exist in 1998 and became OSPAR, of which an additional objective is to combat maritime eutrophication.

8.6.8 Integrated Pollution Prevention and Control (IPPC)

IPPC is an integrated environmental approach to the regulation of certain activities. This means that emissions to air, water and land, plus a range of other environmental effects must be considered together. These new measures will effectively replace integrated pollution control (IPC) regime under part 1 of the Environmental Protection Act 1990. This is a particularly important issue for the poultry sector due to high levels of ammonia emitted. (Morris, 2001)

8.6.9 Organic farming scheme (OFS)

The OFS is a scheme that offers payments to farmers in Wales to aid them in converting to organic farming and to manage their land in some additional environmentally beneficial ways (Welsh Assembly Government, 2002b). The scheme seeks to increase the area devoted to organic farming in Wales. For food to be sold as 'organic' it is necessary for it to be produced in accordance with certain specified minimum standards. In the UK, standards for organic production are set by the 'United Kingdom Register for Organic Food' (UKROFS).

8.6.10 Other 'drivers'

Other drivers that will have an influence on the management of nutrients in soils are:

- The National Trust Soil Protection Strategy (Jarman, 1999) that highlights livestock production, and eutrophication as issues that will be relevant for nutrients.
- Government Codes of Practice for soil, water, atmosphere and manures (MAFF, 1993; MAFF, 1997; MAFF, 1998) and Fertiliser Recommendations (MAFF, 2000).

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9. DIFFUSE SOIL CONTAMINATION

Summary

- Atmospheric deposition of particulates emitted by vehicles and industry, application in sewage sludge and other waste materials applied as fertiliser, in inorganic phosphorus fertiliser and through excretion of food additives can all increase concentrations of heavy metals (eg Cd, Cr, Hg, Ni, Pb, Zn) in soils above naturally occurring levels..
- There is a substantial body of evidence that soil processes can be adversely affected by heavy metals, at concentrations that have no apparent impact on soil animals and plants.
- Many Welsh soils contain heavy metals at concentrations which are close to, or higher than, limits proposed by the EU to prevent heavy metal toxicity from sewage sludge application. Critical limits and loads for Pb are exceeded in many upland soils in Wales.
- Atmospheric deposition rates of heavy metals are uncertain but current and proposed legislation will reduce emissions of heavy metals considerably.
- A watching brief needs to be maintained for heavy metals contents of Welsh soils, especially where these are subject to known inputs. There is much still to be learned about heavy metals effects on soil micro- and meso- biology, and associated processes.

- Radiocaesium contamination is widespread in Wales from global fallout from nuclear weapons tests and from the Chernobyl accident in 1986.
- Radiocaesium from Chernobyl continues to cycle within the soil/plant system and restrictions remain on around 186,000 sheep from approximately 360 holdings in north Wales.
- The contribution to soil in Wales from windblown radionuclides from the Irish Sea is believed to be minor, and less than in the Lake District coast.

- Current concerns about persistent organic compounds are focused on those added inadvertently to soil in organic wastes, including polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) and dioxins.
- There is little or no information on concentrations of these compounds in Welsh soils, although the UK Soil and Herbage Pollutant Survey will measure them at 28 locations in Wales.
- Although the legislative framework for pesticides is designed to remove from sale those that are persistent in soils, the fate and persistence of many organic compounds in soils is uncertain and requires further research.
- The revised Sewage Sludge Directive will set limit values for the concentrations of many organic pollutants in sewage sludge.

- Sewage sludges, agricultural wastes and municipal composts may contain pathogens such as bacteria, viruses and protozoa that pose potential risks to receptors such as humans, crops and grazing animals. Some of the particular organisms of concern are *Escherischia coli* O157, *Salmonella* spp., *Cryptosporidium, Campylobacter* and *Giardia*.
- Treatment of sewage sludge is designed primarily to reduce the persistence of pathogens. Research is currently sponsored by EA to assess the effectiveness of this treatment.
- Animal wastes produced and re-used on farm may result in a cycle of contamination and re-infection of the same animals. Some 30% of cattle herds in some parts of the UK may be infected with *E. coli* O137. This organism can survive in soil for more than 3 months.
- Other contaminants of concern, for which little or no information is available, include Transmissible Spongiform Encephalopothies (BSE and scrapie) and antibiotics.

9.1 Background

Diffuse forms of soil contamination considered here are:

- heavy metals
- radionuclides
- potentially harmful pathogens such as viruses and bacteria , and
- poorly biodegradable trace organic compounds, including pesticides.

The main sources of these pollutants are:

- aerial deposition of emissions from industry and transport (mainly heavy metals, radionuclides and organic compounds
- sewage sludge (mainly heavy metals, pathogens and organic compounds)
- landspreading of industrial, commercial and municipal wastes (heavy metals, pathogens, organics and possibly radionuclides)
- agricultural sources, including manures and slurries, fertiliser and liming materials, pesticides/herbicides, irrigation water.

Other contaminants, for which little or no information exists, include Transmissible Spongiform Encephalopathies (TSEs), which include BSE and scrapie: TSEs are the subject of a proposed research programme by DEFRA (D. Jones, University of Wales, Bangor, personal communication, 2002), which will examine their persistence, migration and leaching in the environment, and potential for contamination of the soil. Little is known of their behaviour in soils, so they are not referred to again in this report, but it is clearly necessary to maintain a watching brief on these contaminants.

The effects on soil biota of antibiotics in animal feed are largely unknown and are not refereed to again here, but have been noted as an area of concern by the CEC (2002) in their list of threats to soil. Once again, a watching brief should be maintained.

Other diffuse forms of diffuse contamination, acidification and nutrient enrichment are considered in Chapters 11 and 8 of this report. Gross contamination of soils is considered in Chapter 10.

9.1.1 Heavy metals

Heavy metals such as Cd, Cr, Cu, Hg, Ni, Pb and Zn occur naturally in soil at levels dependent upon concentrations in soil parent material. Many are essential to living organisms in trace concentrations, but human activities can cause elevated concentrations and there is a substantial body of evidence that soil processes can be adversely affected. Heavy metals contamination of soils can be through a variety of routes, but these are primarily:

- in atmospheric deposition of particulate material emitted by vehicles and industry
- in sewage sludge and other waste materials applied for agronomic benefit.
- in inorganic phosphorus fertiliser (mainly Cd)

9.1.2 Radionuclides

The main radionuclide of concern in Wales is radiocaesium deposited as a result of bomb tests conducted up until 1962, and the Chernobyl accident in 1986. The latter resulted in particularly large deposition of ^{137}Cs in North Wales.

9.1.3 Persistent organics

Persistent organic compounds considered here are those which enter soil from aerial deposition, are applied to soil in organic wastes such as sewage sludge, and in pesticides. A very wide range of compounds is involved, but it is only those with a long half-life in soil that will accumulate if there are repeated applications. This has been the case with certain herbicides, many of which are now withdrawn. Current concerns are focused more on compounds added inadvertently to soil in organic wastes, including polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) and dioxins. Although PCBs were banned several years ago, soils have now become major sources of these chemicals.

9.1.4 Pathogens

Pathogens reaching the soil are primarily in sewage sludge, septic tank waste, municipal compost and other wastes derived from industrial utilisation of agricultural products, such as abattoir waste and pose potential risk to receptors such as humans, crops and grazing animals. The pathogens of concern include bacteria, viruses and protozoa, and some of the particular organisms are *Escherischia coli* O157, *Salmonella* spp., *Cryptosporidium, Campylobacter* and *Giardia*.

9.2 Information sources and literature

9.2.1 Heavy metals

Concentrations of total[1] Cd, Co, Cr, Cu, Mn, Ni, Pb, Zn, As, Hg and Se, and extractable[2] Cd, Co, Cu, Mn, Ni, Pb and Zn are held in the National Soil Inventory (NSI) database at the National Soil Resources Institute (NSRI). These data are from samples collected from the upper 15cm of soil from a 5km x 5km grid throughout England and Wales in 1978-1982. Maps showing the distribution of these heavy metal concentrations are published, together with data for other soil properties, in McGrath and Loveland, (1992). In Wales, approximately 800 samples were collected, and summary statistics for these are given in Tables 9.1 and 9.2.

Table 9.1 Total concentrations of heavy metals (mg/kg) in 0-15 cm depth from Welsh soils (Loveland, 2002, personal communication).

	Cd	Co	Cr	Cu	Mn	Ni	Pb	Zn	As	Hg	Se
Mean	0.90	11.10	41.2	23.4	934	22.0	88.4	99.6	5.30	0.07	0.96
Median	0.8	10.3	43.7	18.7	759	21.0	51.5	84.0	4.00	0.00	0.80
Minimum	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.40	0.00	0.00
Maximum	11.7	321.8	97.9	298	17349	193.9	3461	2125	37.60	1.20	6.40
N	804	804	804	804	804	804	804	804	316	316	316

Table 9.2 Concentrations of extractable heavy metals (mg/l) in the 0-15 cm depth of Welsh soils.

	Cd	Co	Cu	Mn	Ni	Pb	Zn
Mean	0.29	0.66	5.34	128.7	0.85	27.8	8.68
Median	0.20	0.50	41	93	0.60	13.1	4.40
Minimum	0	0	0	0	0	0	0
Maximum	7.50	10.8	54.3	2347	8.80	1384.5	712
N	799	799	799	799	799	799	799

A sub-sample of soils from the NSI sites was re-sampled and analysed in 1995. The results for this sub-sample (which is for England and Wales) are shown in Table 9.3. A moderate reduction in Zn, Cr and Pb is seen.

Table 9.3. Total concentrations (mg/kg) of heavy metals in agricultural topsoils in England and Wales, 1980 and 1995. Source: Soil Survey and Land Research Centre/NSRI, from Environment Agency website.

	1980	1995
Zinc	91	70
Chromium	44	40
Lead	45	39.5
Nickel	27	28
Copper	20	18
Cobalt	11	10.5
Cadmium	1	0.5

[1] *Aqua regia* digest
[2] EDTA extraction

In addition, heavy metals are being analysed on approximately 100 soils collected in 1998 from Countryside Survey 2000 (CS2000) squares in Wales (DETR, 2000b), which will provide a baseline for future surveys (H. Black, CEH Merlewood, personal communication, 2002).

Soils are also analysed from the Snowdon Environmental Change Network (ECN) site. Baseline samples were collected in 1995 for determination of total heavy metals (Pb, Zn, Cd, Cu, Hg, Co, Mo, As, Cr, Ni) according to standard protocols (Sykes and Lane, 1996) and the analysis will be repeated in 2015.

9.2.2 Radionuclides

Radiocaesium contamination of soils is widespread in Wales. This is the result of global fallout from atmospheric nuclear weapons tests conducted between 1945 and 1962 (with peak releases occurring between 1961-1962) and from the Chernobyl accident in 1986, the latter affecting North Wales in particular. There may also be a small contribution of radiocaesium from the Windscale accident in 1957. Other radionuclides may also be present from global fallout, including ^{90}Sr and Pu isotopes.

The contribution from radioisotopes blown inland from the Irish Sea is likely to be relatively minor, based upon studies conducted in Cumbria (personal communication, S.Wright and N. Beresford, Radioecology section, CEH Merlewood), and Sanchez *et al*., 1998 have recently shown that on the Irish Sea coast anthropogenic radionuclide concentrations in Wales are much lower than near Sellafield.

Responsibility for monitoring radionuclide levels in soils and food post-Chernobyl, and around nuclear installation in Wales, is with the Food Standards Agency (FSA), which has taken over from the former MAFF Foods Division in this role. The FSA regularly publish results of radionuclide concentrations in soil, and in food grown near nuclear establishments (e.g. FSA and SEPA, 2001)

One unexpected consequence of radiocaesium, both from weapon tests and Chernobyl, is that ^{137}Cs present in the soil may be used to estimate rates of erosion. ^{137}Cs has a long half life and, assuming deposition is known, erosion rates can be inferred from the total ^{137}Cs present under disturbed and eroded sites. The technique has been used at Plynlimon (Bonnett *et al*., 1989; Institute of Hydrology, 1991).

9.2.3 Persistent organics

There is very little information on the concentrations and fate of persistent organic compounds in soil, and until recently no systematic monitoring of these compounds in soil had occurred. In the particular case of pesticides, the Pesticides in the Environment Working Group (PEWG), (Environment Agency, 2000), reported that "The relevance of collating data on residues in soil or vegetation needs to be considered. No systematic surveys take place to investigate pesticide residues in soils or to determine the community structure and thus the health of the soil". However, in the same report there was a recommendation that "Characterisation of residues in soil and vegetation is not considered to be a priority area. However, it is recommended that PEWG review the existing data on residues in relation to priority habitats and species under the Biodiversity Action Plan and evaluates them in the context of population dynamics and recovery."

The legislative framework for approval of pesticides used in the UK includes an assessment of their persistence and fate in soil. Many older pesticides which were persistent in soil have been withdrawn, but still may be present in soil. The EU is committed to reviewing existing pesticides, which could lead to withdrawal of more of these older pesticides.

The Environment Agency has recently established a consortium of organisations to fund the UK Soil and Herbage Pollutant Survey (P.Redfern, EA, personal communication 2002), co-ordinated by the University of Liverpool. This will report in August 2003. The survey will report on pollutant levels and soil properties, make comparisons with previous studies, undertake risk assessment, and undertake a radiometric survey. The survey will examine 122 rural, 28 urban and 53 industrial locations throughout the UK, of which 11 rural, 14 industrial and 3 urban locations are in Wales. Pollutants to be measured are dioxins, PCBs ('dioxin-like' and non-dioxin like'), PAHs and metals.

Information on other persistent organics, which are generally contaminants in sludge, is mostly lacking. Although the effects of these compounds on soil properties and organisms is not well known, and the potential risk is thought to be low, the uncertainty of their fate and rate of breakdown demonstrates a clear need for further research.

9.2.4 Pathogens

It is UK Government policy that in most cases the Best Practicable Environmental Option (BPEO) for management of sewage sludge is to recycle the material to agricultural land. However, following a series of high profile food scares in the 1990s (*E. coli, Salmonella* etc.), there has been increasing public concern over the microbiological quality of food. Concerns have been expressed about the application of sewage sludge to land used to grow crops for human consumption, despite the fact that none of the food scares have been attributed to the recycling of sewage sludge in agriculture. Consequently, the Environment Agency, DEFRA and UKWIR are funding research to characterise the microbiological risks associated with the use of sewage sludge.

In addition to the risk of pathogen contamination of soils from sewage sludge, there is also potential for contamination from municipal composts and recycling of animal manures produced on farm. Other potential sources of pathogen contamination of soil are through landspreading exempt industrial wastes such as blood and gut contents from abattoirs and untreated waste from the food industry. The scale of the latter issue is at present unknown because there are no reliable figures for the quantities of this type of waste spread on land in Wales (National Assembly for Wales, 2001)

9.3 The current situation

9.3.1 Heavy metals

The heavy metal status of soils in Wales shows a mixture of geological influences and anthropogenic effects (McGrath and Loveland, 1992). For instance, higher concentrations of Cd and Zn are often linked with substrates of Carboniferous age that have undergone mineralization, and where Pb and Zn mining and associated smelting has occurred. These areas include parts of the North Wales coast, Glamorgan and the lower Swansea Valley. Other heavy metals, such as Cu and Ni are also found at higher concentrations in soils of areas with a history of metal smelting. For Pb, comparatively high lead concentrations have been noted by McGrath and Loveland (1992) in areas of very acid upland ombrotrophic peats and peaty-surfaced soils in Wales, some distance from the main smelting areas.

Sources of heavy metals, apart from those derived from underlying geology, include atmospheric inputs derived from disused metaliferous mine workings (e.g. in Gwydir Forest, and at a variety of sites in mid-Wales), as nutritional supplements in animal feed, contaminants in inorganic fertilisers, and as contaminants in sewage sludge and other organic ‘wastes’ applied to land.

Continuous records of air concentrations of heavy metals in rural locations are available from five sites in England and one in Scotland (AEA Technology, 2001). There is no information for rural Wales. However, mosses have been used as a sampling medium for metals deposited from the atmosphere. In 2000, moss samples were collected and analysed from 17 sites across Wales as part of a UK wide survey of metal contents (Ashmore *et al*., 2001a). This survey revealed high concentrations of Cu, Cd and Zn in South Wales and a high value for Cd in North Wales, almost certainly derived from recent windblown dust from the Gwydir Forest mining district which operated in the last century.

Ashmore *et al*., (2001a), derived deposition estimates for the UK from the moss data, and these have been used in conjunction with estimates of critical loads for heavy metals to derive critical loads exceedance areas for heavy metals in the UK uplands (Ashmore *et al*., 2001b). Critical loads were calculated using critical limits (concentrations) for metals in soil solutions (for Pb and Cd only) which should prevent damage to soil biota and biologically-mediated processes. Critical limits of lead, but not those of Cd, based upon soil solution concentrations are exceeded over a significant area of upland Wales, as is the case for the most of the UK uplands. However, Ashmore *et al*., 2001b, point out that there are considerable uncertainties over the deposition estimates for heavy metals and further refinement of methodology is a priority.

Heavy metals enter into the more intensively managed agricultural soils through a variety of pathways. Cadmium is naturally present in rock phosphate fertilisers and application rates to arable land have been estimated at 2.1 g/ha/year (Alloway *et al*., 1998). However, where sewage sludge is applied to agricultural soils it is a major source of heavy metals, e.g. for Cd, Alloway *et al*. (1998) quote input at 22.3 g/ha/year. Where sludge is applied, it can be a significant source of Cd locally, however at the country/regional level it is not considered as a significant source (Environmental Resources Management, 2000).

Concentrations of heavy metals in sewage sludge are also extremely variable, depending upon the source. However, for sludge with typical concentrations of heavy metals, SEPA (1998) estimated that 113 and 160 applications for Zn and Cu respectively would raise the concentration in uncontaminated soil to the maximum acceptable concentration. Many soils in Wales have heavy metal concentrations approaching proposed new limits for heavy metals (see later in this section). However it is likely that unless heavy metal inputs from other sources are significant, excessive concentrations in soils will be reached only when sludges with particularly high concentration of heavy metals are repeatedly applied to the same land.

D r Cymru/Welsh Water (2000) report that sewage sludge production in 2000 was 40 thousand tonnes of dry solids (ttds) and that the company's strategy is "where possible, to dispose of this to land following digestion, lime treatment or thermal drying in accordance with regulations set out by the DETR". Maximum application rate to land is 250 tonnes/ha in any 12 months (MAFF, 1998a), (or 250 kg/ha total nitrogen (MAFF, 1998b)). The latter figure will dictate that if total N content, for instance, is 10 kg/t, in digested sludge data, maximum application rate per hectare will be 25 tonnes, which will require 40,000/25 = 1600 ha for disposal. This is a tiny proportion of the land in Wales upon which sewage sludge may potentially be spread, although in practice transport costs dictate that sludge tends to be recovered to land within a few km of the source.

Sewage sludge is potentially a valuable forest fertiliser because of the useful amount of N and P that it contains. In Wales, sewage sludge has been successfully used in re-establishment of trees on restored former opencast colliery sites in South Wales where the 'soil' consists primarily of nutrient poor overburden.

An estimated 6 million tonnes of 'animal matter' was produced on Welsh farms in 1998 (Environment Agency, 2001). This also contains heavy metals, though not at such high concentrations as sewage sludge (Alloway *et al.,* 1998). These enter the farm nutrient cycle through artificial fertilisers, sewage sludge (if used) and dietary supplements.

Other forms of waste 'recovered' to land in Wales include commercial and industrial wastes of which 21,000 tonnes were applied in 1998/99 (Environment Agency, 2001). Information on the nature of this waste is hard to come by but there is likely to be potential contamination from metals and organics from these wastes.

9.3.2 Radionuclides

Of the various issues related to radionuclide deposition in Wales, the one with the greatest impact is probably radiocaesium deposition resulting from the 1986 Chernobyl accident. Immediately after the accident MAFF stated that the problem would only last a matter of days, based upon knowledge of the behaviour of radiocaesium in lowland soils with high clay content, where immobilisation is rapid. However, radioactive caesium deposited on acid organic soil in upland Britain in 1986 is continuing to cycle through the soil-plant-animal system. In 2001 there were still 386 farms with 230,000 sheep with restrictions in Cumbria, Southern Scotland and North Wales (Food Standards Agency and SEPA, 2001), the majority of which were in Wales. The continuing mobility of Cs in these organic acid soils has been the subject of considerable research (e. g. Hird *et al*., 1996; Livens *et al*., 1996). This has shown that in acid organic soils Cs ions are unlikely to be fixed by interlayer collapse of the clay, but are absorbed in particular wedge zones of illite clays. Even though these mineral components are present in very small quantities, they are sufficient to absorb the Cs. The Cs is released when the solution concentration of Cs declines, as when taken up by roots (because Cs mimics K). Once in the plant, ingestion by sheep or leaching from leaves takes place, in the latter case continuing the cycle within the soil –plant system.

9.3.3 Persistent organics

The current situation with regard to these pollutants is described under 'Information sources and literature.

9.3.4 Pathogens

The current situation with regard to these pollutants is described under 'Information sources and literature.

9.4 Impact on soil functions

9.4.1 Biomass, food and fibre production

Heavy metals

Heavy metals, or trace metals, is the term applied to a large group of trace metals which are both industrially and biologically important. Agricultural productivity can be limited by deficiencies of 'essential' trace elements such as Zn, Cn and Mn in crops, and Co, Mn, Cu and Zn in livestock. However, when present in excessive concentrations, certain heavy metals give rise to concern with regard to human health and agriculture. The effects have been summarised by SEPA, 1998, as follows:

Effect	**Causal element**
Phytotoxicity	Zn, Cu, Ni, possibly Cr
Human food chain via crop uptake	Cd
Human food chain via offal from meat from animals ingesting soil with elevated levels of heavy metals	Cd, Pb
Animal health	Cu, As, Se, Mo, F
Soil fertility	Zn

On agricultural land, heavy metals may be applied as sewage sludge and other waste disposal to land, and also in organic fertilisers and feedstuffs. Maximum concentrations have been set for heavy metals in soils and SEPA (1998) conclude that current limits for Cu, Ni and Cd in soil are acceptable for the protection of plants, animals and humans, but further work is needed in relation to the intake of Cd by sheep. They also recommend a reduction of maximum allowable soil Pb concentration from the current figure of 300 to 200 mg/kg to provide additional protection from accumulation in the liver.

In the past (and to a large extent today) soil has been regarded as a receptor for waste and the emphasis has been placed in ensuring contaminants were locked into the soil, thereby avoiding pollution of watercourses or uptake into the food chain. More recently, greater attention has been paid to developing an understanding of the sensitivity of soils to contamination, through the effects on soil ecosystem functions and sustainability. This theme is discussed further under 'Support of Ecosystems, Habitats and Biodiversity'.

Radionuclides

Impacts of diffuse pollution by radionuclides are restricted primarily to the affects of the Chernobyl explosion. The ^{137}Cs deposited in the uplands of Wales has remained mobile within the soil-plant system, resulting in its uptake by vegetation and ingestion by sheep. Restrictions remain on approximately 360 holdings in Wales, affecting 180,000 sheep, 16 years after the accident. The controls require that any sheep to be moved out of the restricted area, whether to market or alternative grazing, must first be tested on farm for radiocaesium. Sheep that fail the test are colour marked and it is an offence to slaughter them. Sheep may be moved to uncontaminated land but only when radiocaesium levels drop below the 'action level' may they be slaughtered. Approximately 150,000 tests are still conducted annually (FSA Wales, personal communication, 2002).

Persistent organics

For organic contaminants in soils, there is very little evidence of potential impacts on crop production. Bromilow *et al*., 1996, found no adverse effects on crop production of five pesticides applied in various combinations over a 17-year period. Repeated pesticide applications were either rapidly degraded in soil or were bound to soil organic matter and made biologically inactive. However, some herbicides affected the following crop (RCEP, 1996).

There remain some concerns over the persistence of certain pesticides in soil (RCEP, 1996, paragraph 5.87) but overall, RCEP (1996) conclude that "Continuous pesticide use does not seem to have affected the potential for agricultural productivity of soil. No long-term effects on soil fertility have been demonstrated."

Other organic pollutants applied to soil in waste products such as sewage sludge may be more problematical. Wilson *et al*., (1997), reported that certain dioxins and PCBs persisted for at least 260 days applied to the surface of ploughed land in Northwest England. In Scotland, paper mill sludge adversely affected crop yield at high application rates, and was attributed to the presence of pentachlorophenol in the sludge (Palmer *et al*., 1998). Information for Wales in generally lacking, but evidence from elsewhere is probably applicable to Wales.

Pathogens

Sewage sludges, some exempt wastes and agricultural wastes may all contain pathogens posing potential risks to receptors such as humans, crops and grazing animals. The approach adopted by the Code of Practice for the Agricultural Use of Sewage Sludge is to break the chain of transmission from pathogens in sludge to contamination of soil and water, to food, animals, crops and humans. Sludge is treated to reduce pathogens, and land use after application is restricted. Waiting periods between application and grazing or cropping allow remaining pathogens to decay further. Other organic wastes may present a greater risk of transmission to animals and humans. Septic tank sludge and blood and gut contents from abattoir wastes are not treated prior to application. Agricultural waste consisting of manures and slurries form the bulk of the organic waste applied to land in Wales (EA, 2001). On the whole, these wastes are applied without treatment and there is a considerable risk of transmission by mouth amongst members of a herd, and of contamination of neighbouring crops. Contamination by *E. coli* O157 is of particular concern. Regional incidence in the UK may be as large as 16% for cattle (Chapman *et al*., 1997), 2.2% for sheep and 0.6% for pigs. *E. coli* O157 can remain viable in soil for more than four months (Jones, 1999). Most human cases of *E. coli* O157 related food poisoning have been associated with the consumption of contaminated meat and dairy products, but there is also evidence that human infection has occurred through the ingestion of contaminated soil, fruit, vegetables and drinking water. Disposal of untreated abattoir waste to land clearly risks transmission of pathogens back to the land.

9.4.2 Environmental interaction

In addition to the consideration in this section of the main groups of diffuse pollutant, it is relevant here to examine the impacts of contaminated soil if erosion occurs, such that the contaminants are delivered to water courses, lakes and ultimately the sea. Eroded soil may carry with it many forms of contaminant, including nutrients (P adsorbed to mineral soil particles), heavy metals, pathogens and organic pollutants. Detailed consideration of these issues is outside the scope of this report, but it is clear from Chapter 5 of this report that erosion is an important issue in Wales, such that land management activities which cause contamination and promote erosion will potentially result in damage to downstream environments.

Heavy metals

Heavy metals concentrations in soils are influenced by soil parent material concentrations, atmospheric deposition, inputs from fertilisers, feed and wastes, leaching losses and offtake in crops. Ashmore *et al*., (2001a 2001b) report that estimates of heavy metal deposition vary, depending upon method used and type of collector. Deposition rates also vary with vegetation type, such that inputs to forests can be higher than to grasslands because of increased rates of deposition in dusts. Whether this enhanced deposition reaches the soil is another matter. Studies of rain and throughfall chemistry reported by Parker, (1983), show that Ni, Pb and Cd may be enhanced in throughfall, compared to incident rain, whereas Zn, Cr, Cu and Hg may be reduced due to foliar uptake. Foliar absorption may be exploited in agriculture as a means of supplying plants with micronutrients, such as Mn, Cu and Zn.

In soils, heavy metals are subject to a great many processes which tend to immobilise them – e. g. organic complexation, precipitation, adsorption, cation exchange. As a general rule, heavy metals are more mobile in acid soils, which explains why lower limits are likely to be set in forthcoming legislation for total heavy metals in acid soils to which sewage sludge is applied. Sewage sludge should also not be applied to soils with a pH lower than 5. Soils of the uplands of Wales are predominantly acidic, so heavy metals should be more mobile. However, little is known of the soil solution chemistry of heavy metals in Welsh soils. Studies such as the 1995 Wales Acid Waters Survey (Stevens *et al*., 1997) may be used as a guide to the heavy metal availability in soils. This survey sampled 102 streams in the upland, acid sensitive zone of Wales. Concentrations of Mn and Zn (and also Fe and Al) were highly significantly correlated with stream acidity.

Radionuclides

Issues discussed under Biomass, Food and Fibre Production are relevant here.

Pathogens

No issues of relevance here

Persistent organics

Pesticides applied to soil, crops and animals may be adsorbed by, or degraded in soil, or may reach streams or groundwaters through leaching, spillage, aerial transport or attached to eroding soil. The Environment Agency in England and Wales monitored over 3,000 freshwater and groundwater sites in 2000 (Environment Agency, 2000). Analysis of some 180 different pesticides was undertaken. Some 29% of sites were found to have at least one pesticide present at above 0.1µ, which is the pesticide standard in the EC Drinking Water Directive. Many of these pesticides are solely or mainly used in agriculture. The majority of failures were caused by sheep dip chemicals such as cypermethrin and diazinon, and these were predominantly in Wales and North East England (EA, 2000a). Routine monitoring of pesticide residues in soil is not carried out by any organisation (Environment Agency, 2000) although the Health and Safety Executive samples vegetation and soil in support of enforcement as part of its pesticide investigation role and the Control of Pesticides (Amendment) Regulations 1997.

Soil remains both the main sink and an important source of persistent organic pollutants (POPs) in the environment. In the case of PCBs, reductions and controls on the use of PCBs since their manufacture was banned in the 1970's, means that re-volatilisation from the soil is now regarded as the major emission source of these substances to the atmopshere (Cousins and Jones, 1998; Sweetman and Jones, 2000).

9.4.3 Provision of a platform

Not considered relevant.

9.4.4 Support of ecosystems, habitats and biodiversity

Heavy metals

There is little or no direct evidence that diffuse heavy metal pollution has affected Welsh semi-natural habitats and biodiversity. Effects are normally found in grossly contaminated sites and possibly in the more intensive agricultural ecosystems. However, there is an increasing body of evidence that micro organisms are far more sensitive to heavy metal stress than soil animals or plants growing on the same soils (Giller *et al*., 1998). Enhanced heavy metal concentrations associated with applications of sewage sludge may affect the soil microbial biomass. Brookes and McGrath (1984) reported that microbial biomass was 50% smaller in sewage sludge amended soil than in adjacent soil with low metal content. Effects of Cd in sewage sludge have been noted on symbiotic nitrogen fixation (*Rhizobium*) (Obbard and Jones, 1993) whereas other studies on *Rhizobium* in sewage sludge-treated soils concluded that Zn was the toxic metal (Chaudri *et al*., 1993). It is now clear that soil microbial communities are sensitive to metal toxicity and changes in biomass and community structure may occur at loadings close to currently accepted thresholds for sludge-treated agricultural soils (Giller *et al*., 1998).

Radionuclides

There is no evidence of an impact at the concentrations found in the wider countryside.

Pathogens

Pathogens will not thrive if there is strong competition from other soil-borne organisms (Killham, 1995). Manure from intensive rearing units and human sewage sludge is not permitted in organic systems (Soil Association, 1999). A biologically active soil reduces the risks of harmful organisms in manure surviving and being transferred to humans

Persistent organics

Inappropriate use of pesticides and in particular nematicides can have very negative effects on soil biodiversity and biological activity because of their poor selectivity. The herbicide glufosinate-ammonium has been shown to suppress soil bacteria and fungi activities up to 40% and 20% respectively (Ahmad and Malhoch, 1995). Organic farming systems restrict severely the use of pesticides. Organic farming systems can result in greater soil health (Reganold *et al*., 2001) and generally improved biological soil properties compared to conventional management (Glover *et al*., 2000).

Environment Agency (2000a) summarise the impacts of pesticides on invertebrates, including soil invertebrates such as earthworm and nematodes. Pesticides, it is concluded, have been shown to have variable effects on monitored species depending on chemical applied, crop type and timing.

9.5 The future situation

9.5.1 Heavy metals

Emissions of heavy metals from industry and other sources are heavily regulated, under a variety of legislation. Regulation is likely to be tightened further under a variety of EU proposals (see section on policy responses). Consequently, deposition to and subsequent immobilisation in soils should decline in line with emission reductions. There will remain considerable uncertainties over deposition rates, and critical levels and loads to upland soils. Many soils contain concentrations of heavy metals higher than the limits proposed by the EU, as a result of historical deposition (see section on policy responses). Since depletion rates from soils are slow, higher than desirable concentrations will prevail for many years.

9.5.2 Radionuclides

It is hoped there will not be any significant releases of radionuclides in future.

9.5.3 Pathogens

Application of sewage sludge to land is expected to increase and consequently the risk of pathogen contamination may increase. On the other hand, applications of untreated sludge will cease and a variety of sludge treatments are in use. Further research is under way to assess the effectiveness of these treatments (see policy responses).

Perhaps the main issue of concern with regard to pathogens is the cycle of contamination and re-infection which may occur on farms where a herd or flock become infected. Re-use of accumulated sludge or manure produced on farm presents a considerable risk of re-infection, since survival of many of the contaminating organisms may be several months in soil.

9.5.4 Persistent organics

Many of the persistent organic compounds enter soil from sewage sludge and other agricultural and industrial wastes. As already discussed, sewage sludge disposal to land is likely to increase, and the potential for persistent organics to reach soil should also increase. Although in low concentration in sludge, they will significantly elevate levels in the soil, where their fate and rate of breakdown are uncertain. A range of processes is employed to treat sludge, primarily with the objective of reducing pathogen concentrations before land spreading. The effects of these processes on organic compound concentrations is currently mostly uncertain.

9.6 Policy responses – Present and future

9.6.1 Aerial deposition

Regulations are already in place in the UK that control and reduce emissions to air, land and water. Existing processes involving lead, cadmium or mercury are covered by Integrated Pollution Control under Part I of the Environmental Protection Act 1990. The Pollution Prevention and Control (England and Wales) Regulations 2000, implement the European Directive on Integrated Pollution Prevention and Control (IPPC), which controls emissions to air. IPPC is a regulatory system that employs an integrated approach to control the environmental impacts of certain industrial activities. To gain a permit, operators have to show that:

- their proposals represent best available techniques (BAT) to prevent and minimise pollution
- that no significant pollution is caused

As part of the assessment, the operator has to show that there are no significant off-site impacts on receptors including any from deposition of emissions from air to land. The Environment Agency is developing the Horizontal Guidance Note (IPPC H1) – Environmental Assessment and Appraisal of BAT to assist operators in making such an assessment (this is out for consultation at the moment). One of the difficulties in making such assessments is the lack of information or environmental benchmarks that can be used to assess the potential impacts on soils. Critical loads for acidification are an exception. Clearly, research is required in order to develop better tools that can be used to assess the effects of pollutant deposition on soil systems.

Other relevant current and future EU controls on emissions include the Waste Incineration Directive and Revised Large Combustion Plant Directive, Water Framework Directive and Fourth Air Quality Daughter Directive. DEFRA, in collaboration with the devolved administrations in the rest of the UK, is seeking views (4th April 2002) on a draft strategy to implement the 1998 UNECE Heavy Metals Protocol to the 1979 convention on Long Range Transboundary Air Pollution. This Protocol deals with Cd, Pb and Hg, and the reduced emissions required have already been achieved under existing legislation.

Existing legislation is already reducing emissions of heavy metals, and consequently atmospheric deposition to soils. Future legislation will undoubtedly reduce this further. The outstanding question, however, is to ensure heavy metal content of soils are not so high that they affect the soil microbiological community and consequently biologically–mediated processes in soils. Many of the heavy metals in soils accumulated there when emissions were much higher, or inputs from wastes less regulated. This is born out on recent work on critical levels, or concentrations, in upland soils which are exceeded for Pb over much of Wales (Ashmore *et al*., 2001a; 2001b).

Discharges, emissions and losses of Cd, Pb and Hg will be regulated under the Water Framework Directive (2000/60/EC) which by 2003 should be transposed into UK law. Within each river basin, the ecological conditions of surface waters and contamination of ground waters will need to be assessed. Measures implemented under this Directive will undoubtedly bring benefits to soils and waters.

All radioactive discharges in the UK are regulated under the Radioactive Substances Act 1993 to ensure that radioactivity discharged remains well within internationally agreed levels which are designed to protect both human health and the environment. Such regulation is carried out by the Environment Agency (EA) in England and Wales, who, with the Department of Health (advised by the Food Standards Agency) conduct regular surveys of the UK terrestrial and marine environments to check that discharges are within the appropriate limits.

The UK Government is committed to progressive and substantial reductions in radioactive discharges. On 21 June 2000 the DETR published for consultation a draft UK Strategy for Radioactive Discharges (DETR, 2000a). The consultation period ended on 22 September 2000. The UK Strategy will implement the OSPAR*[3] Strategy for Radioactive Substances which was agreed at the 1998 meeting of the OSPAR Commission in Sintra, Portugal. The OSPAR strategy requires that, by the year 2020, discharges and losses of radioactive substances are reduced to levels where the additional concentrations in the marine environment above historic levels, resulting from such discharges, emissions and losses, are close to zero. DETR intend to publish the final version of the UK Strategy in spring 2001. The UK Strategy consultation makes no mention of deposition to soils, but any reductions in emissions must be regarded as beneficial to all components of the environment. Besides, it is the accidental releases of radionuclides, again the case of Chernobyl, which has proved to be the main problem for Wales.

Following the review of the Chernobyl accident, the UK Government published a National Response Plan to deal with the consequences for the UK of overseas nuclear accidents. The hub of this Plan is a network

[3] OSPAR – Oslo and Paris Commission, Contracting Parties to the 1992 Convention for the Protection of the Marine Environment of the North East Atlantic.

of 92 monitoring stations in the UK (9 in Wales) designed to detect overseas accidents (and presumably any nearer to home).

9.6.2 Sewage sludge

Use of sewage sludge is regulated by the Sludge (Use in Agriculture) Regulations, 1989 (as amended) (HMSO 1990) and supported by a complementary Code of Practice (DoE, 1996). Both Water and Soil Codes (MAFF 1998a; 1998b) provide guidance and MAFF have also published a leaflet on sewage sludge use (MAFF, undated). Applications of sewage sludge should not result in soil concentrations higher than laid down in the Regulations, but these levels will need to be lowered to conform to future EU legislation. Tir Gofal agreement holders are expected to manage their land in accordance with the Codes of Good Agricultural Practice for Air, Soil and Water (CCW, 1999). These farmers are not prevented from applying sewage sludge (or other fertilisers and 'wastes'), potentially containing heavy metals, to their intensively managed land. However, semi-improved or unimproved habitats in Tir Gofal should in general receive no fertiliser (organic or inorganic), except for certain grassland types where farmyard manure may be applied at 10 tonnes/ha every other year.

Use of sewage sludge in forestry is restricted to certain types of site due to the risk of contaminating surface runoff and groundwater (Forests and Water Guidelines, Forestry Commission, 2000). Sludge must only be applied in forestry to redress infertility problems and where it will not have detrimental effects upon wildlife conservation and other environmental values (Forests and Soil Conservation Guidelines, Forestry Commission, 1998). Statutory limits associated with sewage sludge application in forestry must be conformed with, and guidance is provided in the Manual of Good Practice for the Use of Sewage Sludge in Forestry (Forestry Commission, 1992). These limits are the same as in the Sludge (Use in Agriculture) Regulations (HMSO, 1990).

Revision to the sludge regulations in England and Wales was expected to come into force on the 1st January 2002 but has been delayed pending a further consultation. It is hoped that the new changes will be in force by early 2003. Even so, most of the changes affecting landspreading that would have been introduced in January 2002 are likely to remain unchanged. These changes have the support of the water companies and all of them are already operating as though the new controls are already in place. The changes that the water companies have already made are:

- the Safe Sludge Matrix is incorporated into spreading controls
- Sewage treatment plants have to have Hazard and Critical Control Point monitoring (HACCP monitoring) in place in order to ensure that the treatment process is successful in reducing pathogen counts. The new regulations will require that at least a 2 log kill (99% reduction) is achieved for E. coli*. From 1 Jan. 2002 to 31 Dec. 2003 there will be minimum final product standard for treated sludge of 10^5 colony forming units (CFU) of E. coli per gram dry solids on a 90 percentile basis, with a maximum allowable concentration (MAC) of 10^7 CFU per gram dry solids. From 1 Jan. 2004 this will change to a MAC of 10 to the 5 CFU per gram dry solids.

  (* e. coli is used as an indicator for the presence of other pathogens – the kill levels therefore indicate reduction in other pathogens)

Water UK and the British Retail Consortium have also agreed that the spreading of untreated sludge on food crops will cease and that the spreading of untreated sludge on fields growing industrial crops will be phased out by the end of 2005.

Such treatments have importance with respect to implementation of the Safe Sludge Matrix and will reduce the pathogen contamination of soil.

The Agency also hopes to have a charging scheme in order to recover costs involved in registration of sludge spreading which will help provide additional resources to help regulation of sludge spreading.

The Sludge Regulations contain metal limits that protect plant/crop health or limit uptake of metals. Although this provides some degree of soil protection, they do not explicitly protect soil health. DEFRA, WAG, EA and UKWIR are looking into the effects of metals in sludges on soil microbial activity and long-term soil fertility. As discussed earlier, the revised sludge regulations in England and Wales will introduce measures that will reduce the contamination of soil by pathogens and the new European Union directive on sludge expected in 2003 is likely to include limits on organic contaminants.

The current European sewage sludge directive (86/278/EEC) does not take any organic pollutant into consideration but five member states (excluding the UK) put limit values on some organic pollutants in sewage sludge for direct land application (Devoldere *et al*., 2001). During 2003 the European Commission will undertake a revision of the Sewage Sludge Directive, and currently have issued a Working Document on Sludge (EU, 2000) for consultation. The Working document presents limit values for concentrations of heavy metals and organic compounds in sludge for use on land. The organic compounds include dioxins, PAHs and PCBs, but the scientific basis for setting the limits proposed is not stated. However, the Working Document specifies that "The use of sludge shall be carried out in such a away as to minimise the risk of negative effects to ……..the long term quality of the soil, and the biodiversity of the micro-organisms living in the soil." Once implemented, the Revised Sewage Sludge Directive should provide additional protection to the soil, though continuing assessment of its effectiveness is essential and strict regulatory framework is needed to ensure its proper implementation and policing.

The EU review (EU, 2002) of the provisions contained in the 1986 CEC Directive (86/278/EEC), on the protection of soil when sewage sludge is used in agriculture, may propose lower limits for heavy metals. These are shown in Table 8.4 together with 1986 limits and median values for Welsh soils in 1978-82 (Loveland, 2002, personal communication).

Table 9.4 Current (CEC, 1986) and proposed (EU, 2002) EU maximum concentrations in soils, and median values for Welsh soils (Loveland, 2002 pers comm.).

	CEC, 1986	**EU, 2002**			**Wales 1978-82**
	Soil pH 6-7	**pH 5-6**	**pH 6-7**	**pH>7**	
Cd	1-3	0.5	1	1.5	0.8
Cr	-	30	60	100.0	43.7
Cu	50-140	20	50	100	18.7
Pb	50-300	70	70	100	51.5
Ni	30-75	15	50	70	21.0
Zn	150-300	60	150	200	840
Hg	1-1.5	0.1	0.5	1	0.07*

*mean

Considering that the values for Wales are medians, it would appear that a significant proportion of Welsh soils contain higher concentration of Cd, Cr, Pb, Ni, Zn and Hg than the proposed new EU limits, especially as so many Welsh soils are acidic.

9.6.3 Landspreading of industrial wastes

The landspreading of industrial wastes on agricultural land is controlled by the Waste Management Licensing Regulations (1994) and is covered by paragraph 7 of schedule 3 of the regulations. Under paragraph 7, only certain specified, 'exempt', waste types can be spread and these wastes can only be spread if an agricultural benefit or ecological improvement results and no more than 250t/ha (5000t/ha for dredgings) is spread in any 12 month period. Any landspreading activity must also meet the relevant objectives that:

"waste is recovered or disposed of without endangering human health and without using processes or methods which could harm the environment and in particular without –

i. risk to water, air, soil, plants or animals; or
ii. causing nuisance through noise or odours: or
iii. adversely affecting the countryside or places of special interest"

The introduction of the Landfill Tax in October 1996 and implementation of the Landfill Directive, which aims to reduce the amount of biodegradable waste going to landfill, is likely to lead to an increase in the amount of waste spread on land and hence the pressure on the soil resource.

The controls within paragraph 7 and the relevant objectives should protect soil from being damaged or contaminated by waste spreading; however, in practice, this is not always the case. Accusations that paragraph 7 and other exemptions are being abused was investigated by the House of Commons Select Committee on the Environment, which commissioned research on the use of the exemptions (Ecotec, 2000). One of the main problems is that many of the regulations are open to interpretation of the definitions of allowed waste types and especially, the definition of agricultural benefit and ecological improvement. Allied to this, the regulations do not state the kind of information that should be provided in order to support a claim for benefit: leading to confusion and lack of clarity for both operators and regulators.

Many stakeholders believe that the regulations are in urgent need of revision in order to clarify many ambiguities and afford better protection of soil and the wider environment. The Ecotec report made several recommendations including:

- the need for a charging scheme in order to provide additional resources for the Environment Agency to make better assessment of proposals
- tighter specification of quantities and types of waste that can be spread
- greater time with which to assess an exemption application (currently the regulations do not specify a time interval and operators only have to give a few hours notice). This will allow the Agency to undertake a proper assessment of environmental impact as a pre condition of granting an exemption rather than it simply recording them as a matter of right.

The Environment Agency has also suggested that the regulations should include a tighter definition of agricultural benefit and ecological improvement.

9.6.4 Agricultural sources

Nearly six million tonnes of animal matter waste and by-products were produced in Wales in 1998 (Environment Agency, 2001) and it is unlikely this figure will change significantly in the near future. Widespread adoption of Tir Gofal may result in an overall reduction in animal numbers in Wales, with a corresponding decline in the amount of waste produced.

Manures and sludges produced and re-used on-farm also may contain pathogens. These on-farm wastes are not regulated, and the extent of any contamination is generally unknown, although it is reported (Jones, University of Wales, Bangor, personal communication 2002) that *E. coli* O157 infection may occur in as much as 30% of cattle herds in some parts of the UK. Use of these on-farm wastes presents a particular problem for farmers. Slurry and manure accumulated over winter from stock housed indoors needs to be spread on land in spring to ensure its fertilisation value is synchronised with the period of active grass growth. However, animals will need to be turned out as early as possible to take advantage of the early growth. The time between spreading and grazing will be compressed, especially if it is not possible to 'get onto the land' to spread the slurry or manure early because of wet soil conditions. The period between spreading and grazing is unlikely to be long enough to ensure pathogen numbers decline sufficiently to ensure that no re-infection takes place.

The Food Standard Agency (FSA) has an ongoing programme of research to assess the prevalence and survival of pathogens in farm manures and subsequent potential risks to food safety. FSA (FSA, 2002) guidelines aim to reduce the risk of pathogen contamination of food following spreading of manure or grazing by livestock, and ADAS are conducting research on the survival of pathogens from manure applied to soil.

The Feeding Stuffs Regulations 1991 control the amount of additives such as trace elements (heavy metals) that can be added to feedstuffs. This therefore controls the amount of metals such as Cu, Zn, Cr etc. that can enter soils from livestock manure. Controls on the use of such additives are currently being reviewed in Europe and are expected to tighten them further.

The Groundwater Regulations 1998 allow land to be registered as a sacrificial site for the disposal of a substantial number of toxic and persistent chemicals including waste agro-chemicals such as sheep dip. These regulations are intended to protect groundwater but do not consider the impacts on soil function.

The expected revision of the Bathing Waters Directive might contain stricter controls on the levels of pathogens in bathing waters, which could have important implications for waste spreading and in particular for livestock manures. The revised directive will 'look at…..actively tackling pollution sources, in particular waste water discharges and agricultural run-off' (CEC, 2000). Implementaion of the revised Bathing Waters Directive will be well on track before the first deadlines of the Water Framework Directive.

Composting of garden and food waste is a priority in the Wales Waste Strategy (NAW, 2001). However, in 2001 animal health legislation (Animal By-Products Order -ABPO) was amended with the effect of making it an offence to, inter alia, allow livestock to have access to catering wastes or compost produced from them. Catering waste includes any food or kitchen waste from households. This measure is aimed at preventing the introduction and spread of animal diseases such as Classical Swine Fever and Foot and Mouth, which could potentially be present in infected meat in catering waste.

The Environment Agency has been supporting the work of the Waste and Resources Action Programme [WRAP] who are looking to produce standards for composting, including a high quality compost that can achieve a British Standard. The Environment Agency released a guidance note to its staff on the implications of the amended ABPO upon composting and landspreading. Research has been commissioned by DEFRA to determine the level of risk such waste activities pose to animal health, as well as human and plant health. The Environment Agency has also produced and recently consulted on its technical guidance document for composting operations (EA, 2001c) and they hope to publish the document, which will be an essential reference source on the regulatory and technical aspects of composting, in summer 2002.

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10. GROSS CONTAMINATION OF SOILS

Summary

- A 1988 Welsh Office report suggested that there were 749 potential sites, covering more than 4,000 ha of 'legacy land contamination' in Wales. Clean-up has occurred over the last two decades of a large number of sites. However pockets of 'legacy contamination' do still exist.
- The present scale of current contaminated land in Wales is not explicitly known and the lack of available information quantifying the degree of, and extent of land contamination is therefore a concern.
- Pressures on sustainable soil use exist from both historic and present negative anthropogenic activity, particularly from traditional sources of industrial activity.
- However loss of greenfields due to development, excessive production of waste from industry, commerce and households, and the impact of illegal waste disposal and litter from accidental, or unlicensed disposal all add to the pressures on the sustainable soil use in Wales.
- Although in their infancy it is believed that the three-pronged approach to regulating land contamination through Planning, PPC, and Part IIA will provide an effective control in the future. Via these instruments, land contamination should decline in the future and, although it will never be eradicated, should eventually become manageable. In other words a balance between prevention and cure will eventually be achieved.
- In general terms therefore, soil sustainability must be considered in the context of end use, and appropriate 'fit for purpose' levels of clean up implemented as and where necessary. The return of sites to virgin, pristine conditions is neither realistic nor necessary.

10.1 The current status of contaminated land in Wales

10.1.1 Background

The geology throughout the whole of Wales has historically been exploited for building stone, for slate from Preseli and North Wales, for iron ore, limestone, and coal from the south and the north-east, and for metals including lead, zinc, copper, and gold from mid and north Wales. All of these processes and the subsequent industrialisation of Wales have incurred significant land contamination across the whole of the country. These aspects are explored in this section from both the viewpoints of historic and modern sources of contamination. The latter section, specifically, outlines *potential* sources of contamination that exist from both ongoing and recent activity post industrial revolution.

This section deals only with gross aspects of land contamination, which are in general localised but widespread in Wales. Diffuse forms of pollution, such as aerial deposition and agricultural pollution including heavy metals, pathogens, persistent organic compounds are considered in Chapter 9.

10.1.2 Historic contamination

Mineral resources have been exploited in Wales since at least the Roman occupation with mining, processing and industrial development continuing ever since. Iron-smelting, for example, rose and declined between the sixteenth and nineteenth centuries in Wales, to be succeeded by the iron and steel, and tinplate industries (EAU, 1988). Around 1760 coke came into use for smelting and a chain of ironworks was built across the northern rim of the South Wales coal field, with similar smaller development also occurring in the Wrexham area of north Wales. By 1870 steel making had taken over and many of the smaller iron works had closed.

The slate of North West Wales was always regarded as high quality and available in extensive quantity, and although the total land area affected by slate extraction itself was always relatively small the waste materials generated were vast. At its peak in 1898, the North Wales slate industry produced over 500,000 tonnes of slate and was a major employer of over 16,000 men (NAW, 2001a).

The mining of lead copper and zinc in Wales boomed during the period of 1850 and 1910. However, the subsequent decline has led to the abandonment of many hundreds of mines throughout Wales (EAU, 1988). Refinements in the crushing and separation techniques for ore produced large amounts of fine-grained tailing around the mines operating from the nineteenth century onwards. These heaps have been particularly susceptible to wind and water erosion and their high metal content has caused many cases of environmental contamination (EAU, 1988).

Coal production, and its subsequent global export, increased dramatically during the Industrial Revolution particularly with the growth of the iron industry, which in turn led to the development of greater transport infrastructure of canals, railways, roads, and docks in what is today know as the Industrial South Wales Area. As the world wide demand for coal increased so did production and export. A record 13 million tons of coal was exported from Cardiff Docks alone in 1913 with Cardiff's Coal Exchange building setting the global price for coal and the location of the first £1 million deal (CHA, 2002).

The expansion of industry generally in this period and in particular coal mining created a demand for items such as cables, rails bolts etc, and many factories, foundries and small engineering works were established in the coastal areas adjacent to ports and steelworks.

The chemical industry in Wales also developed significantly in the nineteenth century in the manufacture of acid and alkali and the distillation of coal products. Initially acid and alkali production developed to satisfy the demands from the steel, tinplate, soap, glassmaking and fertiliser industries (EAU, 1988). Early works dating from around 1850 used certain methods for alkali manufacture that produced extensive waste heaps of calcium sulphide containing traces of arsenic residues. Further development of these works continued up to and including the 1914-18 war when several plants were set up to manufacture nitric acid which was required for explosives manufacture.

Although the establishment of major refineries and petrochemical industries in the south west coastline did not really start until the latter half of the twentieth century, there were industrial methods of oil-distillation in Wales much earlier. A small area of the North Wales coalfield south of Mold for example, supported a thriving oil-distillation industry as early as 1850 to 1900 (EAU, 1988). The carbonisation of coal in such a way produced a wide range of substances. But many of the collieries ceased such operations when mineral oil became more widely available in the twentieth century.

By the 1900 most towns in Wales possessed gasworks. The subsequent linking of towns by pipelines and purchase of gas from colliery and steelworks coke ovens led to the closure of many production sites (EAU, 1988). This continued well into the latter half of the twentieth century. South Wales was supplied by gas works at Cardiff, steelworks at Port Talbot and Pontypool, a gas-oil plant near Neath and four colliery coke oven plants. In the North, supplies were obtained from gasworks at Wrexham, Shotton Steelworks and Point of Ayr colliery.

10.1.3 Modern sources of contamination

Today the production of high-technology goods and a variety of service industries dominate the market economy in Wales, with tourism, driven by the outstanding wealth of cultural heritage and natural topography, providing a higher income per head of population than in England (1994 data) (EAW, 1999). This development provides changing environmental pressures, combined with the unavoidable industrial legacy of the Welsh past, and produces significant challenges to environmental sustainability in Wales. This section therefore outlines *potential* sources of contamination that exist from both ongoing and the relatively recent activity of the latter half of the twentieth century.

Urban

Urbanisation does not necessarily lead to forms of 'gross contamination' of the land. However there are a few notable examples. Typically urban developments today have two separate drainage systems. The first is provided to convey foul drainage and industrial effluents to a treatment facility, while the second is to accept clean, uncontaminated rainwater from roofs and paved areas. Surface waters from such areas are usually discharged directly into rivers and streams, or sometimes via soakaways into the underground strata. Such surface waters from both residential and urban areas become contaminated and can, as a result of current discharge principles, cause varying levels of contamination (EAW, 1999).

Oil and petrol tank leakage from both domestic and distribution depots such as petrol stations are additional known sources of severe contamination particularly where installations are old and badly maintained. Such sources of contamination can be quite severe with leakage occurring unnoticed for many years. Oils, rubbers and petroleum products from roads as well as sewage and dirty water from badly connected toilets and domestic appliances can also, for example, contaminate the land and drainage in residential areas. Road gullies can also be used for the convenient deliberate disposal of used engine oils, garden pesticide and washings for example. Urban areas are therefore vulnerable to continual pollution by accidental spillage and the deliberate disposal of unwanted liquids, solids and wastes.

Industrial

Industrial urban areas are often extensively contaminated with a wide range of polluting materials as a result of both current and past activities on site. Heavy transport movements, material handling, deliberate fly tipping, or accidental leakage are all causes of ongoing current localised land contamination.

The process of industrial change and the recent decline of some activities in large industry in Wales have created large areas of land which is derelict, and often contaminated, over the last 50 years. By the turn of the century the major steel works in Wales had been relocated to the coastal locations of Swansea, Llanelli, Briton Ferry, Port Talbot, Cardiff, Newport and Mostyn with most inland works shutting down. However, increasing production efficiencies and international over capacity in recent years have led to the closures of many of these Welsh works.

All piped gas production in Wales ceased when North Sea production commenced in the 1970's. About 130 municipal gasworks in 1988 (EAU, 1988) were retained for storage and used as depots but have subsequently fallen into decline or have been regenerated. Similarly electricity-generating stations have undergone processes of rationalisation in the latter half of the twentieth century and several of the older units have been closed and subsequently demolished.

Greater dependence in the latter half of the twentieth century on oil led to the establishment of 'new industry' in refineries and petrochemical plants on the south west coastline. Around the deep-water sheltered estuary of Milford Haven, which can accomodate large tankers, are many large, long established refineries and chemical plants. Smaller installations are found at Barry and Cardiff. Chemical works producing raw materials and finished plastics also exist today at many sites in both North and South Wales.

Radioactivity

Of the two nuclear power stations in Wales, only Y Wylfa on Anglesey is still operational. The other at Trawsfynydd in Gwynedd, is in the process of being decommissioned. Nycomed Amersham International at Cardiff, which incorporates radionuclides into pharmaceuticals for use in medical diagnosis and life science research, is also authorised to discharge radioactive waste by sewer into the Severn estuary. There are also many minor sources of radioactivity arising form industrial and medical uses such as non-destructive testing of materials, fire detection, level detection, medical diagnosis or therapy and scientific research. In 1998, 51 such establishments were authorised for the accumulation and disposal of low-level radioactive waste and another 314 were authorised for holding a radioactive source (EAW, 1999).

Extraction processes

Extraction of natural resources has provided raw materials for our society for a very long time in Wales, but their exploitation has created, and continues to create, significant pollution and damage to the natural landscape.

Although the slate industry declined rapidly throughout the twentieth century, current production levels in North Wales, being only a small fraction of what they once were, continue to account for 85% of UK output of roofing slate at about 30,000 tonnes per year. However, it is estimated that this industrial legacy has generated approximately 450-500 million tonnes of slate waste in Gwynedd alone, more than in any other UK authority (NAW, 2001a). Current research is being undertaken by the Welsh Assembly Government to determine the physical, commercial and planning restraints which are preventing the use of this material as an aggregate source. However it is recognised that in some cases the removal of the slate waste would be undesirable because of its ecological or landscape value, or because of disturbance to local communities or the environment.

Production of deep mined coal has also fallen dramatically, from 16 million tonnes in 1970 to approximately 2 million tonnes in 1993 (NAW, 2001a). Opencast production, having remained relatively unchanged for the last 20 years, was 2.5 million tonnes in 1994 and continues to remain a pressure on the landscape (EAW, 1999).

Other examples of extraction processes in Wales include 400,000 tonnes per year of clay and shale in Gwynedd and Flintshire, approximately 900,000 tonnes of limestone extracted and used for iron and steel manufacture, and 24,000 tonnes of silica sand in Denbighshire and Flintshire (NAW, 2001a).

In general mining and smelting of non-ferrous metal ore has ceased in Wales and most sites are now either derelict or have been redeveloped. Related industries, including the smelting and refining of arsenic, nickel, aluminium and cobalt, however, continue at several locations to the present day.

Unfortunately both managed and abandoned mines have left a legacy of pollution issues, most notably in their spoils, continued water pollution from mine drainage, and land contamination (EAU, 1988). Contaminated discharge problems for example still exist, with some 150 such discharges from coal mines, and about 1,300 abandoned metal mines known to be polluting streams and rivers in Wales (EAW, 1999). In response to these problems the Environment Agency has recently produced a report which outlines a 'Metal Mines Strategy for Wales' (EAW 2002) which explores strategies for future development and site management options relating to these issues.

Leachates from spoil heaps may often be acidic and have high concentrations of heavy metals, but nevertheless in some cases have conservation value by providing habitats for rare acid and metal tolerant plants (CCW, 1999).

Waste

Throughout the UK, waste is typically categorised in relation to its source and to relevant legislation. Certain wastes are deemed to be 'controlled wastes' under legislation regulating the production, handling and disposal of waste (NAW, 2001b). Controlled wastes are categorised into household, commercial and industrial waste. Construction and demolition waste is part of the controlled wastes but is often reported separately because of its significance in terms of quantities produced.

Recent figures indicate that approximately 11 million tonnes of controlled waste is produced annually in Wales of which around 4 million tonnes is landfilled (NAW, 2001b). Unfortunately only 5% of the 1.5 million tonnes of municipal waste produced annually in Wales is recycled. The other 95% is sent directly to landfill. Consequently Wales has one of the lowest municipal waste recycling rates in Western Europe, and a much lower rate than either the USA or Canada. Based on British averages, the construction industry is the largest source of controlled waste in Wales, with approximately 40% either re-used or recycled in 1996, commonly as foundation material and for land reclamation.

Currently excluded from control are the 4 million tonnes of agricultural waste and 5.5 million tonnes of mining and quarrying waste produced in Wales each year. These sources are therefore very significant in comparison to the production of controlled wastes, and so it is likely that their current exclusion from control will be changed in the near future (EAW, 1999).

Sewage sludge and radioactive wastes and explosives are currently regulated under other specific legislation.

A further category of waste used is that of 'special wastes' which describe that which is deemed potentially damaging to human health or the environment and are controlled under the Special Waste regulation 1996. In 1997/98 for example after imports and exports, it is estimated that about 400,000 tonnes of special waste were retained for disposal or recovery in Wales.

Wales continues to have an over reliance on landfill with respect to its waste management (NAW, 2001b). Whilst landfill might be the best/only option for some wastes, landfilling can lead to a variety of environmental problems. A significant impact of landfill on soil quality is from the production of leachate, a liquid that may contain a wide array of pathogens and chemical pollutants (EAW, 1999). In the past landfilling was based on the principle of ‘dilute and disperse’ and very little or no control was placed on leachate generation and leakage. The extent of soil contamination from landfill sites is unknown. However it is recognised that leachate from landfill sites can significantly alter soil characteristics and making it anaerobic. Leachate is contained within modern landfills by impermeable membranes and is sometimes treated on site, tankered away to sewage treatment works, recirculated though the landfill or sprayed on nearby land.

10.2 The extent of contaminated land in Wales

The total amount of land that is currently contaminated or would be considered contaminated under the current legislation in Wales is, at present, unknown. There are limited quantifiable records, but those that are available are both restricted in their consideration and relatively out of date.

The most recently available documentation on the extent of land contamination in Wales is a survey published in 1988 by the Welsh Office (EAU, 1988). At that time the survey identified 749 *potentially* contaminated sites across Wales covering more than 4,000 hectares. Unfortunately this desk survey did not include those sites that were considered in active use nor those which covered less than 0.5 hectares. No direct field sampling or analysis was conducted on any of the *potentially* contaminated sites listed.

The survey therefore excluded a large number of areas, and in particular those that were then actively being contaminated. The report also acknowledged that, even in the time taken to complete the report, details of some identified sites would have changed due to redevelopment, and new sites would need reporting as a result of industrial closure and change.

It is likely therefore that there have been many more changes in the data between 1988 and the present day, and that many more sites of actual contamination exist than those 749 *potentially* contaminated sites and the estimated 4,000 hectares of the 1988 report.

These next sections cover the limited information which is available for derelict land, authorised pollution and active landfills as well as the extent of contamination as reported in the 1988 Welsh Office report.

10.2.1 Extent of contamination in 1988

Unsurprisingly, the 1988 Welsh Office report identified that the industrial south Wales regions of West Glamorgan and Mid Glamorgan, as they were then, accounted for the largest number of contaminated sites in Wales with 27% and 20% respectively. Gwent, Dyfed and Clwyd accounted for the 12 to 14% each.

West Glamorgan was reported as having the largest area of potentially contaminated sites in Wales. This was largely composed of land in the Lower Swansea Valley. Over half of the contaminated land in Mid Glamorgan occurred in the district of Merthyr Tydfil but presented very little problems in terms if environmental pollution. The areas and numbers of sites in the then Dyfed, Gwynedd and Powys, were largely due to metalliferous mine working in the districts of Ceredigion, Aberconwy and Montgomery respectively. Clwyd had a mixture of contaminated land, derived largely from mine sites in Delyn and a steelworks in Alyn and Deeside. Finally Gwent had a variety of sites in Newport and on the coal field in Blaenau Gwent and Torfaen.

The survey also identified that Clwyd had a disproportionately high number of hazardous and priority sites including chemical works, a steelworks, lead mine tailings dams and gasworks in the districts of Delyn, Alyn and Deeside and Wrexham Maelor. Mid Glamorgan also had a number of coke ovens and hazardous waste tips, particularly in the district of Taff-Ely and Rhymney valley.

It is anticipated that the degree of contamination is much more widespread than that indicated by the 1988 Welsh Office report and is predominantly formed from both the legacy of Wales's industrial past and its subsequent decline in recent years.

10.2.2 Derelict land

A survey in 1988 identified about 10,900 hectares or about 0.5% of land in Wales which it would class as derelict (EAW, 1999). It should be noted that derelict land does not necessarily mean sites that, under statutory definition, include contaminated land. The Department of the Environment's definition of derelict land is: ‘land so damaged by industrial or other development that it is incapable of beneficial use without treatment’. This damage would include land containing obstructions to development such a buried foundations that would require treatment. Primary sources of derelict land are abandoned mining areas, and others include redundant industries and railways. These sites may contain physical hazards such as shafts, holes, tanks and tunnels or chemical hazards that may present considerable risks to people. But derelict land also includes abandoned and unoccupied buildings in an advanced state of disrepair. Land damaged by development, which has been restored for agriculture, woodland or other open countryside use is typically excluded.

It should also be noted that the definition of derelict land can exclude a wide range of contaminated land-uses, including that which is contaminated but still in active beneficial use. Additionally, whilst derelict land sites might not necessarily be considered contaminated under statutory definition, a degree of contamination might be present which might affect the potential land use in the future.

Areas of continued dereliction are both unsightly and often pose hazards to humans and the environment. From the 1988 survey, 28% and 24% of the 10,900 hectares were in Mid-Glamorgan and Gwent respectively, and reflected the industrial and coal mining history of these areas. Three-quarters of this derelict land required major reclamation work with the rest needing only low-cost enhancement with vegetation. Subsequent reclamation programmes between 1988 and 1996 have successfully developed approximately 4,800 hectares leaving about 6,000 hectares outstanding (Welsh Office, 1997). Since then, reclamation in Wales has proceeded at an average rate of 330 hectares per year, most of this in south east Wales (Environment Agency, 2002). The remaining areas of dereliction are considered a waste of land resources, and therefore clean-up remains important.

10.2.3 Authorised discharges

All industries are currently subject to IPC legislation and as such require ‘authorisation’ for discharge of controlled pollutants to surface waters, emissions to the atmosphere and disposal of waste to the land (EAW, 1999). These *authorisations* are issued under The Environmental Protection Act 1990, but significant discharges from other sources require a 'consent' under the Water Resources Act 1991. These latter *consents* define the limits for the type and quantities of substances in the effluent such that *significant harm* does not occur.

There are currently 180 *authorisations* for major industry in Wales and about 1,480 *consents* for discharges (EAW, 1999). Of these *consents* 46% are from a variety of industries and 54% are from sewage treatment works. It should be noted that sewage treatment works not only treat domestic sewage but may also be required to treat industrial discharges, particularly since in Wales there are currently about 900 trade effluents consented to discharge directly to sewer (EAW, 1999).

A new regulatory regime is currently being phased in, however, which will eventually replace IPC. The Pollution Prevention and Control (England and Wales) Regulations (PPC Regulations) came into force in August 2000 and is being introduced gradually on a sector by sector basis between 2000, and 2007.

10.2.4 Landfills

Available information indicates that in 1987/88 there were 1,200 closed landfill sites in Wales, over half of which were in the south-east (EAW, 1999). Groundwater pollution linked to contamination of the land in Wales was predominantly linked to the chemical industries, iron and steel works, and gasworks. Such examples of soils and groundwaters were often contaminated with a wide range of metals, solvents, fuel, pesticides and other organic and inorganic chemicals.

There are currently 112 active landfill sites for the disposal of controlled wastes in Wales (NAW, 2001c). Of these, seven are co-disposal landfills that accept small quantities of special waste along with household, commercial and industrial wastes; 19 take biodegradable household waste commercial waste and industrial waste, 67 take inert waste only, and 19 are restricted access sites for 'single factory' waste only.

A small number of current landfill sites give rise to a significant number of public complaints. One of the most serious started in 1989 at the Heyope site near Knighton in Powys, which contains about 10 million tyres. The fire caused polluting substances such as oils and phenols to enter a nearby watercourse, which in turn affected the River Teme. Action was taken to suppress the fire but it is still burning underground and the environmental effects are being closely monitored (EAW, 1999).

10.2.5 Metal mines

Metal rich rocks have been extracted in Wales on a near continuous basis from pre-Roman times. The last recorded metalliferous extraction in Wales took place at Gwynfynydd Gold Mine, which ceased production in 1998. This long period of industrial activity has left an indelible mark on the landscape of Mid and North Wales. The land contamination associated with these former metal mining areas consists of numerous spoil heaps of excavated host rock, spoil heaps of waste process materials which are high in metals, adits and shafts, and various derelict structures including processing areas, power houses and drainage channels. The number of actual mines and mining sites in Wales is extensive with the Environment Agency's databases holding records for over 1,300 mine sites where discharges to watercourses are known to occur (EAW, 2002).

In many instances metal mine sites in Wales present significant point sources of water pollution and locations of land contamination due to the abandoned workings, contamination of the localised area and spoil heaps. There have also been cases of metal-rich dust from old spoil heaps presenting a risk to human health through inhalation and ingestion by local population (EAW, 2002). However at the same time these sites can provide valuable habitats that allow the development of unique ecosystems, with a number of mine sites having been designated Sites of Special Scientific Interest.

10.2.6 Coalfields

The South Wales valleys are particularly badly affected by coalfield dereliction due to the high density of former mines and the local topography. Due to the scarcity of flat land, spoil heaps are often sited on steep valley slopes. Additional factors in such areas are mineshafts, mine openings from hillside adits, underground voids, and coal content of the tipped spoil. All of these factors need to be addressed in the investigation of sites and the preparation of reclamation and afteruse proposals.

Former colliery and tip sites continue to be reclaimed predominantly by the Welsh Development Agency (WDA) and Coal Authority and have removed hazards, created heritage and tourism opportunities, and removed acute visual blight. These changes have allowed them to create new roads, road improvements, recreation areas, railways, country parks, cycleways and amenity areas as well as new development land.

The WDA has, for example, been very successful in removing the blight of coalfield dereliction throughout Wales, the majority of colliery sites reclaimed under their Land Reclamation Programme having been acquired by Local Authorities from British Coal. The WDA believe that of the total £390m spent in reclaiming approximately 7,800 hectares since its inception in 1976, approximately 50% has been on coalfield reclamation alone.

10.3 Impact on soil functions

Land contamination, particularly where that contamination is high, has serious negative effects on all soil functions. Contamination can, at its worst, affect the soil to such a degree that it can destroy the soil's ability to sustain any of those functions under consideration.

10.3.1 Environmental interaction

Soil quality can be severely affected by land contamination. Both current and historic industry and manufacturing activities, the abandonment of land, build-up of toxic chemicals and heavy metals in soils can have very serious adverse effect on the soil quality and resulting environment. Both spillage and unregulated disposal of chemicals and waste to the land can cause significant loss to the environment, thereby affecting all soil functions. In extreme cases land contamination can cause the virtual sterilisation of the soil making it devoid of any environmental function for biomass, food and fibre production. In these instances very little, if any, support is then possible of ecosystems, habitats and biodiversity. In many instances of contaminated land in Wales the soils and groundwater are contaminated from a wide range of substances from metals, solvents, fuel, pesticides and other organic and inorganic chemicals. However many of these sites can be brought back into use after remedial treatment.

10.3.2 Provision of a platform and of raw materials

In most cases of severe land contamination, especially where environmental or human health considerations are necessitated, this function is virtually eliminated until sufficient clean up has been completed.

10.3.3 Biomass, food and fibre production

Contaminated land can have severe adverse effect on these soil functions. Chemical contaminants can be taken up through the soil to the plants and animals and through the food chains. The impact of the contamination however is dependent not only on the type and concentration of the contamination, but also on existing soil properties, which will affect both the mobility and persistence of the contaminant.

10.3.4 Support of ecosystems, habitats and biodiversity

Quarries, and mines have in some cases severely damaged and sometimes destroyed habitats in Wales. However some sites, as in the cases of some abandoned mines and derelict land sites, have shown changes to this function which now make them unique. Some sites now support ecosystems, habitats and biodiversity which otherwise would not be available in the area. Whilst these changes are due to anthropogenic disturbance and pollution, there are occasionally benefits where unique features have developed and there has been subsequent designation as SSSI's.

10.4 Constraints on the use of contaminated land

Land contamination, or the possibility of it, is a material planning consideration under the Town and County Planning Act 1990 and can impose significant constraints on the use of land. This however also offers opportunities to secure environmental benefits during the planning process and can effect land cleanup and future contamination potential. Sites already causing pollution, public health or nuisance are governed by the regulatory authorities of the Environment Agency or Local Authority, and may require direct intervention to ensure that action is taken to cease, mitigate and reduce the current land contamination (Environment Agency, 1999).

Throughout Wales it is the local planning departments which predominantly determine future land use, and a precautionary principle is being applied, especially where scientific knowledge is not conclusive, for redevelopment and consent for re-use of contaminated land. A risk-based approach to managing contaminated land has therefore been adopted in the UK is set out in the UK Framework for Contaminated Land (Department of the Environment and Welsh Office, 1994) (ETL, 2002). Under this approach, in order to determine the extent of land contaminated for a particular site, the existence of ‘pollutant linkage’ must be established. This involves a method of risk assessment known as ‘Source – Pathway – Receptor’, and is typically the main starting point in the identification and assessment of contaminated land. The principle is that a contaminant source must be linked together with both a pathway and a receptor in order for a piece of land to be considered as contaminated. This concept is outlined in detail in the National Assembly's guidance to enforcing authorities, under Part IIA of the Environmental Protection Act 1990, entitled ‘Remediation of Contaminated Land’.

However the contaminated land industry as a whole is relatively new and whilst it is developing fast, detailed scientific knowledge and understanding of 'pollutant linkages' is still limited. There is concern that whilst the Part IIA regime requires the recognition of a large array of statutory receptors as part of the risk assessment some of these receptors do not yet have adequate assessment criteria. Additionally, the exclusion from control under Part IIA of some receptors and the degree to which harm applies to receptors not considered 'likely' to be present, either now or in the future, is also of concern. The nature of contaminants found can vary considerably and it is not always possible to predict the exact behaviour of these contaminants. Further research, information and guidance is required in these areas, to not only include the direct and indirect pathways for contamination but also adequate assessment criteria for the non-human receptors considered under Part IIA.

DEFRA is currently in the process of preparing a new set of guideline values, whose main purpose is to establish whether a site poses actual or potential risks to human health, in the context of the existing or intended usage of the site (Contaminated Land, 2002). This, along with the principle of risk assessment methodology, has been used to develop CLEA (Contaminated Land Exposure Assessment). The advantages of CLEA-derived guidelines are:

- they are based on risk assessment
- they specifically provide for uncertainty
- they provide an objective basis for decision making

New development on brownfield' land is actively being encouraged by Westminster, which has established a target for England of 60% of all new houses to be built by 2016 shall be on brownfield sites (EAW, 1999). Unfortunately no such explicit targets for Wales have been established. This may add to a reluctance to use Welsh brownfield sites in future land development. However new legislation, from both national and EC initiatives, is driving the control of future development and potential contamination through the planning processes, with modification and extension of past Integrated Pollution Control regimes to new Pollution Prevention and Control (PPC) legislation.

Unfortunately the technical skills required to deal with land contamination issues are extremely wide ranging, requiring a vast array of stakeholder groups and professions. It is felt that the degree to which land contamination affects the whole array of stakeholders has not yet been widely appreciated. Neither too have all the professions potentially involved ensured that they are adequately 'up-to-speed' with the required technical aspects and the framework under which these sites need to be considered and addressed. Many stakeholders have been reluctant reactionaries to land contamination issues in the past and much of this will inevitably delay the future effective use, remediation and regeneration of contaminated land sites.

In recent years Westminster has started to actively promote contaminated land remediation through its support of CL:AIRE (Contaminated Land: Applications In Real Environments) a public-private partnership that aims to demonstrate and promote the use of more sustainable remediation technologies in the real world. The Environment Agency, DEFRA and Forestry Commission also have research and public programmes aimed at developing techniques for, and promoting best practise in, the investigation, assessment and remediation of contaminated land. These are in addition to other projects run by other organisations such as, for example, Contaminated Land Rehabilitation Network for Environmental Technologies in Europe (CLARINET), the Construction Industry Research and Information Association (CIRIA) in the UK, and the Land Regeneration Network (LRN) here in Wales.

Unfortunately however, the cost of treating contaminated land can be very significant in relation to other development costs, particularly when considered against the future market value of the restored site (EAW, 1999). Until relatively recently grants were available for such work from the DoE's Derelict Land Grant, Urban Development Grant, and until 1999 DETR's Contaminated Land Fund. In Wales some limited grants are available under a number of schemes such as the Urban Investment Grant and Land Reclamation grants via the WDA. It is also anticipated that the European Structural Funds in Wales have and will be used to remediate and regenerate some contaminated and derelict sites. However the lack of substantial financial assistance is potentially a significant constraint at both current and future sites and will act as a considerable disincentive to clean up, redevelop and re-introduce to beneficial use brownfield sites in Wales.

Of further concern is the severe lack of funding available to the enforcing authorities under Part IIA to not only undertake site investigations but also to fund the requisite remediation of 'orphan' sites. Whilst DEFRA has established an 'England only' fund for such work undertaken by both the Environment Agency and Local Authorities, no such funds exist here in Wales. Consequently there is significant fear that, since the necessary funding streams in Wales have yet to be made available, this lack of finances will place a large constraint on the ability of Wales' enforcing authorities to improve the soil resources via the statutory regime.

Finally the 1988 Welsh Office survey (EAU, 1988) on contaminated land in Wales also considered the possibility of '*land blight*' as a constraint on the identification of contaminated land. This should also now be perceived as a potential constraint on the use of contaminated land and land which has received reclamation / remediation. This '*land blight*' is where property owners experience a loss in the value of their property and, at worst, experience subsequent difficulty in selling their property once that land is recognised as, or be associated with, land contamination. Misinformation and in-adequate public consultation can significantly fuel negativity public perception of these issues. The potential for significant harm to economic sustainability and subsequent viability of projects should therefore be recognised even when good will and environmental sustainability benefits exist.

10.5 Policy requirements

A balanced approach to issues of contaminated land has been developed throughout UK legislation over the last 10 to 15 years. The approach has been built primarily around three principles (Crowcroft, 2001)

- Ensuring that existing development and land use are protected from existing contamination via the contaminated land regime (Part IIA of the 1990 Environmental Protection Act)
- Ensuring new development and land uses are protected from existing contamination through the planning systems;
- Ensuring that no new contamination is created by major industries with the Pollution Prevention Control Regime (Pollution Prevention and Control Act 1999)

It has been the government's approach that through legislation, contaminated land should be tackled, where possible, either on a voluntary basis or through work completed in conjunction with new development. The imposition of remediation notices should only be used where absolutely necessary. Part IIA alone is therefore not a preventative regime, with prevention itself intended to be provided via combinations of adequate planning, the Pollution Prevention Control Regime, and waste management strategies. Consequently the intention of legislation in this areas is that a balance is afforded between preventing significant harm to health and or the environment, to encourage the market to actively re-use brownfield land, and promote the responsible clean up of land which has become or is contaminated (Crowcroft, 2001).

10.5.1 Review of the current situation

Almost all policy and legislation in this area is either very new, in the process of being implemented, or still at the draft stage and consequently it is difficult therefore to comment to the adequacy and effectiveness of policy, strategy and legislation to protect non-contaminated land from future contamination. It is encouraging that the draft 'Planning Policy Wales' has been drawn up in tandem with the development of the Wales Waste Strategy. The provision and development of a cohesive approach to these issues is certainly being developed and enhanced by the latest PPC Regulations. Much is therefore being done for future prevention of contamination through the combination of PPC, Wales Waste Strategy, and Planning Policy Wales, which all implement sustainability at their core. However it is far too early to say if these will ultimately be effective in their aim. Particularly since, unfortunately for Wales, many of the new strategies and policies are massively dependent upon UK government. The success of the Welsh strategies and initiatives depends significantly on Westminster agreeing to take similar approaches and particularly in influencing UK business and society as a whole to make the necessary changes to both their use of and perception of soil as a finite resource.

Certainly, the aspects introduced by IPPC into the Part A of the PPC regulations to prevent deterioration of a site are a large step forward. This integrated approach to site condition prior to, during, and after cessation of operations has direct parallels to a sustainable soils approach. The only question that remains is the degree to which the soil might, in the event of severe contamination, be restored, particularly in view of the fiscal and financial implications introduced by BAT (the system of using 'Best Available Techniques').

Education and research must be at the core of any sustainability approach: to build better public perception, greater information dissemination, ease of access to information, the transfer and application of new technology and the continual development of best available techniques. These unfortunately are not aspects that are sufficiently championed under current strategy and policy in Wales. Without sufficient public support and understanding of the issues, current policy and strategy could either fail to meet targets or at least not be as successful as possible.

There also exists a need for a more cohesive visible source of information in Wales. Much information exists for the UK, but with the devolution of many of these aspects to the Welsh Assembly Government there exists a significant need to establish, verify and publish good up to date baseline data for Wales. The current development of the periodic English Derelict Land Survey to generate a new National Land Use Database (NLUD) aims to provide a complete consistent and detailed geographical record of land-use in England (Environment Agency, 2001). However no such developments have yet been implemented either in, or to include Wales. Information resulting from Part IIA duties held by local authorities could prove useful sources of data in the future. Such information will include the inspection strategies, records of determinations of sites as contaminated land, registers of remedial action under Part IIA, and other information collected under the Part IIA process. Local authorities will also be obliged to provide the Environment Agency with information for the State of Contaminated Land Report collected under Part IIA, which will include information from both formal determinations of contaminated land and the register of remediation. However there is likely to be additional data collated by local authorities on a wide range of sites where there are, or have been, potentially contaminated uses without demonstration of sufficient degree of pollution required under legislation. Whilst local authorities will not be under any obligation to maintain this data such an additional resource could be maintained, if issues of cost, blight and confidentiality could be overcome, as a valuable record of land quality.

Adequate policy does however exist to ensure the successful implementation of remediation/reclamation of land from dereliction and brownfield sites with the introduction of sustainable approaches to both Planning Policy and contaminated land. Part IIA of the Environmental Protection Act provides a sound regulatory framework for contaminated land making it clear and more consistent, particularly with respect to definitions of unacceptable risk, remediation standards, enforcement mechanisms and the allocation of liabilities. Unfortunately the cost of treating contaminated land can be too significant in some cases in relation to other development costs, particularly when considered against the future market value of the restored site. This might deter sufficient re-development of such sites in order to re-introduce them to productive use.

Finally the exclusion of vast quantities of wastes, particularly agricultural, and the exclusion from control under Part IIA of some receptors, and the degree to which harm applies to receptors not considered 'likely' to be present either now or in the future, does have implications to future soil sustainability. Further research, information and guidance might be required not only to include site specifications but also the direct and indirect pathways for contamination. The nature of contaminants found in waste streams are so varied and complex that it is not often possible to predict the exact composition of contaminant that will be discharged into the environment or found as pollutants in the substrate. Greater understanding therefore is needed on how they interact with soil substrate materials through research and further study.

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11. ACIDIFICATION

Summary

- Wales has an extensive area of acid and acid-sensitive soils reflecting the combined effects of underlying geology, relief and climate.
- Landuse is an important control on soil acidity with plantation conifer foresty having some of the more acid soils compared to unmanaged acid grassland, moorland and broadleaved woodland. Further research is required to quantify the extent to which repeated commercial forestry cycles may deplete soil base cation reserves.
- There is evidence of an overall increase in soil pH in Wales over the last 20 years or so. However it appears that soil pH beneath managed / permanent grassland has decreased in line with a decline in the amount of lime use. This may represent a threat to the productivity of managed upland pastures.
- International emission control policies have delivered reductions in the acid deposition loading to Welsh soils as indicated by the lower exceedance of soil acidity critical loads by non-seasalt sulphur deposition. Although full implementation of the Gothenburg protocol by 2010 should deliver further reductions in acid deposition loading and critical load exceedance, 30% of 1 km squares in Wales will continue to receive non-seasalt sulphate deposition in excess of the empirical critical load of acidity.
- There is experimental evidence that upland soils have a significant capacity to immobilise reduced forms of atmospheric nitrogen deposition. However there is empirical evidence of 'nitrogen saturation' in older forest stands. The dynamics of nitrogen in upland soils needs further investigation so that the role of nitrogen in soil acidification can be better quantified.
- There are very few predictions as to the timescale and degree of recovery from acidification expected as a result of reducing sulphur and nitrogen emissions. This remains an important area for research particularly with respect to nitrogen.
- The acidity status of Welsh soils has been regionally assessed using three national data sets of soil pH measurements. Within these, Wales is under represented in the CS2000 data base and several important soil-landuse combinations are poorly represented in the more extensive NSI data base. A 'Wales only' analysis of the RSSS data set would be valuable.
- Soil solution chemistry is an important and rapid indicator of chemical change in soils, but there is currently only one site in Wales (ECN Snowdon) providing long-term data.

11.1 Background

One of the most important chemical characteristics of the soil is the cation exchange complex which arises from the presence of negative charges on the surfaces of clay minerals and soil organic matter. The acidity of the soil is determined by the relative proportions of base cations (Na, K, Ca, Mg), protons and acid aluminium species occupying the exchange complex. In neutral soils, base cations will dominate, whereas in acid mineral soils, the exchange complex will be dominated by acid aluminium species such as Al^{3+}, $Al(OH)^{2+}$, $Al(OH)_2^{+}$. In acid organic soils, protons may be the dominant exchangeable cation.

Any processes which either remove exchangeable base cations or increase the number of negative charges without adding further base cations will acidify the soil. In contrast, addition of base cations to the soil by mineral weathering or from an external source such as liming will counteract acidification. Loss of organic matter from soil by burning will reduce the negative charge and thus ameliorate acidification.

The process of soil acidification can be considered in terms of a careful application of the mobile anion concept (Reuss and Johnson, 1986). This states simply that as the soil solution must remain electrically neutral, cation leaching must be accompanied by an equivalent amount of anions. Thus for soil acidification to occur, there has to be a source of protons to exchange for base cations and a supply of mobile anions to accompany the leached cations. There are several processes whereby this occurs naturally, for example soil respiration, organic acid production and base cation uptake, (See Appendix VII).

Within the soil, there are a number of processes which neutralise acidity from both internal and external sources of which the most important is mineral weathering. This process is the source of base cations from the soil and the rate of weathering is fundamental to the soil response to acid rain and the definition of critical loads. Unfortunately the rate of weathering is one of the most difficult processes to quantify because it depends on a wide range of internal and external factors such as abundance of weatherable minerals, soil texture, climate, slope etc. At any one site these factors will interact to define the weathering rate.

Addition of lime is an artificial means whereby the weathering rate of a soil can be increased. Effectively it introduces a source of rapidly weatherable minerals to the soil which can increase soil base saturation and pH. Agricultural liming has been practised for centuries in order to counteract soil acidification resulting from cultivation and nitrogenous fertiliser additions. In the uplands, where the majority of acidic soils occur, liming has been used to improve the productivity of grazing land often in association with other agricultural treatments. Liming has been used to counter excessive acidification of forest soils in Scandinavia and Europe but has not been practised in the UK other than on an experimental basis. Addition of lime to organic soils can also increase the cation exchange capacity as the surface charge on soil organic matter is pH dependent. Liming of peats and wetland soils can cause damage to plants, particularly *Sphagnum spp,* although there are no reports of damage other plants such as cotton sedge (*Eriophorum vaginatum*), bell heather (*Erica tetralix*) and bog asphodel (*Narthecium ossifragum*) which are typically found on acid, peaty upland soils.

Other acid consuming processes include sulphate adsorption and sulphate reduction (See Appendix VII) both of which are reversible.

11.1.1 Effects of acid deposition

If soil acidification is regarded in the light of the 'mobile anion' concept, then acid deposition provides both a source of protons to exchange for exchangeable base cations and mobile anions (SO_4^{2-} and NO_3^-) to accompany the displaced cations. For sulphur deposition, the process of sulphate adsorption reduces the acidifying effect by effectively removing both the sulphate and hydrogen ions, but this is a temporary effect until new equilibrium conditions are established. The processes determining the role of nitrogen in the acidification of soils is, however, more complex. In the absence of nitrate leaching and external inputs of nitrogen, there is no net proton production associated with the nitrogen cycle. The cycle within the plant and the soil is balanced. However, in broad terms, the balance between nitrogen supply and utilisation by plants and the soil microbial biomass will be the main control on nitrate leaching (See Appendix VII).

11.1.2 Measuring soil acidity

The acid status of soils can be considered in terms of capacity and intensity factors. Capacity factors deal with amounts, e.g the amount of exchangeable cations or exchangeable acidity in a soil. These parameters tend to change slowly over a timescale of decades, and often the pool size in the soil is large and spatially heterogeneous. Thus over a short time scale, for example 5 years, their value for detecting change may be limited by the ‘noise’ in the measurements, particularly if the magnitude of change is small relative to the size of the pool. Capacity factors can be compared with input loads or input-output budgets to assess impacts.

Intensity factors relate to concentrations and apply mainly to soil solutions. Although they can be highly variable in space and time, intensity factors can change rapidly by a large amount in response to changes in concentration in the inputs at a seasonal or single event timescale. They should be compared with concentrations of ions in deposition inputs to assess impacts. More detail on capacity and intensity factors is given Appendix VII.

11.2 The current situation

In Wales a combination of geographical features have led to the widespread development of acid soils particularly in the uplands. High hills rise steeply from a narrow coastal plain and proximity to the sea makes the climate moist and mild with heavy rainfall on the hills. Most of Wales is geologically ancient dominated by hard, mainly lower Palaeozoic rocks which weather slowly and contain only small amounts of base cations (calcium and magnesium). Successive glaciations have covered these rocks with locally derived superficial deposits. Clearance of once common native woodland and scrub from the uplands since Neolithic times has led to the widespread development of heathland with subsequent formation of acidic humus, podzolisation and soil acidification (Rudeforth *et al.*, 1984). The overall result is that most of the soils developed in the uplands of Wales contain little calcium or magnesium, are highly leached and acidic with a peaty surface horizon of varying depth. More recent changes in land use in the uplands through agricultural and forestry activities have subsequently modified the chemistry of soils in some areas.

11.2.1 The acidity of Welsh soils

The National Soil Inventory (Appendix VII) provides the most comprehensive set of soil pH data for Wales although sampling only covers the surface 0-15 cm of the profile. A summary (Table 11.1) shows that the mean pH of soils is just below 5, with a wide range of nearly 5 pH units.

Table 11.1 Summary statistics for pH (1:2.5 soil:water) in the 0-15 cm layer of the soils of Wales (NSI data: 1980).

Country	Mean	N	Std dev	Median	Min	Max
Wales	4.96	776	0.882	4.9	3.2	8.1

Acid soils are widespread in Wales with just over 50% of samples in the Welsh NSI data set having a pH in water of less than 5, compared to the full England and Wales data set in which 50% of samples are at pH 6 or less. Data from the CS2000 survey suggest that Welsh soils are of intermediate acidity between England and Scotland (Table 11.2).

Soil pH is strongly determined by land use as well as soil type. Summary statistics for the Welsh NSI data set (Appendix VII), show that managed agricultural land (arable, ley and permanent grassland) have consistently higher mean pH values (pH 5.4 –5.8) than semi-natural systems due to maintenance by liming although there is an interaction with soil type. Thus the brown earths and stagnogleys found in the lowlands are generally less acid (mean pH > 5) than the common upland soils such as the humic and stagnohumic gleys, brown podzolics, stagnopodzols and peats (4 < mean pH < 5; see Appendix VII).

Table 11.2 Summary pH data for CS2000 soils collected in 1998/99.

Country	Mean	N	Std dev	25%ile	Median	75%ile
England	6.35	522	1.394	5.40	6.37	7.58
Wales	5.51	94	0.998	4.82	5.54	6.16
Scotland	5.04	455	0.872	4.34	4.79	5.67
All	5.72	1071	1.324	4.56	5.58	6.57

Land used for rough grazing, unenclosed upland grassland and upland heath have acid soils with an average pH between 4.6 and 4.1. Soils under coniferous forest (mean pH 4.16) are of similar acidity to those under upland grass (mean pH 4.12) and upland heath (mean pH 4.15) but are more acid than those under deciduous woodland (mean pH 4.49). This partly reflects an interaction with soil type as deciduous woodland is present in both upland and lowland areas generally on more fertile soils whereas conifer forest plantations tend to be predominantly located in the uplands on poorer soils. The interaction between soil type and land use is difficult to disentangle because of the limited size of the data set compared to the potential number of soil and land use combinations. A minimum sample size of 10 is required for statistical analysis (NSRI per comm 2002) and this is only satisfied for a limited number of soil / land use combinations (See Appendix VII). Amongst these, the widest range of land use types is present for the typical brown podzolic soils which become progressively more acid as land use changes from managed grassland (mean pH 5.33), through upland grassland (mean pH 4.30), deciduous woodland (mean pH 4.27) to conifer forestry (mean pH 3.99). This pattern is generally upheld for other soil types within the NSI but the low sample numbers constrains the validity of the conclusion.

Data from the CEH Forest Nitrogen Survey (Appendix VII), which includes information for the entire soil profile suggest that for stagnopodzols, soil pH values (in $CaCl_2$) are uniformly acid across all sites, with the majority of horizons having a mean pH less than 4 (Table 11.3). Soil pH increases with depth in the profile at moorland and forest sites, but there are no trends with forest age. The mean pH of the moorland sites is slightly higher throughout the profile compared to the forest sites. Podzol B horizon soil waters under conifers are also more acidic and aluminium rich compared to similar soils under oak woods (See Appendix VII).

Table 11.3 Average soil pH (in $CaCl_2$) at 5 moorland and 20 Sitka spruce plantations in Wales.

Horizon	Grassland	Forest (age range)			
		0-14	15-30	31-45	+45
O	3.3	3.1	3.0	3.0	3.3
E	3.5	3.2	3.3	3.2	3.2
B	3.8	3.6	3.7	3.7	3.7
C	4.1	3.8	3.8	3.8	3.9

11.3 Evidence for change

The national surveys of soil chemistry suitable for indentifying changes in soil acidity in relation to either land management or acid deposition start either at or soon after the peak of sulphur emissions in the 1970's. A very small data set of 31 samples from 13 sites in north west Wales documents an increase in the acidity of soils under semi-natural grassland between 1957 and 1990 (Kuylenstierna and Chadwick 1991; Appendix VII). The original pH values ranged between 4.4 and 6.4 and all the separate samples showed reductions in pH with the decline ranging from 0.1 to 1.6 pH units and with the decline in pH 'broadly positively correlated to the original pH' (Figure 11.1). The sites sampled represented a range in altitude from *c.* 130 to 915 m with consequent variations in precipitation and deposition of pollutant and non-pollutant ions. The variation in the magnitude of pH change with deposition or salt content of soils was not explored.

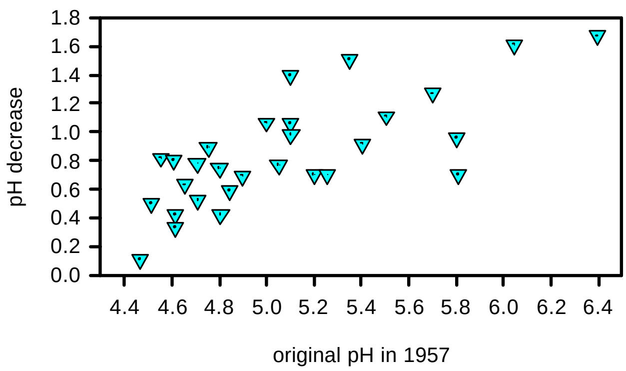


Figure 11.1 The measured pH decrease for soils in north-west Wales originally sampled in 1957 and re-sampled in 1990. (after Kuylenstierna and Chadwick 1991).

More recent surveys include the NSI, RSSS and CS2000 (Appendix VII). Permanent grassland and arable/ley rotation sites within the NSI were resampled in 1996. In the 16 years since the original survey, soils under arable/ley rotation showed a small increase in mean pH whilst there was no change in the mean pH of permanent grassland soils (Table 11.4).

Table 11.4 Summary statistics for the pH of the original and resampled NSI sites under permanent grassland and arable/ley rotation (NSI data: 1980 & 1996).

	Permanent / managed grassland		Arable/ley rotation	
	1996	1980	1996	1980
Mean	5.38	5.38	5.99	5.65
Min	3.7	3.9	4.5	4.2
Max	8.0	7.1	7.9	7.4
N	100	100	55	55

The NSI results contrast with those from the RSSS which show that in the first 25 years (1969 – 1990/93) there was no significant change in the pH of arable soils across England and Wales but there was a linear decline over the period of the pH (in $CaCl_2$) of managed grassland soils, from a mean of just over 5.7 to 5.4. In the grassland soils, the proportion of soils with pH <6.0 (in $CaCl_2$) increased from 39% in 1969-73 to 56% in 1990-93 (Skinner and Todd, 1998). Unfortunately in this analysis Wales is lumped together with the southwest of England, but within the combined region, which has a high proportion of grassland, pH has declined by 0.24 units in the 25 year period (Skinner and Todd, 1998). The authors express concern at this change because many of the managed grassland pH values were already low in the period 1978-88, with almost half the fields in continuous grassland below pH (in water) 6.0 and 14% of values below 5.5 (Skinner *et al*., 1992). These values are considered sub-optimal for grassland production. The Agricultural Lime Association recommends a pH of 6.5 for mineral soils, pH 6.2 for soils with 10-25% organic matter and pH 5.8 for organic soils with more than 25% organic matter (ALA 2002). Increasing acidity in permanent grassland results in loss of productive grass and clover species which are replaced by less vigorous and less digestible species (Forbes *et al*., 1980).

More information on pH change will be forthcoming from the CS2000 study. Preliminary results for the entire GB data set suggest an increase in mean and median pH in all major soil groups except Pelosols (Appendix VII). Overall, soils in Wales show some of the largest increases in mean pH (Table 11.5), but sample numbers are too small to justify analysis by soil type.

Table 11.5 Change in soil pH between 1978 and 1998/99 in sample squares in which land use is known to have remained the same.

	Mean	N	Std. dev.	25%ile	Median	75%ile
England	0.27	361	0.948	-0.29	0.27	0.82
Wales	0.51	67	0.874	0.00	0.55	1.21
Scotland	0.22	339	0.783	-0.24	0.23	0.61
All	0.27	767	0.874	-0.27	0.28	0.79

Much fewer data are available to assess changes in soil water chemistry over time. A long run of data from soil water samplers in an agriculturally unimproved stagnopodzol soil at Plynlimon, covering a period from September 1984 to September 1994, reveal a gradual upward trend for pH and ANC in surface organic and mineral horizons (see Appendix VII). There is considerable variability in the data between sampling occasions much of which is controlled by periodic seasalt deposition. In the future data will become available from the ECN site on Snowdon (Appendix VII). Soil waters from the A horizon at the ECN site are somewhat higher than at Plynlimon with a mean pH of 6.12 and an alkalinity of 3 $\mu Eq\ l^{-1}$.

11.4 Acidification and critical loads

The low base cation content of the parent material comprising much of the Welsh uplands means that the soils are not only acid but sensitive to acidification by acid deposition. Critical loads provide a means by which this acid sensitivity can be quantified and compared with current and future predicted levels of acid deposition (See Appendix VII).

Table 11.6 Number and percentage of 1 km squares in each class of the empirical soil acidity critical loads map for Wales.

	Critical loads class (class ranges in keq ha^{-1} yr^{-1})			
	<0.2	0.2 – 0.5	0.5 – 1.0	>1.0
Number of 1 km cells	1785	7451	8039	3823
Percentage of 1 km cells	9	35	38	18

The empirical critical load map (Figure 11.2) amply demonstrates that soils in much of Wales are very sensitive to acidification with 44% of the 1 km squares having a critical load at or below 0.5 keq ha^{-1} yr^{-1} (Table 11.6). The predicted impact on Welsh soils of changing pollutant sulphur deposition over the period 1970 to the present day and into the future can be assessed by overlaying deposition scenarios for 1970, 1983, 1995/97 and 2010 onto the critical loads data to produce maps of the exceedance of the empirical soil acidity critical load (Figure 11.3). The large emissions and hence deposition in 1970 results in the largest number of 1 km squares for which the empirical critical load of acidity for soils is exceeded (87%), with correspondingly smaller numbers of exceeded squares in 1983 (81%) and 1995-97 (59%) as emissions of sulphur dioxide decline (Figure 11.3; Table 11.7). Assuming the Gothenburg protocol is fully implemented by 2010, the predicted decline in sulphur deposition reduces the proportion of exceeded 1 km squares to 30%. For the same years, the proportion of 1 km squares in which critical loads are exceeded by more than 1 keq ha^{-1} y^{-1} are respectively: 47%, 25%, 3% and 0 (Table 11.7).

Despite the improvements so far achieved in Wales and those predicted for the future as sulphur deposition declines further, comparable statistics for the UK as a whole (shown in parentheses in Table 11.7), highlight that soil acidification is a continuing environmental issue in Wales. This arises because under the Gothenburg scenario some of the most acid sensitive areas in north and south Wales will be amongst those in the UK which continue to receive relatively large non-seasalt sulphur deposition in 2010 (NEGTAP 2001; Reynolds *et al*., 2002).

Table 11.7 Exceedance of the empirical soil acidity critical load by non-seasalt sulphur deposition. Figures in parentheses are for the whole of the UK (NEGTAP 2001).

	Percentage 1 km squares in each exceedance class (class ranges in keq ha^{-1} yr^{-1})					
Year	Not exceeded	<0.2	0.2-0.5	0.5-1.0	>1.0	Total exceeded
1970	13%	5%	13%	23%	47%	87% (70%)
1983	19%	11%	20%	25%	25%	81% (62%)
1995/97	41%	11%	24%	20%	3%	59% (46%)
2010	70%	19%	10%	1%	0	30% (16%)

Within the UK, ecosystem specific critical loads for total acidity are calculated for coniferous and deciduous woodland using the simple mass balance equation (SMBE; See Appendix VII). The exceedance values have been calculated in two ways in order to demonstrate the potential acidifying effect and importance of NH_x deposition to terrestrial ecosystems. It is assumed firstly that NH_x deposition does not contribute to ecosystem acidification and secondly each equivalent of NH_x deposition is assumed to contribute one proton. A recent evaluation of critical load models (Skeffington, *pers. Comm.* 2002) has clarified the position with respect to NH_x deposition and shown that it cannot be omitted from the exceedance calculation, implying that the second estimate of exceedance provides the correct interpretation.

Table 11.8 Exceedance of the SMBE critical load for acidity for coniferous woodland in Wales.

	Percentage of 1 km squares in each exceedance class (class ranges in keq ha^{-1} yr^{-1})					
Year	Not exceeded	<0.2	0.2-0.5	0.5-1.0	>1.0	Total exceeded
1995/97 (including NHx)	4%	2%	7%	29%	57%	96%
2010 (including NHx)	44%	9%	15%	20%	13%	56%
1995/97(excluding NHx)	92%	3%	1%	2%	2%	8%
2010(excluding NHx)	97%	<1%	3%	<1%	0	3%

The resulting exceedance maps showing 1 km squares containing coniferous woodland under current day deposition (1995-97) and the 2010 scenario are shown in Figure 11.4. For 1995/97, the critical loads model predicts that 96% of 1 km squares are exceeded (Table 11.8). This falls to only 8% when NH_x deposition is excluded, underlining the importance of this component of acid deposition. Assuming that the Gothenburg protocol is fully implemented by 2010, the critical load of acidity is exceeded in 56% of squares containing coniferous woodland. The proportion of squares in the highest exceedance class is reduced by more than 40%. Again the importance NH_x deposition is demonstrated, as excluding this component of deposition reduces the proportion of exceeded squares to only 3%.

Key to the interpretation of these maps and statistics is the recognition that the critical loads and exceedances are calculated assuming long-term, steady state conditions. Thus critical load exceedance at the present time does not necessarily equate to currently observable ecosystem ‘damage’, but indicates that damage may occur in the long-term if acid deposition continues at the same level. Steady-state models can say nothing about the timescale over which the effects of exceedance will occur. For nitrogen deposition, the controls on nitrate leaching in response to the increasing nitrogen richness of the ecosystem are the crucial factors. These will determine the timing of nitrate release and the associated acidification following continued atmospheric nitrogen inputs. Predicting the timescale for these effects requires the use of dynamic models.

Figure 11.2. Empirical critical loads of acidity for soils.

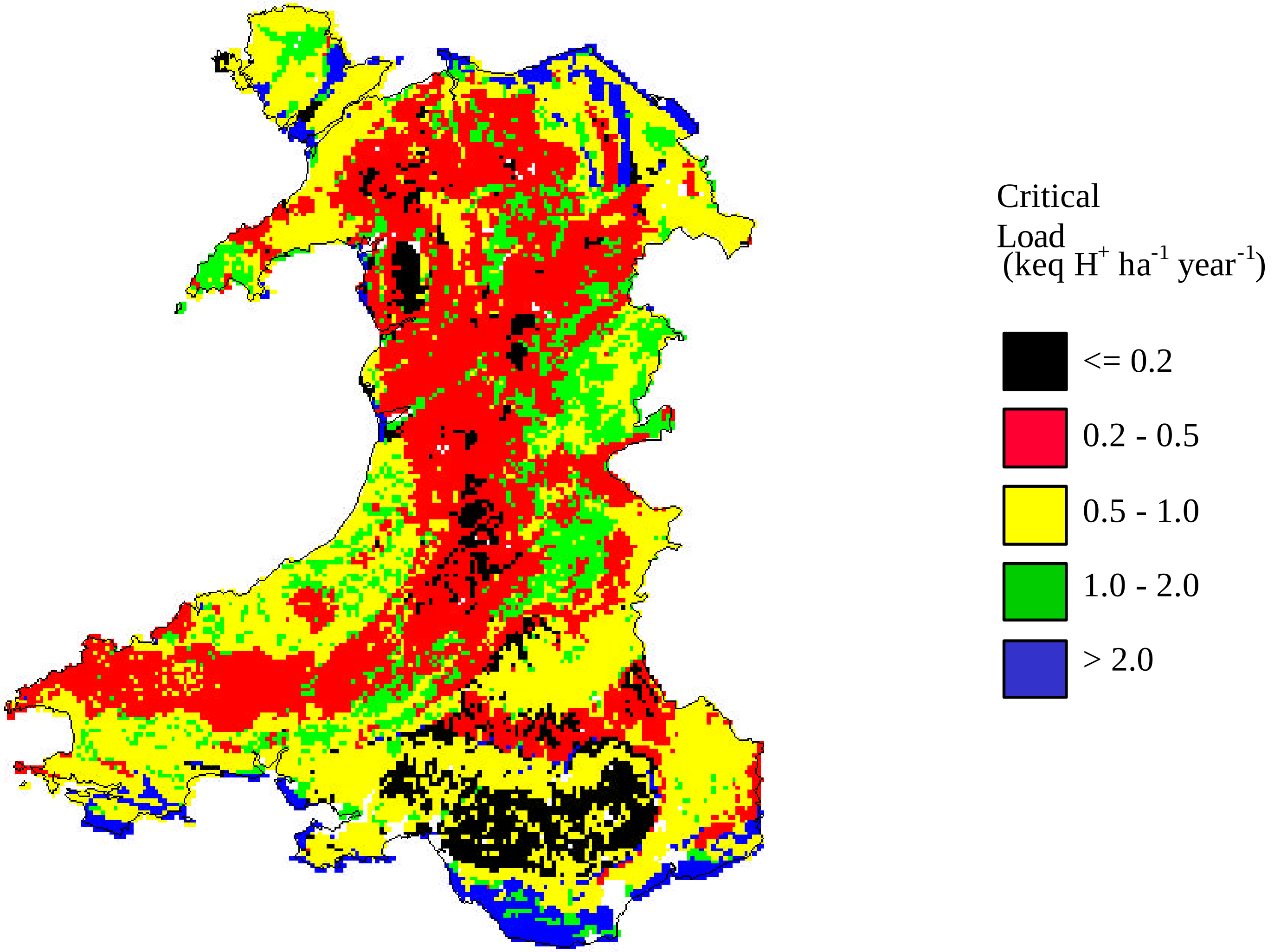


Figure 11.3. Exceedance of empirical acidity critical loads for soils by non-marine sulphur deposition predicted by HARM for 1970, 1983, 2010 (Gothenburg protocol, uses HARM and FRAME) and measured values for 1995-97.

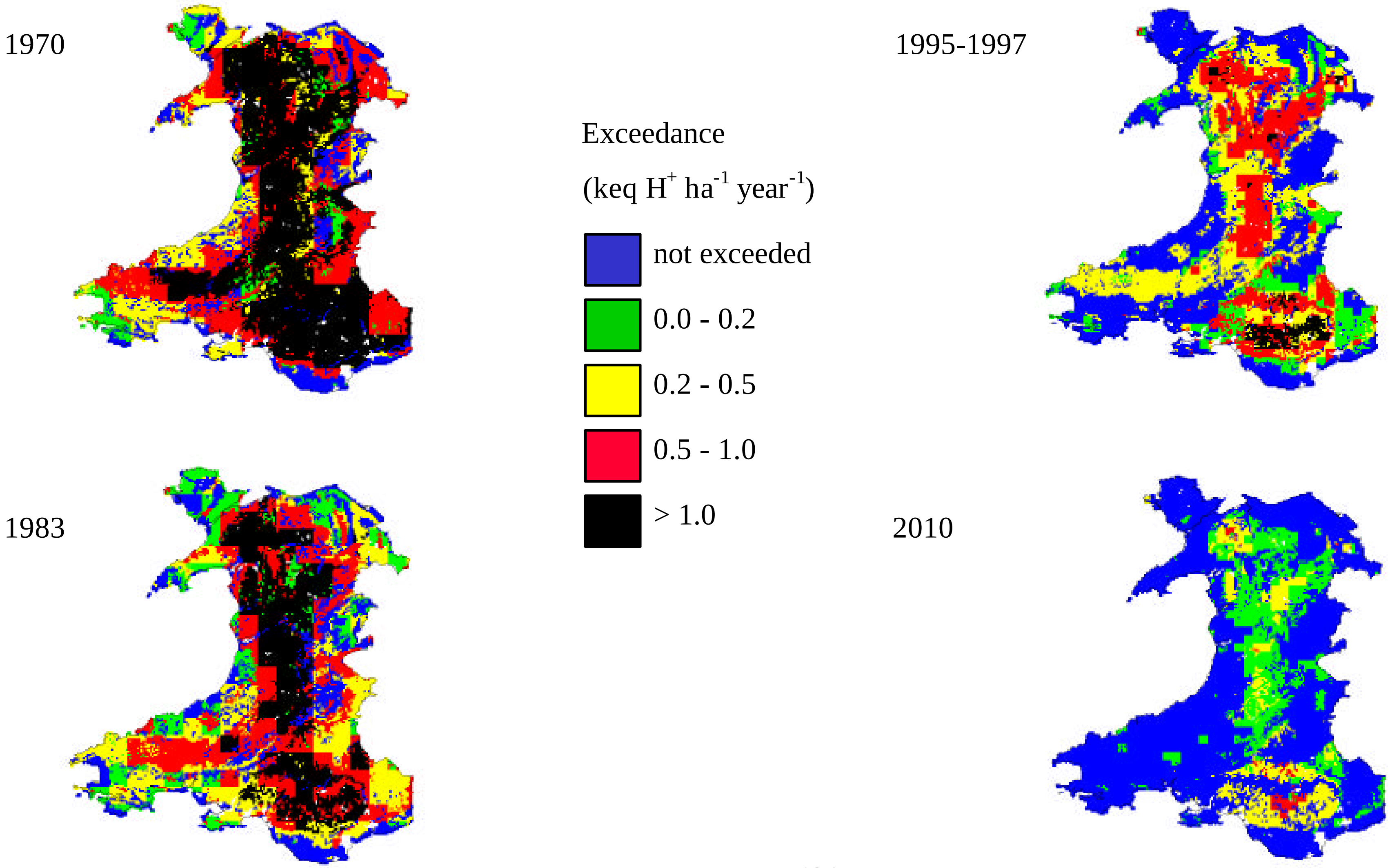
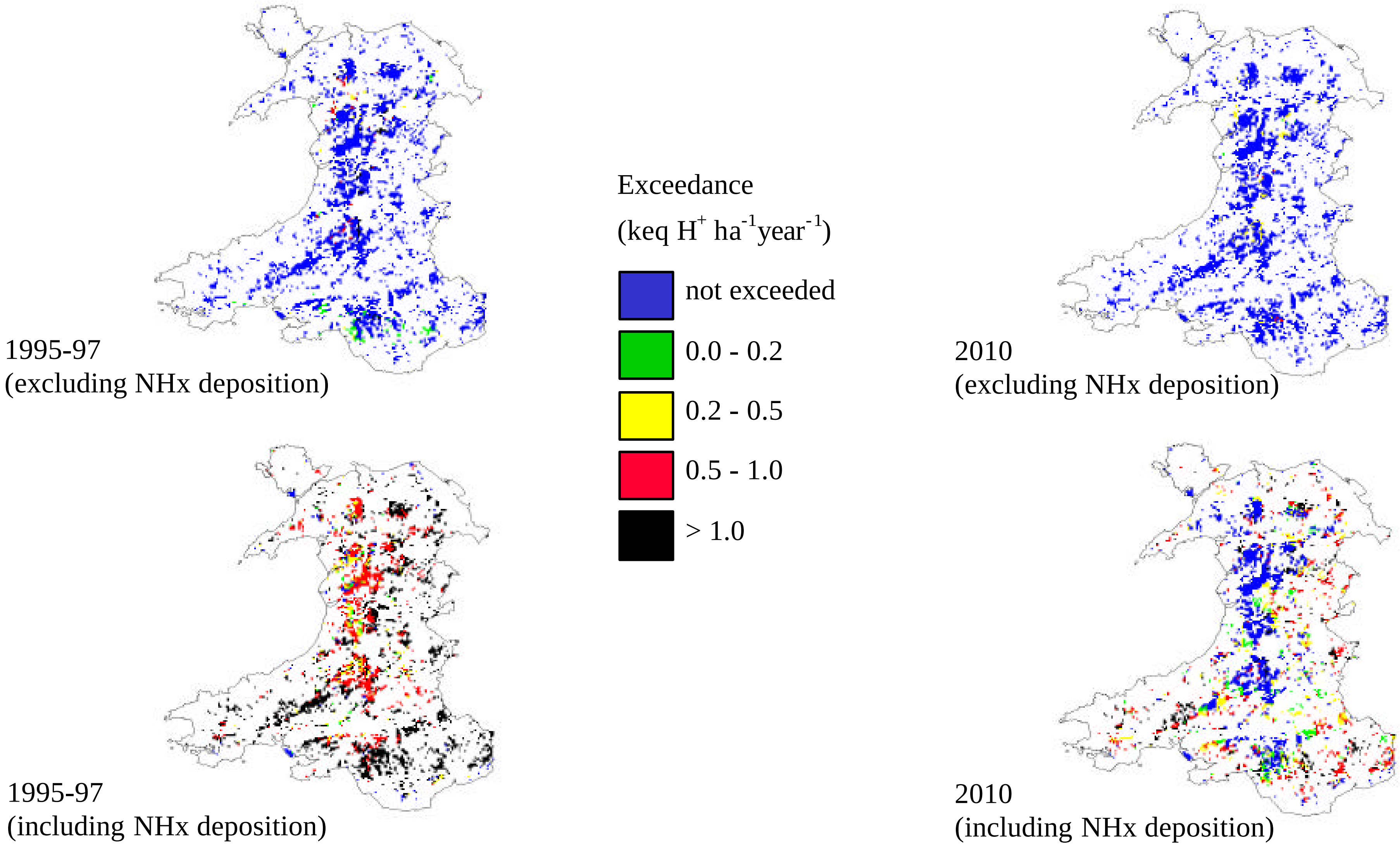


Figure 11.4. Exceedance of SMBE acidity critical loads for coniferous woodland by measured acid deposition for 1995-97 and predicted acid deposition for 2010 following implementation of the Gothenburg protocol.



11.5 Predicting future acidification trends using dynamic models

Dynamic models can predict both the magnitude and timing of soil and soil water chemical responses to changes in acidic deposition and/or land use. The models provide a test bed for our understanding of the processes involved in acidification and recovery. There have been relatively few soil specific dynamic modelling exercises in the UK although a number of dynamic model predictions of soil chemistry are available as an adjunct to catchment scale stream hydrochemical modelling using the MAGIC model. These are of limited value for simulating soil and soil water chemistry. The 'lumped' nature of the model and the requirement to achieve a mass balance of elements at the *catchment scale* rather than for the *soil profile* means they provide a very simplified assessment of the soil response. In catchments with significant inputs of groundwater enriched in base cations from deep weathering sources, predicted 'catchment' weathering rates will often be much larger than those found in the soil profile. As a result the simulation of exchangeable cations and base saturation can be unrealistic.

The future response to nitrogen deposition is likely to be crucial to determining the rates of recovery of acidified soils. However, our understanding of key processes in non-managed, acid sensitive, upland soils is limited. Adequate modelling of soil nitrogen dynamics in these soils, in relation to acidification, has yet to be undertaken in the UK.

Although there has been relatively little work specifically on soil acidification modelling in the UK, there are a number of studies from Wales (See Appendix VII). These have consistently shown a decrease in base saturation and increasing soil water acidity in response to increased acid inputs from the mid 19th century onwards. Following the decline in sulphur emissions from their peak in the mid to late 1970's, soil water acidity is predicted to decrease relatively rapidly towards levels predicted before 1850. The exact trajectory of recovery beyond present day is determined by the sulphur emission protocol simulated by the model. However none of the studies predict a complete return to 'pre-acidification' conditions within the modelling time frame of 40 to 50 years beyond present day irrespective of the emission protocol under consideration. Base saturation is predicted to increase much more slowly towards 'pre-industrial' values, although again complete recovery is not attained within the future 50 year time frame of the models irrespective of which sulphur emission protocol is simulated.

The applications of MAGIC and SAFE described above contain very simplified representations of the nitrogen cycle. The increasing importance of nitrogen to acidification has necessitated the development of models with more sophisticated nitrogen dynamics with the focus on representing the dynamics of soil organic matter transformations within the context of nutrient cycling within the soil-plant system. However, in contrast to many models of nitrogen cycling, emphasis is placed on the soil N leaching term as one of the key outputs (Emmett *et al*., 1997). A new ecosystem scale nitrogen model (MERLIN) has been developed using the data from the Forest Nitrogen Survey and the CEH nitrogen manipulation experiment at Aber forest (See Appendix VII). At Aber, the model successfully reproduced the increase in nitrate leaching losses with forest age described by Stevens *et al*. (1994). Furthermore, the model also captured the increases in nitrate leaching and the changes in soil organic matter and tree nitrogen content observed at the site in response to the experimental nitrogen additions (Emmett *et al*., 1997). Unfortunately the MERLIN model requires large amounts of detailed data on the ecosystem carbon cycle before it can be applied to a particular site, limiting its more general use. Work is currently in progress under the NERC-DEFRA 'Terrestrial Umbrella' to adapt an American ecosystem nitrogen model and link it to acidification models such as MAGIC and SAFE. The combined models will be developed and tested at sites throughout the UK, including a number of Welsh sites (eg Plynlimon, Aber, Ruabon; See Appendix VII).

11.6 Predicting future acidification responses using manipulation experiments

Field-based or ecosystem-scale manipulation studies provide another means of investigating ecosystem responses to changes in acid inputs, land management and climate change. Provided they are performed carefully with realistic dose rates and adequate controls, these experiments can provide a wealth of detailed data for parameterising and validating dynamic models. Due to cost and complexity, manipulation studies have to be site–specific and results must be generalised carefully, acknowledging the limitations and constraints of single site experiments. Three important experiments have been undertaken in Wales to investigate the effects of increased nitrogen deposition on coniferous forest, heather moorland and acid grassland (See Appendix VII). The forest and moorland experiments demonstrated that the retention capacity for additional nitrogen varied according to the form of nitrogen applied. Ammonium was completely retained within the soils even after 5 years of additions. The forest had no capacity to retain additional nitrate whilst leaching losses of nitrate also increased in response to inputs to the grassland. Overall between 50% and 70% of the added nitrogen was retained mainly in the soil at the grassland site. This figure was exceeded at the moorland experiment where only 4% of the annual N addition was leached from the site in 1999, and this after total additions over the duration of the study amounting to 2000 kg-N ha^{-1}. Alongside these 'headline' results, considerable detailed information has been acquired about soil processes and plant responses which can be used to inform model development (See Appendix VII).

In contrast to the main theme of this section, acidification of soil may be desirable in habitat restoration and re-creation schemes, particularly where the starting point is agriculturally improved grassland that has been limed and fertilised. An experiment at Trawsgoed Experimental Farm has followed the acidification of an experimentally fertilised *Lolium* grassland since liming and fertiliser treatments ceased in 1996 (See Appendix VII). In 4½ years the average pH has decreased by 1.25 units, suggesting that there may be advantages in targeting grassland restoration schemes at those sites that do not have a long history of liming.

11.7 Impacts on soil functions

11.7.1 Biomass, food and fibre production

Soil acidification is primarily an issue focused on the uplands where the main products are meat and wool from extensive grazing by sheep and cattle together with softwood from Forestry Commission and privately owned plantation forests.

The RSSS has highlighted that a significant proportion of soils under managed permanent grassland are at a sub-optimal pH and that there has been a steady, linear trend towards increasing acidity. Presumably this will be affecting the productivity of these grasslands as productive grasses and clover species are replaced by less productive ones. In the analysis of the RSSS, Skinner and Todd (1998) point out that UK agricultural lime consumption had declined from 4.2 million to 2.9 million tonnes over the period of the RSSS (1969-1993). They also note that while some observers have attributed the decline in lime use to removal of the lime subsidy in 1976, the decline in lime consumption actually started some ten years earlier and continued over time with a small increase in lime use during the mid 1980s. From the Welsh perspective it is important to know whether the main decline in lime consumption has been in the areas of managed permanent grassland. This sector is probably the most marginal economically, and the most likely to be targeted in terms of cutting production costs. The extent to which acid rain has placed an additional burden on maintaining soil pH in upland areas of high deposition is not known.

The effects of acidification on the productivity of rough grazing and unimproved pastures is unknown but not likely to be significant. These areas have low productivity swards developed on acid soils.

The conifer species grown in UK commercial forests generally tolerate acid soil conditions and there is no requirement to ameliorate soil acidity in order to improve tree growth. Soil acidity may be limiting to some broad leafed species, but where this occurs, more acid tolerant species are planted. Lime may be applied in UK forestry where stream water acidification is perceived as a problem.

The longer term soil acidification impact plantation conifer forestry is linked to the overall balance in the soil between i) the export of base cations in harvest products, ii) acclerated leaching losses of base cations at felling and iii) the supply of base cations from atmospheric inputs and weathering. Analyses of calcium cycling within Sitka spruce stands growing on base-poor soils typical of the Welsh uplands suggests that the soil calcium budget for plantation Sitka spruce in Wales is finely balanced (Reynolds and Stevens 1998; Evans *et al*, 2001), lying within the errors of the measured parameters. The issue of maintaining long-term soil base cation reserves in production forests is complex and requires further research, but changes in forest management which encourage retention of base cations on site and increase inputs to the soil, particularly the more acidic near-surface horizons, should ameliorate soil and stream water acidification.

11.7.2 Environmental interaction

Soil chemistry and hydrological flow routing through the terrestrial catchment provide the link between the deposition of acidic pollutants and surface water acidification. Soil acidification in response to increased sulphur deposition, depletes base saturation and increases the dominance of inorganic aluminium and hydrogen ions on the exchange complex. Upland podzolic soils have some capacity to buffer inputs of sulphate through adsorption onto oxide surfaces in the B horizon, however this capacity is thought to be small compared with the flux of sulphate through the system. As the soil acidifies, aluminium and hydrogen ions increasingly accompany the mobile sulphate anion in runoff leading to surface water acidification.

Nitrogen deposition has the potential to cause a similar surface water acidification response to sulphur however as most nitrogen is utilised within the terrestrial catchment, relatively little is leached to surface waters. The majority of the deposited N is immobilised in the soil, but long-term deposition can result in chronic nitrogen enrichment of the soil relative to carbon availability. As a result, the capacity of the soil to immobilise nitrogen is reduced, leading to an increase in nitrate leaching (Gundersen *et al.,* 1998). This response was experimentally induced in the Aber forest nitrogen manipulation experiment (see above) and can be seen in the increased nitrate leaching and stream water nitrate concentrations observed in older (+30 years) forests in Wales (Emmett *et al.,* 1995). Rapid changes in vegetation cover, such as accompanying forest harvesting may also temporarily increase nitrate leaching over a period of five years or so (Neal *et al*., 1998). Ammonium deposition only contributes to surface water acidification after interaction with the terrestrial system. Conversion of ammonium to nitrate via the nitrification process will produce a mobile anion which will behave in the same way as sulphate.

Hydrological flow routing is important under episodic conditions of high rainfall on acid sensitive upland catchments. Under these conditions, acidic runoff from surface soils and from peats in the headwaters increasingly dominates the stream hydrograph leading to acidic stream water, rich in aluminium and dissolved organic carbon but depleted in divalent base cations such as calcium. These conditions are particularly toxic to stream biota, although the toxicity of aluminium is mediated to some extent by the presence of dissolved organic carbon. At low flows stream water is dominated by inputs from deeper in the soil profile and by shallow groundwater. Weathering reactions in these zones increase the concentration of base cations in these waters, neutralising acidity. As a result, the chemistry of baseflow, even in upland streams with catchments dominated by acid soils, can be relatively high pH (6-6.5) with low concentrations of toxic metals and enriched in divalent base cations.

11.7.3 Provision of a platform

Little or no impact apart from consideration as a platform for agriculture and forestry (covered above) and as a platform for specific habitats (see following).

11.7.4 Support of ecosystems, habitats and biodiversity

Soil is a major pool of biodiversity and is the support of terrestrial ecosystems. Soil pH is a master variable determining chemical nature of soils and the ecosystems they support. Many plants and soil organisms have preferred soil pH ranges or are restricted to specific pH ranges through competition. Distinctive habitats develop in particular pH ranges, for example acid, neutral and base-rich grasslands, but there is little evidence to indicate that these habitat types have been affected by acidification from atmospheric pollution. Land management and the soil parent material tend to be the dominating influences. Biodiversity Action Plans include targets for restoring or re-creating some of these more acidic habitats (eg heath, acid grassland and some broadleaf woodlands), in which cases acidification of agriculturally improved pastures can be considered beneficial. In contrast, attempts to increase the diversity of plantation conifer forests may be hampered by the very acid soil conditions which have developed and the lower acidity tolerance of some broadleaf species. Very acid soil conditions can promote toxicity to plants and organisms through increased mobility of aluminium and trace metals.

11.7.5 Provision of raw materials

Little or no impact.

11.7.6 Protection of cultural heritage

Generally little impact although soil acidification may have damaging effects on buried artefacts such as bone, shells and other mineral materials due to increased rates of dissolution. However, organic material is preserved well in anaerobic, acid bog soils.

11.8 Policy responses – present and future

11.8.1 Acid deposition

The United Nations Economic Commission for Europe (UNECE) Convention on Long-Range Transboundary Air Pollution (CLRTAP) has formed the framework for the control on the emissions of acidifying atmospheric pollutants across Europe since the mid 1980's. The effectiveness of the various protocols can be seen in the overall reduction in UK sulphur dioxide emissions from a peak of 3259 kt-S in 1970 to 594 kt-S in 1999 (NEGTAP 2001). Nitrogen oxide emissions were at their peak in the 1980's at about 850 kt-N, declining to less than 500 kt-N by 1999. Annual emissions of ammonia are very uncertain but are currently estimated at 287 kt-N for 1999 (NEGTAP 2001). International emission control policies have delivered reductions in the acid deposition loading to Welsh soils as indicated by the lower exceedance of soil acidity critical loads by non-seasalt sulphur deposition. A key issue for the future protection of Welsh soils from acidification is the full international implementation of the Gothenburg protocol by 2010. Source attribution analysis as part of the Scoping Study for Acid Waters in Wales Strategy (Reynolds *et al.,* 2002) showed that emissions from within the EMEParea will contribute 60% of the sulphur and 54% of the oxidised nitrogen deposition to the acid sensitive areas of north and mid-Wales in 2010. As of September 2001, the protocol had 31 signatures but had only been ratified by one nation.

A major uncertainty remains as to the extent to which continuing nitrogen deposition to terrestial systems will affect recovery from acidification. Research is ongoing within programmes funded by DEFRA and the NERC to address this issue. In particular there is a need to understand the key processes which need to be represented in dynamic acidifcation models. As results become available, these will continue to inform policy concerning any future emission reduction requirements targetted at nitrogen. In dealing the nitrogen dynamics, interactions with climate variability and carbon dynamics may become increasingly important.

11.8.2 Land use

Landuse is an important control on soil acidity with plantation conifer foresty having some of the more acid soils compared to unmanaged acid grassland, moorland and broadleaved woodland. With significant changes proposed to commercial forest management in Wales (NAW 2000) through a shift from patch clearfelling to continuous cover forestry, the consequences for soil acidification remain to be seen. Further research is also required to quantify the extent to which repeated commercial forestry cycles may deplete soil base cation reserves.

Whilst there is evidence of an overall increase in soil pH in Wales over the last 20 years or so, it appears that soil pH beneath managed / permanent grassland has decreased in line with a decline in the amount of lime use. This may represent a threat to the productivity of managed upland pastures.

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12. CLIMATE CHANGE

Summary

There is increasing evidence that the UK climate is changing driven by increased emissions of greenhouse gases. The mean temperature of Wales has increased a rate of about 0.3 ^{o}C over the last century whilst annual precipitation has increased by 3%. These trends are expected to continue with predictions for 2080 of increased temperature of 2 - 4 ^{o}C, increased seasonality in rainfall and a net change in sea-level change of 11 – 71cm. Assessing the impact of these changes on soil is highly problematic as climate is just one anthropogenic factor which affects the state and function of soils. Other factors include land management practices and atmospheric deposition which have also changed significantly in the last century. Several key issues have been identified:

- Soils are both a source and sink for greenhouse gases. As the processes which produce these gases are themselves affected by climate there is the potential for a positive feedback. However, acclimation has been reported in some cases and short term studies should be interpreted with care.

- Some indications of changes in soil state and function are available. These include a decrease in soil carbon stores in the top 15cm of arable and grassland systems, increased transfer of soil carbon to streams increasing colour, and release of metals accumulated in peatlands since the industrial revolution following periods of prolonged drought.

- The impact of climate change on soils may influence the productivity of agricultural and forestry soils. There is the potential for increased erosion, poaching and workability of heavier soils if winter rainfall and storms increase together with an increased risk of transfer of nutrients and contaminants to streams and rivers. The effects on nutrient availability and quantity and quality of carbon inputs from plants are difficult to predict and are likely to vary within different systems. Some loss of productive land due to sea level rise is possible.

- There is a high level of uncertainty in current estimates of soil carbon stocks and there is a need for improved monitoring and survey of soils in Wales.

- The magnitude of the soil carbon sink is highly variable both temporally and spatially making it difficult to quantify current sinks and forecast future sinks under different land use or climate change scenarios. However there is potential for particular options to be evaluated.

- There remain major uncertainties about underlying controls of key soil processes which have a critical influence on the capacity of the soil to provide a range of functions including carbon storage.

12.1 Background

Climate change associated with greenhouse gas emissions is expected to alter temperature, rainfall, sea-levels and winds (Houghton *et al.,* 2001). There is clear evidence that climate change is already happening with an increase in the global average surface temperature by 0.6 ^{o}C. over the 20th century, a reduction in snow and ice extent and a rise in global average sea levels (Houghton *et al*., 2001). The impacts of these changes for the UK as a whole have been summarised by the UK Climate Impacts Programme (Hulme *et al.,* 2002). A scoping study to identify possible impacts on Wales was published in May 2000 (Farrar *et al.,* 2000). In response to the evidence presented in these reviews, mitigation of climate change is becoming an increasing priority for the international community. This will primarily involve intervention to reduce the sources of greenhouse gases but may also involve an enhancement of their sinks. The role of soil needs to be included in any assessment of current and future sources and sinks of greenhouse gases as they act as both sources and sinks. Soils contribute to the production of greenhouse gases through the action of soil microbes which cause the release of greenhouse gases such as methane, carbon dioxide and nitrous oxide. They can also act as a sink as they store carbon dioxide fixed by plants through the photosynthesis process as soil organic matter. Many factors affect these different processes including climate, soil characteristics, land management practices and a range of contaminants.

12.2 Information sources and literature

The Intergovernmental Panel on Climate Change (IPCC) provides the internationally accepted review of current information available concerning past climate trends, future scenarios and potential impacts (Houghton *et al.,* 2000; 2001). In addition, there are various special IPCC reports focussed on specific topics such as mitigation options (Metz *et al*., 2000), land use, land use change and forestry (Watson *et al.,* 2000) and an assessment of regional vulnerability (Watson *et al.,* 1998). Climate change modelling by the UK Meteorological Office's Hadley Centre are used by Hulme *et al.,* (2002) and the Welsh Scoping Study (Farrar *et al.,* 2000) to provide climate change scenarios for the UK and Wales respectively. Within the climate change scoping study for Wales information concerning observed trends in Welsh climate, scenarios for temperature, water balance, sea level and coastal flooding is presented (Farrar and Vaze, 2000). Potential impacts on the natural environment of Wales including terrestrial, freshwater and coastal systems and impacts on historical landscapes, human health and the Welsh economy are also discussed. Indicators of climate change have been identified for the UK as a whole (Cannell *et al.,* 1999), and specifically for Wales (Buse *et al.,* 2001). A national inventory of carbon storage in vegetation and soils in Great Britain has been created (Milne and Brown, 1997) together with estimates of carbon sources and sinks (Cannell *et al*., 1999). An inventory of greenhouse gas emissions for the UK, and separately for Wales, is also available (Salway *et al.,* 2001).

In addition to these scoping and review studies are a range of national and international projects addressing specific questions concerning impacts of climate change on soils and the consequences of these changes for forestry, agricultural production and a range of natural and semi-natural ecosystems. These projects have utilised various experimental techniques including field greenhouse, open-top chambers, soil warming, infra-red lamps, transplantation studies and environmental transects (reviewed by Shaver *et al.,* 2000). Experimental approaches to changing rainfall patterns have been developed using rainshelters and irrigation systems (Jamieson *et al.,* 1998, Ineson *et al.,* 1998). A meta-analysis of the response of experimental warming on soil processes in a range of natural ecosystems has recently been carried out (Rustad *et al.,* 2001). Effects on agricultural production in the UK have been considered in a MAFF review (MAFF, 2000). Various soil models and global carbon models have been used to identify the current magnitude of the soil carbon sinks in different regions and how these may be affected under global change scenarios (e.g. Smith *et al.,* 1997, Potter and Klooster, 1997). Overall, there is a large volume of literature detailing experimental and modelling approaches to determining the effects of climate change on soils and their functions and implications for a wide range of ecosystems too numerous to list.

12.3 The current situation

12.3.1 Climate

Mean temperature of Wales has increased a rate of about 0.3 ^{o}C over the last century (Figure 12.1) (Farrar *et al.,* 2000). Annual precipitation in Wales has increased by 3% over the 20th century. Summer precipitation has fallen by up to 15% since the early 1900s with a trend towards wetter winters with an increase of nearly 10%. The summer of 1976 is the driest summer on record (60% below normal) with the winters of 1989/90 and 1994/95 being the two wettest winters. For the UK as whole, the intensity of precipitation has been found to be increasing in the winter and slightly declining in the summer (Osborne *et al*., 2000).

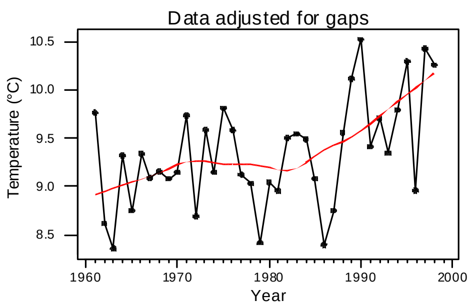

Figure 12.1 Mean annual temperature at Loggerheads, Cwmystwyth, Dale Fort, Swansea (Buse *et al*., 2001).

12.3.2 Greenhouse gas emissions from soil

Soils make a relatively small contribution to the fluxes of carbon dioxide in Wales. Industry and transport are the primary source whilst soils are estimated to only contribute 2% of total Welsh emissions. This is offset by a carbon sink in forests and woody biomass of a similar magnitude. There has been little change in the magnitude of these emissions and removals since 1990 (Salway *et al.,* 2001). No estimate of the contribution of soil to methane production is provided in the greenhouse gas inventory for Wales but they are likely to be small (discounting landfill sites). The major sources are agriculture, waste, coal mining and leaks from the gas distribution system. In contrast, soils have a major role in the production of nitrous oxide in Wales primarily due to emissions from heavily fertilised agricultural soils. Emissions are reported to have increased since 1990 (Salway *et al.,* 2001).

12.3.3 Soil carbon stocks

Welsh soils are relatively young by world standards and predominantly loamy underlain with acid bedrock (See Chapter 2). The upper 15cm of these soils have been calculated to contain at 37 million tonnes of organic carbon (Chapter 7). Peats which represent 3.4% of soils in Wales have the highest concentration of carbon on an area basis at 46% compared to the 3.5 – 4.9% in arable and grassland soils (Chapter 7). Large stores of carbon will also be present in the lower soil but unfortunately it was concluded in this study that there is insufficient data to make any reliable estimates of the magnitude of this store. Elsewhere, existing inventory data have been used to estimate soil carbon stores at a range of scales however significant problems have been identified including; initial classification of vegetation and soil, inaccurate area estimates and unrepresentative values for C contents for soil and vegetation types (Garnett *et al.,* 2001). Global estimates of soil carbon have thus ranged from 700 – 2,946 x 10^{12}kg to a 1 metre depth in different studies due to these many uncertainties (Post *et al.,* 1982). UK estimates of soil carbon have been calculated from the National Soil Inventory and are estimated as 9838 Mt (Milne and Brown,1997). This is significantly greater than the 114 Mt estimated for vegetation. A study to specifically test the United Kingdom terrestrial C inventory by Garnett *et al.,* (2001) evaluated carbon stores in vegetation and soil in a UK moorland and compared these values to those in the national inventory for the site. Vegetation carbon was found to be accurate but soil carbon was three times lower than that in the national inventory illustrating the caution with which these estimates should be treated. Since mitigation options are sometimes based on a percentage change to the soil organic stock, an overestimate in the stock can lead to an overestimate of potential carbon sequestration rates as illustrated in a study of UK arable land (Smith *et al.,* 2000).

12.3.4 Evidence for climate driven changes in soil state and function

Many factors affect the quantity of carbon in soil including land use, management practices, climate and pollution. Analysis of the National Soil Inventory for Wales has identified a loss of organic carbon of 0.5% from the upper 15cm of Welsh arable and grassland soils between 1980 and 1996 (Chapter 7). However, the relative importance of agricultural practices and climate change in contributing to this loss is not known, but is clearly undesirable as this loss of carbon goes against the desired direction to increase soil carbon stores to help meet our obligations under the Kyoto protocol. Soil erosion may contribute to these losses and has been identified as occurring throughout Wales as a result of land use and management practices (Chapter 5).

Additional information on the current effect of climate change on Welsh soils may be drawn from water quality information. A trend for increased concentrations of dissolved organic carbon resulting in dark water has been identified at Plynlimon, Mid Wales (Figure 12.2). Similar trends have been reported in a survey of 20 upland catchments across the UK (Freeman *et al.,* 2001). There are various possible processes underlying this trend however the most likely explanation to date is a change in the breakdown of soil organic matter due to warming. The darker water rich in dissolved organic carbon has implications for freshwater productivity as it may affect transmittance of light and may be an important pathway for carbon loss from the terrestrial system which is generally ignored. It is likely that dissolved losses of carbon may a major pathway for carbon loss from peaty soils and nationally organic carbon loss in rivers was estimated to be of similar magnitude to uptake of carbon by wetlands and uptake by afforestation in Britain (Hope *et al.,* 1997).

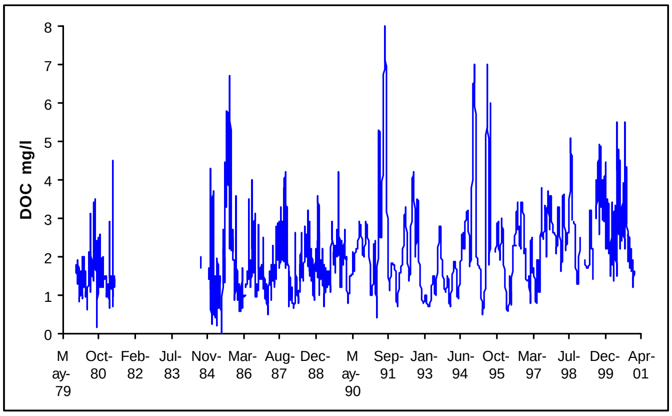

Figure 12.2 Increasing dissolved organic carbon concentrations in a headwater stream in Plynlimon (CEH Unpublished data).

Various experimental and modelling approaches suggest that other changes may be in progress in response to changing rainfall patterns and warmer climate. However, it is often difficult to relate changes to climate change alone and there is often insufficient long term data to identify trends.

12.3.5 Policy

The major international policy mechanism in place at present is the United Nations Framework Convention on Climate Change. The supreme body of the Convention, the Conference of the Parties has adopted the Kyoto protocol which set new targets for greenhouse gas emissions for developed countries. The UK target is to reduce emissions by 12.5% by 2008-2012 relative to 1990 levels with an additional domestic goal of cutting carbon dioxide emissions by 20% by 2010. As full implementation of the Kyoto protocol is only likely to have a small effect on the global climate, some climate change will inevitably occur and it is important that the impact of these changes are understood and possible responses identified. In the Climate Change Agreement in Bonn, July 2001, the range of activities contributing to increased carbon sinks which can be used as a component of emission reductions were agreed. They can include forest management, management of croplands and grazing land, and revegetation as long as they can be shown to have taken place since 1990. A cap for forest management was agreed for each country with emission targets, whilst no caps were placed on agricultural sinks. For the UK the forest management limit was set at 0.37 MtC or 1.5% of the Kyoto emission reduction target. The Marrakech Accord, November 2001 subsequently agreed that countries have to report on efforts to protect biodiversity in the context of sink activities.

12.4 The future situation

12.4.1 Climate

The range of scenarios published by Hulme *et al.*, (2002) for the UK recently suggest average annual temperatures may rise by between 1 and 5^{o}C by the 2080s, depending on the region and emission scenario. For Wales, the increase in temperature may be 2^{o}C. under low or medium-low emissions scenarios and up to 4 ^{o}C under a high emissions scenario. Warming may be greater in the summer and autumn than in the winter and spring with thermal growing days increasing by between 40 and 100 days. Diurnal temperature ranges decline in the winter slightly but increase in the summer. This closely follows changes in cloud cover which are expected to decrease in the summer and increase in the winter.

In Wales, there may be little change in annual precipitation but seasonality may increase. Precipitation in winter may increase by between 10 and 30% in some areas depending on the scenario whilst a decline will be seen in summer rainfall by between 30 and 40%. Precipitation as snow will decline substantially over the whole of the UK, and within Wales by between 50 and 90%. Average annual soil moisture may decline by between 10 and 20% but with the greatest declines of 20 – 50% in the summer and autumn. Relative humidity will also decline by up to 6%. The North Atlantic Oscillation (NAO) (a function of changing pressure patterns in the atmosphere) is a measure of the westerliness of winter weather. Hulme *et al.,* (2002) simulations indicate an increase in the NAO index, i.e. winters will become more westerly in nature which is characterised by mild, windy and wetter conditions. Net sea-level change by 2080 may be between 11cm and 71cm for Wales with simulations of storm surge height suggesting a change of 0 – 60cm although modelling uncertainties are very large.

12.4.2 Potential changes in soil state and function

As carbon dioxide concentrations will continue to rise, this may have beneficial effects on agriculture and forestry by encouraging photosynthesis and reducing transpiration. This may increase transfer of carbon to soils either through plant litter or rhizosphere deposition. However, changes in temperature and rainfall pattern may affect the turnover rates of carbon in soils such that the net effect on soil carbon stores is uncertain. The warmer temperatures may affect the geographical range of current crops and may enable marginal crops to become established in southern regions (MAFF, 2000). As there is a close link between vegetation, soil organic matter quality and turnover rates this may result in changes in soil organic carbon stores although it is difficult to predict in which direction. The effects of changes in rainfall pattern are difficult to predict as drier conditions in the growing season associated with increased seasonality may improve workability and reduce poaching in some wetter areas (Chapter 6). However, the predicted increase in rainfall in winter may offset some of these benefits at critical times and may contribute to a positive feedback through increased production of greenhouse gases such as nitrous oxide and methane from waterlogged soils. Some areas and crops may require more irrigation particularly fruit and vegetables (MAFF, 2000). The possibility of increased storminess could result in an increased potential for soil erosion (Chapter 5) with negative effects for productivity of linked freshwater systems and carbon storage in soils. Sea level rise could reduce the availability of land for production in some coastal areas.

12.4.3 Mitigation

The magnitude of future impacts could be reduced if further emission reductions of greenhouse gases are agreed and the potential for increasing the carbon store is developed. These carbon stores must be relatively stable at decadel or century timescales to be effective. Storage in soils is one example of a potential long term store if the new organic carbon is stabilised in soil pools with relatively long turnover times. Storage is achieved if the balance of inputs from plant productivity which fixes carbon dioxide exceeds that of decomposition by soil microbes in the soil which release carbon dioxide back into the atmosphere. The balance between these different processes is complex as there are feedbacks between the plant and soil and both processes are sensitive to climate. This creates the possibility of the magnitude of the carbon sink being affected by climate change thus creating a ‘carbon cycle feedback’. Changes in land use may be one option for increasing the size of the terrestrial carbon sink. However there are significant unknowns as current soil carbon stocks are uncertain, controls on decomposition poorly quantified and feedbacks sometime unexpected. It is important that a sufficiently long term view is taken to ensure that already stable stores are not depleted and that new carbon is not gained at the expense of other environmental qualities such as biodiversity.

12.5 Impact on soil function

12.5.1 Biomass, food and fibre production

Key soil functions which may affect biomass, food and fibre production include water holding capacity and nutrient supply. These functions will impact on production in combination with those climate variables directly affecting plant growth.

Direct affects of climate change on plant growth include faster crop development associated with higher temperatures. Whilst this may be beneficial for some crops, this can be detrimental if temperatures rise above the crop optimum reducing overall yield and quality (MAFF, 2000). Other adverse effects of temperatures above optimum can include lower pollination, higher respiration rates and increased susceptibility to late frosts. Implications for yield will depend on the individual crop and location. The predicted increase in soil moisture deficit during the growing season may have a negative effect on productivity during the growing season on light soils whilst increased winter rainfall may reduce workability of some heavier soils (Chapter 6). In grassland systems, warming may increase productivity of some species however temperature optima vary with species and there are also known interactions with elevated carbon dioxide concentrations and water stress. On poorly drained soils, a reduction in summer rainfall is likely to increase productivity and the potential for poaching and erosion. However, increased winter rainfall may increase the potential for erosion and transfer of nutrients and contaminants to freshwater (Chapter 5).

Grazing pressure will influence the response of grassland systems to these climate drivers. Grazing may increase the efficiency with which plants use additional carbon dioxide and the interaction with warming (Figure 12.3) (Harmens *et al.*,. Submitted). However, overgrazing may exacerbate the effects of drought by reducing rooting depth, increasing transpiration losses and increasing runoff and risk of erosion during intense rain events (Watson *et al.,* 2000). Overgrazing may cause a significant decline in soil organic carbon due to compaction and reduced production (Chapter 6) and may increase nitrous oxide productions due to high levels of excreta. High animal numbers are also associated with increased methane emissions. In forest systems, increased severity of soil moisture deficits may be detrimental to productivity on some soils whilst warming may be beneficial. Erosion of drainage ditch and forest roads due to increased storminess may occur as may an increased likelihood for wind throw. Increased outbreaks of pests and pathogens may negatively affect production in both agricultural and forest systems.

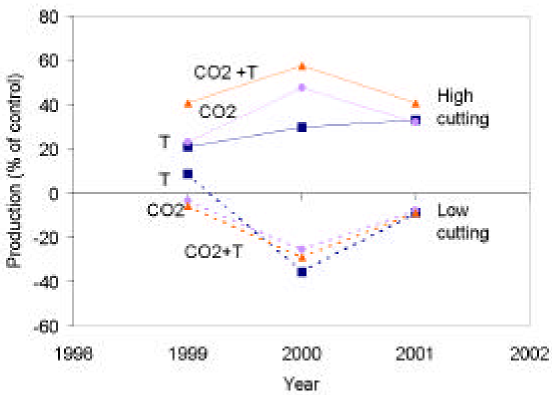

Figure 12.3 The positive effect of cutting on the response of plant production to elevated carbon dioxide (CO_2), elevated temperature (+T) and a combined treatment (CO_2 + T) relative to a control. Data from neutral grassland swards established in the Bangor solardome facility (Redrawn from Harmens *et al*. Submitted).

In all soils, water holding capacity may be reduced if prolonged summer drought in combination with higher temperatures causes an increase in the oxidation and breakdown of soil organic matter. This may be buffered in part by an increase in carbon inputs due to increased annual evapotranspiration and elevated carbon dioxide concentrations resulting in increased plant production and below-ground carbon inputs. As temperature limits decomposition processes more than plant production (Post *et al.,* 1982), it has been predicted that warming will overall cause a decline in soil organic matter (Kirschbaum, 1994). However, more recently, this has been questioned as no clear trends of decreasing soil carbon with mean annual temperature have been observed, and experimental work indicates enhanced soil respiration rates in response to warming are not maintained (e.g. Luo *et al.,* 2001). It has been suggested that physico-chemical reactions which transfer organic carbon to more stable or 'protected' soil carbon pools may be more responsive to temperature than the microbial reactions responsible for carbon loss from soils (Thornley and Cannell, 2001). The combination of these physico-chemical reactions and net increases in plant production together may result in no net loss of soil carbon in response to warming.

Nutrient supply may be increased with warming due to increased soil microbial activity. This may be particularly important in influencing productivity in upland grassland and forest systems. This temperature effect is likely to vary both with soil horizon and ecosystem type (gren *et al.,* 1996) and within ecosystem depending on the stability of the organic matter (Anderson, 1991). The effect of drought is likely to be greatest in waterlogged soils whilst in drier soils, soil activity and thus nutrient availability may decline with soil moisture. In summary, microbial activity is highest at about –0.01Mpa and decreases as soils become dry (< 5 to –10 Mpa) or saturated (0 Mpa). (Nadelhoffer *et al.,* 1995). Combining the temperature with an inbuilt correction factor for deficiencies for water in actual evapotranspiration provides the strongest predictor for both NPP and decomposition (Anderson, 1991).

Evidence for these predictions have been observed in some studies. An average increase in nitrogen mineralisation of 46% has been identified in a recent meta-analysis across a range of ecosystems although variable responses were recorded (Rustad *et al.,* 2000). Surprisingly, responses could not be predicted from climatic, geographical or environmental variables. The impact of drought is equally uncertain as illustrated in an experimental study in a UK calcareous grassland. Warming was observed to decrease nitrogen mineralisation by 7.5% whilst drought caused an increase of 11.8% (Jamieson *et al.,* 1998). These findings were contrary to predictions and were hypothesised to be due to a decline in plant litter inputs by an alleviation of drought and freezing by the treatments. A strong influence by plants on soil processes has also been observed in forests. Soil respiration is primarily driven by plant metabolites in forests supplying up to 50% of carbon required by soil microbes directly through the roots (Valentini *et al.,* 2000, Hogberg *et al.,*. 2001). A final consideration is that shifts in species composition in grassland and woodlands in response to climate change may alter the quality of litter inputs and thus nutrient availability (e.g. Chapin *et al.,* 1995, Potter and Klooster, 1997). These findings highlight the difficulty of predicting changes due to the complex interactions between plants and soil.

12.5.2 Environmental interaction

Changes in soil function may have important implications for the production of greenhouse gases and the quality of drainage water. The total global warming potential of UK greenhouse gas emissions is made up of the following: carbon dioxide 80%, methane 11%, nitrous oxide 7%, industrial gases 2% (MAFF, 2000). During 1990, emissions in Wales alone were estimated to be 10.8 Mt carbon dioxide, 1.6 Mt methane and 0.9 Mt nitrous oxide (Salway *et al.,* 2001). There are many sources of these three gases of which one is soil. Emissions occur from soils under natural conditions but many factors influence the magnitude of fluxes including climate, management practices and atmospheric deposition. In some situations, climate change may increase fluxes of these gases producing a positive feedback to climate. For example, methane and nitrous oxide emissions are likely to increase in soils which are warmer and wetter. However, reduced summer rainfall and increased frequency of drought may reduce emissions. To complicate matters still further, these changes may only be temporary as soil microbes equilibrate to the new more dynamic system over several years. An example of this transient response was observed in a riparian wetland in Mid Wales where methane and nitrous oxide fluxes were observed to return to pre-drought levels after successive droughts (Figure 12.4) (Hughes *et al.,* 1999). Migration of the soil microbes which produce the two gases to a new water table level in the wetland appears the best explanation for this phenomenon. This finding is important as most wetland methane models do not include acclimation and thus model output may underestimate fluxes in response to repeated drought.

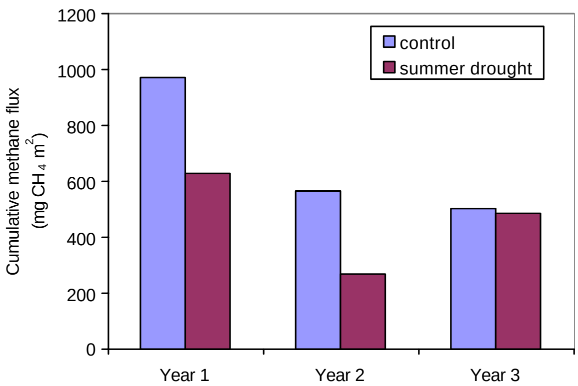

Figure 12.4 The effect of successive droughts on methane production from a small Welsh riparian wetland showing a return to control rates in Year 3 the predicted reductions in response to drought in Years 1 & 2 (Hughes et al. 1999).

The controls on carbon dioxide release from soils are also complex. Increases in soil microbial activity due to warming and drying of soils may result in enhanced carbon dioxide release from soils. However, the response of any particular soil will depend on current constraints on microbial activity. Net carbon dioxide flux from the ecosystem as a whole depends on the balance between carbon dioxide release from the soil and carbon dioxide fixation by plants and the latter is also likely to increase in response to climate change (Anderson, 1991). However, net carbon dioxide balance is highly variable between seasons and years and highly dependent on land use (e.g. Schimel *et al.,* 2001) making future changes difficult to predict. In addition, a decline in the increase of respiration in response to warming after one or more years has been reported (e.g. Luo *et al.*, 2001, Rustad, 2001). This decline have been attributed to limited supply of labile C sources for soil microbes and is likely to be observed in systems with low carbon storage (Luo *et al.,* 2001, Peterjohn *et al.,* 1994). Similarly, increases in plant productivity have been found to decline in response to warming and are thought to be associated with limitations in soil nutrient supply for plants and declines in soil moisture (Arft *et al.,* 2000). These interactions between plants and soil and different environmental variables emphasise the difficulty in predicting the potential direction, timing and magnitude of responses to climate change.

Impacts of climate change on the quality of water draining soil have been found to be highly variable. In a boreal system in Norway, nitrate and ammonium concentrations in drainage water were enhanced in response to warming and elevated CO_2 for three years suggesting increased release from soil nitrogen stores (Lukewille and Wright, 1998). No significant effect on any other major ion, organic-N, organic-C or total-P was observed (Wright, 1998). In contrast, no long-term effect on inorganic-N concentrations were observed in drainage water from three soil types of an upland acid grassland site in a manipulation study in Cumbria, UK (Ineson *et al.,* 1998). This difference may be due to the different nitrogen limitations at the different sites: Increased plant uptake was assumed to mask increased nitrogen release in the UK soil whereas nitrogen saturation of vegetation due nitrogen deposition were thought to have resulted in leaching of released nitrogen in the Norwegian study. Thus, the effect of warming may depend on the nitrogen status of individual ecosystems. Both responses are surprising when compared to the strongly positive relationship between nitrate concentrations in freshwater and the severity of winter temperatures observed across 22 upland UK sites (Monteith *et al.,* 2000). This relationship would imply that warming should cause a decrease in nitrate concentrations by reducing the severity of winter temperatures. Clearly, there is much still to learn concerning the underlying controls on the nutrient leaching potential of soils and the interaction between abiotic and biotic factors in both the terrestrial and freshwater environments.

Warming has been associated with increased concentrations of dissolved organic carbon freshwater draining 20 of 22 upland UK sites (Freeman *et al.*, 2001). This is thought to be due to increased decomposition of soil organic matter. However, in the CLIMEX study no changes in organic carbon were observed in response to experimental warming (Wright, 1998). This is an understudied area and may be of critical importance in determining the carbon balance in upland systems as dissolved carbon losses may be the dominant pathway for carbon loss exceeding the net gaseous flux of carbon in peat-dominated catchments (Billett *et al.,* 1997). An important confounding effect may be the recovery from acidification in these systems which will increase the solubility of organic acids and thus concentrations of dissolved organic carbon in freshwaters. The quality of the organic carbon may also be critical in determining the rate of transformation in freshwater systems. Increases in phenolic compounds resulting from a down regulation of a key soil enzyme in response to warming may decrease its utilisation in freshwater systems and increase still further the amount of dissolved carbon reaching the oceans (Freeman *et al.*, 2001).

A review on the effects of drought on water quality, particularly after re-wetting was carried out for the UK in 1998 (Leeks *et al.,* 1998). At drought break, increased concentrations of metals such as manganese and aluminium were reported in addition to pulses of nitrate and sulphate. More recently, mobilisation of metals have again been predicted across several ombrotophic peatland sites in the UK following droughts (Tipping *et al*., 2001). It is proposed that generation of sulphuric acid in the peat at drought break mobilises metals accumulated since the industrial revolution. These metals can leach into streams and rivers with potentially negative effects on freshwater biota.

12.5.3 Provision of a platform

Changes in water regime will have a significant effect on the stability of infrastructure slopes which make up a large proportion of UK transport networks. Changes to the water content of clay materials leads to shrinking and swelling causing volume changes and areas of reduced strength. Volume changes affect the serviceability of embankments, whilst reduction in strength can initiate failure. The cost of emergency repairs is high and the disruption to transport networks affects many other sectors. The effect of increased failures will be increased sediment load for drainage systems and rivers and increased risk of transfer of contaminants to freshwater and marine systems. Shrinking and swelling may also increase disturbance to the foundations of domestic and commercial properties in some clay-dominated areas.

12.5.4 Support of ecosystems, habitats and biodiversity

Maintenance of appropriate soil conditions are required to support ecosystems and maintain habitats. Sensitivity to changing soil conditions are likely to be greatest in semi-natural habitats with large carbon stores. Soil changes may be greatest here and the associated plants most sensitive to changes in both moisture conditions and nutrient availability. Impacts on animals are often not studied although they may be expected to respond to changes in plant species composition. Implications for soil biodiversity is poorly understood but may be significant in some soils (e.g. Zogg *et al.,* 1997). Within Wales, there are a range of experimental studies underway to identify specific responses of individual ecosystems to a variety of climate change scenarios. Most of these projects are in progress and it is therefore too early to draw conclusions. Some studies include interactions with other drivers of change such as grazing intensity, acidification and nitrogen deposition which are likely to have a major influence on ecosystem responses. Further work is needed if we are to increase our understanding of potential impacts across a full range of Welsh ecosystems.

12.5.5 Provision of raw materials

Raw materials of interest may include peat extraction, clay supply and top soil. It is unlikely that climate change will have a significant effect on the supply or economics of the supply of these raw materials.

12.5.6 Protection of cultural heritage

Degradation of waterlogged soils in response to the fluctuating rainfall pattern may expose some previously buried artefacts to the air resulting in reduced survival of remains (Farrar *et al.,* 2000). Lowering of fluctuating water levels or pH changes may also have significant impact on preservation (Castledine, 1990). The pollen record in peaty soils may also be affected by oxidation reducing information in the upper peat layers. Sea level rise may lead to inundation and erosion in coastal areas leading to loss of, or damage to, archaeological remains which are often concentrated in coastal areas. High river volume and increase flood frequency may also lead to increased soil erosion in heritage sites in estuarine areas (Farrar *et al.,* 2000). The combination of wetter winters and warmer summers may make soils more vulnerable to poaching which is a major source of damage to archaeological sites (Farrar *et al.,* 2000).

Climate effects on species composition could significantly affect the landscape and cultural heritage. Climate change may contribute to increased nitrogen availability in heathlands which can result in a shift to dominance by grass species. A warmer climate may also increase invertebrate herbivory which can play a critical role in driving species composition in heathlands. An increase in colonisation by woody species in new areas are predicted in response to predicted climate change. This would visually alter the landscape and could affect above-ground sites and buried features due to root-growth and damage following tree-blow (Farrar *et al.,* 2000).

12.6 Policy responses – present and future

The Kyoto protocol provides the current framework to counter the potentially severe consequences of climate change. The UK agreed to reduce greenhouse gas emissions by 12.5% by 2008-2012 compared to 1990 levels. In addition, a domestic goal of cutting carbon dioxide emissions by 20% by 2010 has also been made. The principal of allowing increased carbon sinks to contribute to these emission reductions was also agreed. In the Bonn Agreement on Climate Change it was agreed these sinks could arise from management of croplands and grazing land, afforestation and reforestation. A limit was set on the amount allowed for forest management for each country. This was set to 1.5% or 0.37 Mt for the UK. The principal of emissions trading and joint implementation was also agreed at Bonn. Emissions trading enables countries with binding emission targets to buy and sell emission reductions amongst themselves. Joint implementation allows one country with a target to receive an emission credit for performing emissions-cutting projects in another country. Finally the ‘clean development mechanism’ is similar to joint implementation but with projects undertaken in developing countries with no binding targets at national level.

Clearly for any of these agreements to be possible, greenhouse gas emissions have to be quantified at the national level together with national carbon stocks and sinks. Whilst estimates have been prepared, there is significant uncertainty about the numbers. Specific recommendations to improve our understanding of the impact of climate change on soil state and function and its potential role as a carbon sink include:

- **Quantification of current soil carbon stocks**: There is need for an improved soil carbon inventory for Wales to include soil sampling to greater depths in more locations covering all major land uses. Major uncertainties are associated with non-agricultural soils, carbon storage in deep soil layers and estimating a representative soil carbon content.

- **Regular monitoring of the state of Welsh soils:** A network of sites is required to enable changes in soil state to be monitored. The Environmental Change Network terrestrial site located in the Snowdonia National Park in Wales provides one obvious site but this needs to be significantly expanded to a wider network to cover other major soil types and land uses. To facilitate interpretation of the data, some sites could be located where other monitoring programmes already exist for land use, biodiversity, atmospheric deposition and/or water quality purposes. This would provide added value for all concerned providing an ecosystem approach to monitoring in Wales.

- **An analysis of current soil carbon sinks and options for new and enhanced soil sinks:** An assessment of the implications of possible shifts in land management practices and atmospheric pollution levels in response to different socio-economic and political drivers is needed. This should include the potential benefit of reductions in grazing pressure, forest management or afforestation in enhancing the soil sink. Reductions in grazing are likely to result in increased carbon storage where grazing has been extensive and heavy although the magnitude will depend on initial conditions (Watson *et al.*, 2000). Moderate levels of grazing can increase productivity and incorporation of carbon in some soils. Carbon accumulation could extend for 25 – 50 years depending on the rate of plant productivity response. Protection of previously intensive grazed land and reversion of cultivated lands to perennial grasslands may also increase both soil and vegetation carbon pools over a time period of about 50 years (Watson *et al.*, 2000). Changes in forest management could also substantially increase carbon stocks in vegetation. The effect on soil carbon stocks is less certain and may be negative on wetter soils due to drying of the soils. An analysis of sinks in native woodlands with mixed species and age structure should be included to assess the consequences of changes in woodland management in line with the Woodland Strategy for Wales. Management practices (e.g. site preparation, fertilisation, liming, harvesting technique) over a full rotation or equivalent need to be considered in any analysis as should the effect of disturbance for both dissolved and gaseous losses of carbon.

- **Improved understanding of the underlying controls of soil functions: S**ignificant areas of uncertainty remain in our understanding of many processes in the soil which will have a critical influence on the capacity of the soil to provide a range of functions including carbon storage. Key issues include the many controls on soil respiration, the feedbacks between plants and soil processes, the importance of extreme events, and the role of soil biota.

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13. PROTECTION OF REPRESENTATIVE SOIL SYSTEMS

Summary

- There are legal precedents for designating the best representatives of the full range of floristic, faunal, geological and physiographic features in Wales,
- The principle of designated sites should be extended to soil, even if such designations are voluntary and lack legal status.
- Existing designated sites include a wide range of the soil types identified on the National Soil Map of Wales, however representation is not considered adequate.
- Land in certain classes of ownership and in schemes such as Tir Gofal offer opportunities to protect representatives of the full range of soil landscape systems that incorporate soil types, soil biological communities, soil heritage sites and soil features. A recognised network under the management of CCW and with standard recording formats is recommended but will require a comprehensive study of the target sequences, types and features to be included.
- Rare and less disturbed soils support species-rich ecosystems, and are therefore of value to nature conservation. However this is seen by the author to be a separate issue from the scientific and educational interest and value of designating and protecting a representative range of all soil landscape systems and their component parts, not just those that are rare or least disturbed. All soils should be seen as possessing intrinsic value, not just those that are considered rare or that support semi-natural vegetation.

13.1 Background

UK environmental conservation practice is founded in part on a legal duty to identify, designate and protect sites of special scientific interest that represent the best examples of the full range of UK flora, fauna, physiography and geology. Gradual degradation and loss of designated sites had led to policies for nature conservation and re-creation in the wider landscape; hence projects such as LIFESCAPES and agri-environmental schemes such as Tir Gofal. Consideration of the place of soil conservation in this general framework began in Scotland, and Scottish Natural Heritage retains the role of Lead Soil Agency within the UK for that purpose.

This chapter reviews the background to conservation practice and the treatment of soil conservation to date. It then goes on to draw conclusions and recommends a conceptual approach and set of actions for the future.

13.2 The current situation

13.2.1 Conservation of flora, fauna, physiography and geology

Current provisions for the conservation of flora and fauna and for physiographic and geological features stem from Cmd 7122 (Ministry of Town and County Planning 1947). Growth in membership of organisations such as the Royal Society for the Protection of Birds is testament to the popularity of nature conservation. National policy for nature and geological conservation has been founded on the designation of sites of 'interest'. Cmd 7122 was initiated '…..to preserve and maintain places which can be regarded as reservoirs for the main types of community …as well as …physical features of special and outstanding interest'. The 'interest' referred to is scientific although the educational value of these sites has been identified more recently. 'The series [of sites] as a whole should take fair account of the varied requirements and interests of the several different lines of scientific approach…' (Ministry of Town and Country Planning 1947).

The conservation of living resources is regarded as of more than just scientific interest by Moore (1987) who refers to the significance of time. Species and habitats that have taken evolutionary time to develop can be destroyed in less than human generational time thus influencing the course of future evolution. This more philosophical approach is undoubtedly one to which many in the conservation movement would subscribe.

This added dimension, concern for the future, can be regarded as less of an issue in the conservation of geological and physiographic features. Wimbledon *et al* (1995) discuss the origins and rationale behind geological conservation and detail the factors involved in site choice. Ellis *et al* (1996) in the introductory volume to the Geological Conservation Review cite research, environmental forecasting, education and training as justifications for the creation of a network of sites (apart from the legal obligation) and also regard the sites as part of the nation's cultural and ecological heritage.

Over and above the establishment of UK Sites of Special Scientific Interest (SSSIs), the Government is obliged under the Habitats and Species Conservation Directive (97/266/EC) and the Conservation of Wild Birds Directive (79/409) to identify a suite of sites to form part of a coherent European ecological network, Natura 2000. In order to comply with these Directives, Government has established a set of Special Areas for Conservation (Habitats and Species) and Special Protection Areas (Birds). The Commission of the European Communities (2002) states that it could consider the extension of the annexes of the Habitat Directive to complete the so far limited list of soil-based habitats requiring special protection.

Under the Biodiversity Convention the UK has established a UK Biodiversity Action Plan (Department of the Environment 1994) which has led to the establishment of a framework of Broad and Priority Habitats with associated Statements and Priority Habitat Action Plans. Priority Species Action Plans exist for 391 species that have been given priority status including a number of soil-living invertebrates.

13.2.2 Conservation of soil

There is no provision in UK law for the conservation of particular soils through site designation. However it is commonly argued that the protection of a wide range of relatively undisturbed soils is an inevitable by-product of the various site designations that exist for the protection of flora and fauna. This position is supported by Cmd 7122 which includes within the description of factors to be considered '…distinctive characteristics imposed upon communities and species by differences in …soil..'. The conservation of soil types has remained incidental to the conservation of above ground flora and fauna. The Royal Commission on Environmental Pollution (1996) failed to recommend any change to this situation when it reported on the Sustainable Use of Soil. It has never been considered necessary or justified to fund a conservation review of soil sites such as those for flora and fauna (Ratcliffe 1977) and geology (Ellis *et al* 1996).

There are relatively few studies that have considered strategies for the conservation of soil types. Ball and Stevens (1979) conducted a questionnaire-based review of the opportunities for the conservation of relatively undisturbed soils offered by the conservation of ancient woodlands. Respondents identified 110 candidate woodlands, 11 of which are in Wales. Only about a half were designated in some way by the conservation agency. Ball (1993) reviewed the range of soil types present within Welsh conservation sites. Using a subset of designated sites for which there are published detailed soil maps, Ball concluded that 41 of Avery's (1980) soil subgroups out of the 49 thought to be present within Wales are represented (Table 13.1) A further three are highly likely to be represented and only *Disturbed Soils, Typical and Gleyic Brown Sands* and *Typical and Gleyic Brown Alluvial Soils* are not represented. Gauld and Bell (1997) report on a similar exercise for Scotland.

Such assessments fail to recognise the landscape context within which individual soil profiles exist as components of larger soil landscape systems connected by hydrological and other process-driven interactions. They also fail to assess the physical, chemical or biological quality of the soils present. The presence or absence of soil profiles qualifying as members of a particular soil subgroup is a very coarse measure of soil diversity. Lascelles and Jenkins (1995), in response to Ball's report, comment that a simple review of soils present within designated sites fails to identify specific reference or benchmark soil profiles. They identify six specific soil profile sites (Table 13.2) and recommend that soils be included in the Regionally Important Geological/Geomorphological Sites scheme in order to cater for the scientific if not the educational value of type soil profiles. A set of forty six soil profiles representative of the major soil groups in Wales has been identified by John Conway and Margaret Wood. Details are published on the web (Conway and Wood 1999).

Table 13.1 Soil subgroups in SSSIs (after Ball 1993).

Subgroup code	Soil subgroup	Frequency[1]
1.1	Raw sands	4
1.3	Raw skeletal soils	4
2.2	Unripened gley soils	3
3.11	Humic rankers	11
3.13	Brown rankers	17
3.21	Typical sand-rankers	4
3.23	Gleyic sand-rankers	2
3.41	Humic rendzinas	2
4.43	Brown rendzinas	4
3.44	Colluvial rendzinas	1
3.46	Humic gleyic rendzinas	1
3.61	Typical sand pararendzinas	4
4.31	Typical argillic pelosols	2
5.41	Typical brown earths	19
5.42	Stagnogleyic brown earths	6
5.43	Gleyic brown earths	1
5.51	Typical brown sands	3
5.71	Typical argillic brown earths	4
5.72	Stagnogleyic argillic brown earths	2
5.81	Typical palaeo-argillic brown earths	2
6.11	Typical brown podzolic soils	13
6.12	Humic brown podzolic soils	3
6.21	Typical humic cryptopodzols	1
6.31	Humo-ferric podzols	2
6.51	Ironpan stagnopodzols	15
6.52	Humus-ironpan stagnopodzols	1
6.54	Ferric stagnopodzols	1
7.11	Typical stagnogley soils	2
7.12	Pelo-stagnogley soils	3
7.13	Cambic stagnogley soils	15
7.21	Cambic stagnohumic gley soils	16
8.11	Typical alluvial gley soils	3
8.12	Calcareous alluvial gley soils	1
8.13	Pelo-alluvial gley soils	1
8.14	Pelo-calcareous alluvial gley soils	1
8.21	Typical sandy gley soils	3
8.31	Typical cambic gley soils	2
8.51	Typical humic-alluvial gley soils	1
8.61	Typical humic-sandy gley soils	1
8.71	Typical humic gley soils	4

[1] These relative frequency figures relate to a subset of 100 SSSIs

Table 13.2 Six benchmark soils in Wales (after Lascelles and Jenkins (1995).

Soil series	Soil subgroup	Grid reference
Bodafon	Typical podzol	SH471852
Hiraethog	Ironpan stagnopodzol	SH915597
Salop	Typical stagnogley	SH621791
Unnamed palaeosol	Iron humus stagnopodzol	SH645553
Crafnant	Shallow brown earth	SH658530
Cwm Idwal	Brown earth/gley/podzolic soils	SH6459

Scottish Natural Heritage became interested in Scottish soils as a component part of its natural heritage in 1994. As part of a preliminary study to a soil sustainability strategy for Scotland , Gordon (1994) reviews the role of designated sites and concludes that these '…have a particular value for scientific research and education, underpinning ecosystem functions, palaeoenvironmental interpretation and helping to understand and increase awareness of aspects of …landscape heritage'. In the first of a potential series of reports on Soils and Nature Conservation, Puri (2001) documents the nature conservation value of soils in Natural Heritage Zone 21 (Moray Firth). The soils of this zone have been extensively altered by arable cultivation and afforestation, and the loss of shallow surface soil layers is regarded as significant. Using factors such as *rarity*, *uniqueness*, *ecological value* and *cultural value*, Puri identifies a small number of soils regarded as of high nature conservation value. The cultural context of certain soils is also regarded as of value. Plaggen soils, much deepened soils resulting from the historical addition of kelp and beach sand, are sited as one of only five soil types of high nature conservation value because of their cultural history. Green (2002), in an internal paper, proposes a framework for interpreting the value of the soil resource of the UK for nature conservation, and recommends the constitution of an expert panel to take the proposed scheme forward. *Intrinsic* soil values are distinguished from *functional* values, and a set of 15 criteria are proposed for the assessment of nature conservation value. Green places these on a scale of intrinsic through to functional value (Figure 13.1).

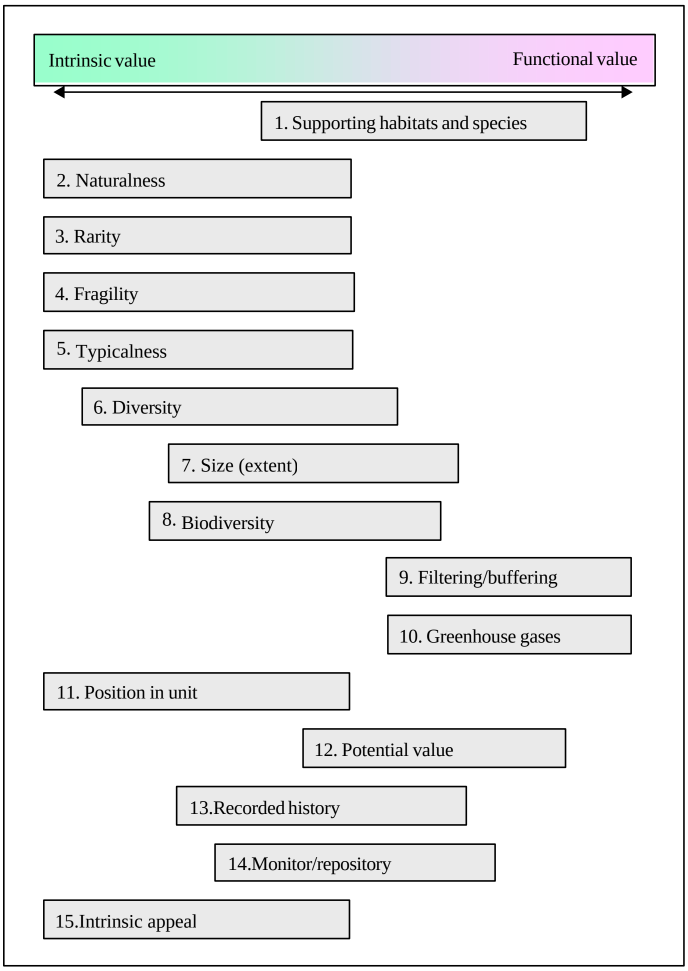

Figure 13.1 Framework for assessing the value of soils in nature conservation (after Green 2002).

The Department for Environment, Food and Rural Affairs (2001) recognises the interdependence of soils and terrestrial ecosystems in the context of designated sites and habitats, and alludes to the importance of appropriate soil management in the long term conservation of such sites.

At the European scale, the Council of Europe (2002) has concluded that '…the importance of certain soils is such that they need to be protected for their intrinsic value'.

13.2.3 Conclusions on the current situation

A number of conclusions can be drawn from this review.

Scientific (and educational) interest has justified site designation for the conservation of representatives examples of natural resources but not of Welsh soils. Considerable resources have been invested in establishing comprehensive networks of designated sites in order to represent the full range of floristic, faunal, geological and geomorphological diversity in the UK, not just those that are most rare or least disturbed. This effort has been driven by policy and legislation based on the perceived scientific and educational value of preserving for the future the best examples of the full range of these resources. No statutory obligation of this sort exists for soil but a number of authors (Ball and Stevens 1979, Ball 1993, Lascelles and Jenkins 1995, Gauld and Bell 1997, Puri 2001) support the need for similar approaches and propose schemes and/or identify specific sites.

The network of nature conservation-driven designated sites is conserving a wide range of soils by coincidence, but not all soils, soil systems or soil features of scientific or educational value are caught in this net. The conservation of soils has been an incidental by-product of floristic and faunal conservation. Most authors conclude that the majority of taxonomic soil types have been included in designated sites but recognise the dangers of such an approach in failing to protect the full range of soils and soil features of scientific and educational interest.

Various frameworks have been proposed as soil 'valuation' schemes in order to provide a set of targets for protection and to evaluate candidate sites, but none has been widely accepted and applied. The majority of studies focus on the soil types identified in conventional schemes of soil classification to characterise the range of soil conditions, but place value on the apparent absence of 'disturbance' and the rarity of a particular soil. These are recognised as difficult concepts. The extent of man's impact on the direction of soil development in Wales has been discussed earlier in this report (Chapter 2). Does the development of stagnopodzols in response to early forest clearance represent 'disturbance', or is the concept most usefully restricted to the impacts of modern and current land use? The plaggen soils of the Moray Firth are the result of gross past human intervention but are now held up as having exceptional cultural value. Perceptions of rarity are influenced by the geographical scale (Wimbledon *et al* 1995) of the review or programme of site designation. Some soils are rare in one part of Wales but extensive in others, some may be rare in Wales but extensive in other parts of the UK or Europe.

Lascelles and Jenkins (1995) identify palaeosols and soils containing archaeological heritage features as particular classes of soils worthy of protection. The superficial layers within normal plough depth are, by inference, regarded as important by Puri (2001). Parent materials and horizon development are mentioned by Green (2002), who also places importance on features that reflect long cultural history, on the biodiversity of a soil's fauna and flora and on its functional performance. The latter is an even more difficult concept to interpret in this context.

A network of identified 'benchmark' soil profiles has been proposed for Wales. Ball and Stevens (1979), Lascelles and Jenkins (1995) and Woods and Conway (1999) have established the foundations of a network of sites across Wales for the identification of sites with particular soils and soil features. The RIGS scheme has been proposed as a framework for these designations. More will be required to make this comprehensive and unless benchmark soils coincide with designations for other purposes they will remain unprotected. A question remains over the scientific and education value of isolated soil profiles as opposed to suites of profiles set within identified soil landscape systems.

13.3 The future situation

A number of reasons have been proposed for identifying and 'designating' sites on the basis that they contain soils or soil features of interest and value to Wales and its people. A network of 'benchmark' soil types would bring soil in line with all other natural resources for which similar provisions exist. But are benchmark profiles chosen for their rarity or semi-naturalness the correct target?

13.3.1 Future management of the Welsh environment and stock of natural resources

Soil is a component of the biosphere and of the lithosphere; indeed it is the only natural resource that combines both. Soil processes govern the working of the terrestrial environment. Soil is the engine room that drives the recycling of dead organic matter and its elemental components, and its performance is reflected in the composition of the atmosphere, freshwaters and of the ecosystems founded upon it. These processes and the fluxes of materials that pass into and out of the soil are not fully understood. More over the stock of trained and experienced scientists to investigate these issues is low, as is the public understanding of the fundamental and far-reaching importance of soil. The interest that justifies protection of representative examples of Welsh soil landscapes should not be vested solely in the rare, unusual or undisturbed but in all soils under all forms of land use. **These are compelling scientific and educational reasons for the identification and 'conservation' of a number of sites that contain high quality representatives of the full range of soil landscape systems, soil types, soil features and soil conditions in Wales.** But how might this best be achieved?

13.3.2 Future conservation of Welsh biodiversity

There is confusion in the literature between arguments for the conservation of type soils and the conservation of soils on the basis of the habitats that they support. While there are strong arguments for increasing the soil science that goes into the management of existing habitats, and the improvement of biodiversity in landscapes such as farmland and intensive monoculture forestry, this is a separate issue from the protection of soils as a scientific and education resource.

13.3.3 Future conservation of the heritage of Wales

Soils contain and express significant elements of the cultural and archaeological heritage of Wales, i.e. landforms and buried features and artefacts. Where gross features are known to exist, they form part of Sites and Monuments Records managed by the Archaeological Trusts. Finer and more ephemeral features are undoubtedly at risk of destruction but it is difficult to identify a practical solution to this threat.

13.3.4 Proposed way forward

Large parts of Wales are already subject to forms of designation that more or less restrict and/or control land management. Rather than seeking a further separate set of designations, **it is proposed that further and more detailed work be conducted on the opportunities that existing designations and schemes offer to the protection of representatives of the full range of Welsh soils and soil features. Significant tracts of Wales are owned by organisations whose land management objectives dovetail with the concept of a network of soil conservation sites and this is a further opportunity that the Welsh Assembly Government should explore.** Establishment of a network of sites can build on work that has gone before but to be comprehensive it will require the following:

1. An agreed set of target soil landscapes, soils and soil features;
2. Agreement over what constitutes a 'site' in this context;
3. Identification and delineation of the network of sites;
4. An agreed format for recording the soils and soil features at each site;
5. Allocation to an appropriate authority of responsibility for overseeing the network;
6. An agreed system for adding protection of the soils and soil features to the broader management prescription for each site;
7. Agreement as to the range of permitted practices on each site (issues such as demonstration, exposure of the soil and/or soil features for educational or scientific purposes).

Each of these is now discussed in more detail.

Target soils and soil features

The purpose of identifying sites is the preservation of high quality examples of the full range of soil conditions into the future. Table 13.3 offers a target list.

Greatest attention has, by implication, to be given to the rarest, most extensively damaged and most ephemeral and vulnerable soils and soil features as these will be the most easily lost.
<u>Rarity.</u> At least initially, it is proposed that particular consideration should be given to soils and features that are rare at the European scale.

Undisturbed soils, ie those that demonstrate a minimum direct or indirect impact from current land use and industrial emissions, will dominate selection on grounds of rarity and vulnerability. They are important in this context as scientific 'controls' for comparison with soils that have been altered by human activity. They are also more likely to have distinctive soil biological communities.

Table 13.3 Target list of soils and soil features.

Identifier	Soil or soil feature
Soil landscapes and sequences – topographically- and hydrologically-connected soil sequences (catenas) developed in a reasonably uniform parent material	
	Lowland and upland representatives for each of the main lithologies and parent materials in Wales
Soil types – the main forms of soil development in Wales	
	The soil subgroups present on the National Soil Map of Wales
	Representatives within each soil subgroup from contrasting parent materials (soil chemistry, mineralogy and ecosystems)
	Representatives within each soil subgroup from contrasting land uses and management regimes (superficial layers and soil ecosystems)
Soil landscape and cultural features	
	Natural and man-induced erosional, slip and depositional features
	Features representative of, or consequent from, historic and current forms of land and soil management
Soil profile features	
	Soil horizon types and sequences including palaeosols
	Pedogenic features (concretions, coatings, palaeo- features, structural features)
	Secondary mineralogies

The nature of a site

It seems likely that, in identifying candidates for category 1 in Table 13.3, sites will be identified that contain many of the target soil types, soil landscape and cultural features and soil features. The majority of sites will therefore be of significant extent and occupy whole subcatchments or hillsides. Where this is not the case, sites are still likely to be around a hectare in extent.

Identification and delineation of the network of sites

Heavy reliance will need to be placed on the accumulated knowledge and records of soil scientists with field experience in Wales. The concept of a 'panel of experts' as proposed by Green (2002) for the UK is a valuable one. The project is probably best led by the Countryside Council of Wales given their responsibility for other forms of site designation.

Site recording

Lascelles and Jenkins (1995) recommend the RIGS recording system. Systems employed in the Geological Conservation Review should be reviewed for their suitability. Consistency and computer-compatibility will be key.

Responsibility for the network

It is proposed that responsibility for establishment and management of a network of sites across Wales be allocated to the Countryside Council for Wales. CCW staff already have experience of managing such networks and have responsibility for many other types of designation.

Protection and the prescription and restriction of land management practices

It is recognised that no legal powers exist that specifically relate to the protection of soils and soil features. However, opportunities do exist where prescriptions targeted at the conservation of soils and soil features might be applied or added to existing prescriptions targeted at other conservation objectives.

1. Government departments and organisations (CCW, Cadw, FC, MoD, DSTL) own or control management over significant areas of Wales.

2. Government departments and organisations (CCW, Cadw) provide financial inducements to private land owners under schemes such as Tir Gofal, ESAs, and Nature Reserve Agreements to direct the landowner's management of the land toward certain defined objectives.
3. Private and charitable landowners with corporate environmental goals (utility companies, National Trust, Naturalists' Trusts, RSPB and The Woodland Trust) have control over significant tracts of Wales.

Many of the required components of the network could be hosted via these opportunities without recourse to legislative powers.

Determining management prescriptions

It is envisaged that this would be part of the remit of the expert group that would identify the scope and membership of the network of sites. Agreed strategies would be required for activities such as educational visits, scientific research and other forms of investigation that required disturbance of the soil. The educational function could be met via permanent displays either of real exposures or of soil monoliths.

13.4 Gaps in soil information

Sufficient information is available to construct the list of target soil sequences, soil types and features.

Insufficient information will normally be available for the detailed description of soil conditions at individual sites. Additional field description and survey will be required with supporting analyses.

Incomplete information is available on features such as palaeosols. Significant amounts of information is in the 'grey' literature or in private archives and will be difficult to collate. Much may come to light with formation of the panel of experts.

13.5 Impact on soil functions

Establishment of a network of soil conservation sites will assist the National Assembly of Wales in understanding better all the functions of soil, and in enhancing the functional capacity of Welsh soils to *support ecosystems, habitats and biodiversity* and *to protect the cultural heritage*.

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14. CONCLUSIONS

This chapter provides an analysis of the issues in relation to soil functions by considering each one under the following set of headings:

- *The relative importance and extent of each issue* – Does the issue impact severely on soil functions? Is it localised or widespread?
- *The level of understanding and characterisation* – How good is the scientific understanding of the issue? Are there adequate spatial and temporal data to describe the effect of the issue?
- *The level of current control* – What control legislation / guidance is in place? How effective is it at tackling the issue?
- *Ease of control by Welsh Assembly Government (WAG)* – What steps can WAG take to strengthen existing controls? Can new controls be introduced? What further information is required?

14.1 Soil loss to development

Relative importance/extent

- This issue has the potential to entirely eliminate soil functions, although soil can remain in an amenity role (gardens and parks) and may be important for controlling infiltration of rainwater in urban situations.
- This issue has a high local impact, and is extensive in the main urbanised areas of Wales (south and northeast).

Level of understanding and characterisation

- The issue is poorly characterised in Wales as no national data are collected. There is limited information from local authorities.
- Technical aspects on the care, storage and re-use of soils to maintain quality are relatively well known from research undertaken on behalf of the minerals extraction industry. The science surrounding transplantation of ecosystems is less well developed.

Level of current control

- Current planning controls to protect soils from development are poor. Those that exist are targeted towards the protection of better quality agricultural land.
- Ecologically valuable land which has a low agricultural value is not adequately protected, although the Environmental Impact Assessment Directive may be helpful in this respect.

Ease of control by WAG

- The Technical Advice Notes used to guide planning policy should be revised to specifically include wider aspects of soil protection.
- The Minerals Technical Advice Notes currently under revision could provide a useful model for revision of TANs, especially in the area of handling, storage and re-use of soils from development sites.

14.2 Soil loss to mineral extraction

Relative importance/extent

- Currently construction materials and aggregates together with some coal are the main minerals produced in Wales. There is an extensive legacy of waste material from historic mining activity including metalliferous mining.
- Mineral extraction has a high local impact on soil functions and is geographically dispersed throughout Wales.
- Extensive peat extraction has now ceased in Wales, although some small scale operations remain.

Level of understanding and characterisation

- The number and extent of mineral workings are well known from information held by the British Geological Survey and the Environment Agency. These information sources are regularly updated.
- There are relatively good estimates of the extent of lowland peat in Wales. The total extent of peatlands in Wales is poorly known and estimates differ widely.

Level of current control

- Current policy documents ("Minerals Planning Policy Wales" and its related Minerals Technical Advice Notes) recognise the importance of soils and give detailed guidance on stripping, storage and restoration.
- Most peat soils are relatively well protected by "Minerals Planning Policy Wales", planning regulations and site designation. The current level of protection for small areas of relatively low conservation importance and areas of degraded peat is less clear.

Ease of control by WAG

- WAG should encourage and monitor implementation of the main control measures already in place and contribute to revisions as new techniques become available.
- Better estimates of the total peat stock in Wales are required.

14.3 Soil loss by erosion

Relative importance/extent

- This is a geographically extensive issue occurring as a result of land use and management practices.
- Erosion from enclosed farmland and open moorland is particularly important for impacts in off-site aquatic systems.
- Footpath restoration and maintenance due to erosion is a major cost to the countryside management industry.

Level of understanding and characterisation

- There has been considerable site-specific process research into soil erosion.
- National data sets describing the extent of the issue are lacking.

Level of current control

- Problems of erosion are recognised by the forestry and construction industries and codes of practice have been developed.
- Farming is a major cause of soil erosion but control measures do not seem to have been adequate in view of the severity of the off-site impacts.

Ease of control by WAG

- WAG should encourage and monitor implementation of the control measures developed for forestry and construction and contribute to revisions as new techniques become available.
- WAG should seek to increase awareness of the environmental and economic costs of soil erosion amongst the farming community.
- Soil conservation practices and standards should be introduced into Tir Gofal and other support schemes for agriculture to encourage adoption of best practices.

14.4 Soil structure

Relative importance/extent

- This is a potentially important issue mainly for agricultural soils but quantitative data are lacking for Wales.
- It may have importance in relation to erosion losses and flooding if structural degradation reduces the permeability of soils

Level of understanding and characterisation

- Virtually no data exist on the structural condition of Welsh soils.

Level of current control

- Good practice guidance is available to farmers and the forest industry.
- Soil management is not currently included within agri-environment schemes such as Tir Gofal.

Ease of control by WAG

- Data on soil structural condition in Wales from both survey and monitoring are required in order to assess the extent and importance of the issue.
- Depending on the outcome, inclusion of soil management obligations within agri-environment schemes may provide a mechanism to encourage adoption of best practices.

14.5 Soil organic matter

Relative importance/extent

- Sustaining organic matter content and quality is important for soil carbon storage, reducing the erodibility of soils, maintaining a capacity to retain contaminants and possibly for preserving biodiversity.
- Between 1980 and 1996 there has been a 0.5% decline in the mean organic carbon content of the upper 15 cm of Welsh soils under arable and permanent grassland.

Level of understanding and characterisation

- There are large uncertainties in the estimates of the carbon store in the 0-15 cm layer of the soil in Wales.
- There are too few data to estimate soil organic carbon below 15 cm.
- The response of soil organic carbon to future changes in climate and land use are poorly understood and cannot be predicted with any certainty.

Level of current control

- There are no specific controls to protect soil organic matter, but less intensive land use is likely to conserve soil organic matter (SOM).

Ease of control by WAG

- More detailed information is required in order quantify soil organic matter in Wales.
- A robust monitoring programme is required to assess changes in SOM.
- Research is needed in order to understand and predict consequences of climate and land use change on SOM.

14.6 Soil nutrient issues

Relative importance/extent

- The main concern is transfer of N and P to surface waters and emissions to the atmosphere of greenhouse gases and ammonia.
- The fragile nature of upland soils means that they are susceptible to damage either through nutrient enrichment or depletion.
- The high quality of Welsh water makes it an important resource to be protected from eutrophication.

Level of understanding and characterisation

- There is a large body of research information on soil nutrients.
- Regional survey information from the NSI and RSSS is available but is generally not analysed specifically for Welsh soils.
- There are insufficient data to quantify changes in soil nutrient status over time.

Level of current control

- A number of policy drivers already exist including various directives and standards for nutrients in waters such as the Water Framework Directive, EU Air Quality Policy etc.

Ease of control by WAG

- WAG should encourage and monitor implementation of existing control measures and contribute to revisions as new information become available.
- A consultancy document is currently available concerning the implementation within Wales of the Nitrates Directive and Nitrate Vulnerable Zones.

14.7 Diffuse soil contamination

Relative importance/extent

- Concentrations of heavy metals are close to or exceed proposed limits in many Welsh soils and this situation needs to be monitored particularly where soils are subject to known inputs.
- Radiocaesium contamination continues to be a significant, but relatively localised issue in north Wales.
- The presence of persistent organic pollutants (POPS) in soils is a significant issue, but there is little firm information to judge the relative extent and importance for Welsh soils.
- There is clear concern about the presence of pathogens in soils, but firm information is lacking about the extent and importance of this issue in relation to Welsh soils.

Level of understanding and characterisation

- There are regional data describing heavy metal concentrations in the surface layers of Welsh soils, but little information as to trends in concentration over time.
- The effects of metals on soil biological components are poorly understood.
- Considerable research has been undertaken into radiocaesium behaviour in soils and the extent of the issue in north Wales is well known.
- There is little information about the concentrations of POPs in Welsh soils, although limited data will be available from the UK Soil and Herbage Pollutant Survey.
- Pathogen contamination from sewage sludge application is well characterised, but little is known about potential sources from the application of farm, food and animal processing waste to land.
- There is little information about Transmissible Spongiform Encephalopothies and antibiotics in soils.

Level of current control

- There is legislation in place to control emissions of contaminants to air, water and land and to cover application of sewage sludge and other wastes to land.
- There are gaps in the control of on-farm re-use of animal waste.
- Legislation covering the landspreading of industrial waste contains ambiguities and needs clarification.

Ease of control by WAG

- WAG should encourage implementation of the controls and be an active participant in monitoring their effectiveness and contributing to revisions.
- WAG should support and encourage further research into the fate and persistence of POPs in soils and an assessment of concentrations in Welsh soils.
- WAG should support research into the potential cycle of contamination which may arise from the re-use of animal wastes on farms.

14.8 Gross contamination of soils

Relative importance/extent

- This is an intense issue at a localised scale with major impacts on a range of soil functions.

- Gross contamination exists from both legacy and present-day activities throughout Wales although the exact extent is not known.

Level of understanding and characterisation

- There is a considerable body of research into the restoration of various forms contaminated land.
- The lack of information about the extent and degree of land contamination in Wales is of concern.

Level of current control

- Legislation to regulate land contamination is in its infancy, but should provide an effective control in the future.

Ease of control by WAG

- WAG should encourage implementation of the controls and be an active participant in monitoring their effectiveness and contributing to revisions.
- Information should be gathered about the extent and degree of land contamination in Wales.

14.9 Acidification

Relative importance/extent

- This is a spatially extensive issue which interacts with land use and management practice in the Welsh uplands.
- Acidification has a chronic effect on some soil functions, especially interactions with the aquatic environment.

Level of understanding and characterisation

- The issue is well understood and moderately well characterised in terms of spatial extent.
- There are relatively few data documenting trends in soil acidity.
- The role of atmospheric deposition of nitrogen in acidification remains uncertain.

Level of current control

- The main controls are through international protocols which, if fully implemented, are likely to reduce the area of acidity critical load exceedance in Wales by 2010.
- Some key, highly sensitive areas will continue to receive acid inputs in excess of critical loads despite implementation of the Gothenburg protocol.

Ease of control by WAG

- WAG should encourage full implementation of the Gothenburg protocol and be an active participant in monitoring its effectiveness and contributing to revisions.
- A network of sites should be established to monitor changes in soil acidity in order to assess the effectiveness of emission control protocols.

14.10 Climate change

Relative importance/extent

- There is increasing evidence that the UK climate is changing driven by increased emissions of greenhouse gases.
- Mean temperature and annual precipitation in Wales have increased by 0.3 ºC and 3% respectively over the last century.
- Climate change is an important issue with widespread consequences for soil function.
- Some of impacts of climate change may have profound consequences for agriculture and forestry in Wales.

Level of understanding and characterisation

- There are some changes in soil state and function indicative of a climate impact, but the links remain uncertain.
- The soil carbon sink is highly variable and poorly characterised in Wales.
- Major uncertainties remain in our understanding of key soil processes controlling the ability of the soil to perform a range of functions, including carbon storage.

Level of current control

- The main controls are through the international agreements and protocols such as Kyoto, the Bonn Agreement and the Marrakech Accord.
- Full implementation of Kyoto is likely to have only a small impact on global climate, so some climate change will inevitably occur.

Ease of control by WAG

- WAG should encourage and contribute to the full implementation of the Kyoto protocol.
- Research into the likely impacts of climate change on soil functions should be encouraged and supported.
- An improved estimate of soil carbon stocks in Wales is required together improved monitoring and survey of soils.

Table 14.1 provides a summary statement of the interactions between issues and soil functions. The terms used in the table are defined as follows:

Significance – How important is the issue in terms of soil function? (None, Low, Medium, High)

Potential extent (scale) – Is it:

- A local issue to be managed at the scale of the individual land holding (Management unit)?
- A regional issue which can be managed at the scale of Local Authorities (Region)?
- A national issue concerning the whole of Wales (Wales)?

Understanding / Characterisation – How well do we understand the issue in relation to each soil function and what information do we have (Poor, Medium, Well understood)?

Control – How good are the current measures for controlling each issue in relation to soil function (Poor, Medium, Well controlled)?

Where an issue has no significance for a particular soil function, the boxes are left blank.

Table 14.1. Summary matrix analysing the relationship between issues and soil functions.

<u>Significance</u> None/Low/Medium/High N/L/M/H	<u>Localised/Extensive</u> Management Unit /Region/Wales M/R/W
<u>Understanding/Characterisation</u> Poor/Medium/Well P/M/W	<u>Current control</u> Poor/Medium/Well P/M/W

	Biomass, Food and Fibre production		Environmental Interaction		Provision of a platform		Support of ecosystems, Habitats and biodiversity		Provision of raw materials		Protection of cultural heritage	
Soil loss to development, and infrastructure	H	M	M	M	N		H	M	H	M	H	M
	W	M	W	M			W	M	W	M	M	M
Soil loss to mineral and peat extraction	L	M	H	M	H	M	H	M	N		H	M
	M	W	M	W	M	W	M	W			W	W
Soil loss by erosion	L	W	H	W	L/M	R/W	H	R/W	N		H	M
	M	P	P/M	P	M	P	P/M	P			M	P
Soil compaction, surface sealing, poaching	M	M	M	M	N		L	M	N		L	M
	P	P	P	P			P	P			P	P
Loss of soil organic matter	L	W	H	W	N		M/H	W	N		L	R/W
	M	W	P/M	P			P	P			P	P
Soil nutrient issues	H	M/R	H/M	M/R	N		H	M/R	N		N	
	W	M	M	M			M	P				
Diffuse soil contamination[1]	H/M	M	M	M	N		L/M	W	N		N	
	P/M	M	P/M	P			P/M	P				
Gross soil contamination	H	M	H	M	H	M	M	M	N		N	
	M	M	P	M	P	M	P	M				
Acidification	L	W	H	W	N		H	W	N		L	W
	W	M	W	M			M	M			W	M
Climate Change	H	W	H	W	L	W	M	W	N		L	W
	M	P	P	P	P	P	P	P			P	P

[1] The scoring represents an overall assessment for the all the contaminants considered

14.11 Other issues

A significant finding of this report and a common theme in many of the issues addressed is that comprehensive information on the state and quality of soils in Wales is lacking. This is seen to hamper scientific progress and policy development. In particular the national soil map of Wales is only available at a reconnaissance scale and there are insufficient data from survey and monitoring to identify spatial patterns and temporal trends in soil properties with any certainty. Within each issue, specific information needs have been identified.

A related issue is that of protecting representative soil systems as a resource for research and education. Precedents exist for the designation of other natural features and biological communities, but there is no specific designation for soils. Whilst rare and the least disturbed soils may support ecologically important systems of high conservation value, this should be distinguished from the need to protect a range of representative soil-landscape systems. Schemes such as Tir Gofal and certain classes of land ownership could facilitate protection through a network of sites under the management of CCW.

14.12 Stakeholder responses

The stakeholder responses fell mainly into two broad groups; identification of specific issues in relation to soils and concerns over the inadequacy of regulations governing the use of soil. Amongst the former, the following were identified as most important by the majority of respondents:

- Soil erosion, including the siltation of water courses and threat to archaeological sites.
- Soil contamination.
- Soil nutrient issues including concerns over both loss of productivity due to a reduction in soil fertility and implications of nutrient enrichment for low nutrient status systems.
- Peat extraction with suggestions that tighter regulations are required.
- Acidification.
- Climate change was seen by many as an important issue for the future.
- Loss of rare soils.

Many respondents considered that current regulations governing the use and protection of soil are not adequately enforced or are lacking in certain areas. These included:

- Inclusion of specific references to soil biological components in regulations and codes of practice.
- Clearer, more effective and centralised legislation for agriculture and agri-environment schemes.
- A suggestion from a few stakeholders that soil entering water courses should be classified as pollution.

Other matters raised by many stakeholders included

- Concern over public access to soil data.
- Waste disposal through application of biosolids.

Finally, a number of indicators of soil quality were proposed, although it should be noted that 'soil quality' was itself considered a rather subjective term:

- Microbial activity / diversity;
- Soil faunal diversity;
- Plant community structure;
- Soil organic matter content.

GLOSSARY

Aggregate stability – the cohesive strength of a crumb or block of soil.

Alluvium – material resulting from the deposition of sediment by water.

Bulk density – the soil's weight per unit volume.

Capping – creation of a very thin crust on the surface of bare soil that can prevent rainwater infiltration. Caps are now common on arable soils, particularly with the autumn sowing of crops.

Clay – normally describes the finest soil particles (<0.002 mm diameter). Such particles are commonly, but not necessarily, composed of particular *clay minerals.*

Clay minerals – platy or occasionally fibrous minerals consisting of layers of hydrated silicates of aluminium mixed with various other cations, e.g. potassium, sodium and calcium. They are formed by the chemical weathering of silicate minerals.

CLRTAP – **C**onvention on **L**ong-**R**ange **T**ransboundary **A**ir **P**ollution (www.unece.org/env/lrtap). This convention was the first internationally and legally binding instrument to deal with the problems of air pollution on a broad regional basis. It was signed in 1979 and came into force in 1983.

Compaction – compression of soil, often by machinery, to a higher bulk density and thereby lower permeability.

Critical load – the maximum amount of pollutant deposition a part of the environment can tolerate without significant harmful effects.

Critical load exceedance – the amount by which pollutant deposition exceeds the critical load.

Denitrification – the regeneration of dinitrogen (N_2) and nitrous oxide (N_2O) gases from the nitrate ion (NO_3^-).

Eutrophication – an increase in the amount of nutrients in waters or soils.

Gleying – the mixed grey and bright yellowish brown colouration of soil that results from repeated periods of waterlogging. It results from the reduction, mobilisation and re-deposition and oxidation of iron compounds in the soil.

Heavy metal – metals of moderate to high atomic number, e.g. copper, zinc, nickel, lead, cadmium.

Hydraulic conductivity – the rate at which a soil allows water to drain through it.

Neolithic – a period in history around 4000 years before the present that witnessed forest clearance and the emergence of settled, pastoral farming communities.

Nutrients – The main elements that plants extract from soil to sustain their growth (nitrogen, phosphorus, potassium, magnesium).

Organic matter – the organic fraction in soil that has come from decomposition and incorporation of dead plant remains.

Palaeosol – the remains of a soil that developed on a previous, but now buried, land surface. Palaeosols provide evidence of the climate at the time of their development, and many relate to warm interglacial periods that predate the last glaciation to cover Wales.

Particle-size fractions – clay, silt and sand particle size ranges.

Pathogen – any disease-producing micro-organism or substance.

Plough pan – a compact, structureless layer that can develop just beneath the maximum depth of ploughing (around 20 - 25 cm) as a result of tractors wheeling along the plough furrow and the smearing effect of the plough in wet soil.

Poaching – the puddling of soil in grassland and forage fields by stock grazing in wet conditions. While poached fields may appear very wet, the soil can be quite dry below the puddled layer because of the sealing effect that poaching has.

Podzolisation – the process by which organic matter and aluminium plus iron are leached out of the upper subsoil and re-deposited as a black and/or ochreous yellow layer at greater depth. Podzolisation requires acid soil conditions.

Raster – a form of digital map in which the properties of an area of land are represented by describing the contents of a set of grid squares covering the area.

Riparian – of or on the river bank.

SAC – **S**pecial **A**rea of **C**onservation designated under the EC Habitats and Species Directive for the protection of habitats and (non-bird) species.

Sand – soil particles with a diameter of between 0.06 and 2 mm.

Silt – soil particles with a diameter of between 0.002 and 0.06 mm. Silt feels slippery and soapy, rather than the sticky feel of clay.

Soil erosion – the wind or water driven processes by which soil particles are transported. Soil erosion is most commonly water-driven and results in gullies, rills on slopes and sediment fans at slope bottoms. Erosion results in increased river sediment loads.

Soil mapping – the production of maps that describe the pattern of soils and soil properties within the landscape. Soil maps are used in the management of land.

Soil structure – the three dimensional architecture of a soil; the way in which all the individual particles comprising a soil are organised. Soil structure is most commonly used as a term to describe the crumbliness and blockiness of topsoil.

SSSI – **S**ite of **S**pecial **S**cientific **I**nterest, these are areas of particular value for nature conservation because of high biodiversity, rare species and rare habitats, for example. Under current UK legislation they are given some protection from development and other forms of disturbance or damage.

Topsoil – the dark, mixed organic and mineral surface layer of a soil.

Trace elements – the group of elements that plants require to sustain healthy growth.