MLURI

THE MACAULAY LAND USE RESEARCH INSTITUTE

ANNUAL REPORT 1995

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Craigiebuckler Aberdeen

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Director's Introduction

This year's Annual Report features first, two articles which deal with specific issues that lie at the forefront of our thinking as we continue to develop land use research in this Institute, these are delivering research output to end-users and setting environmental standards. Second, the Report highlights the progress being made in the various projects which constitute our current programme, and thirdly, the text of the 19th Macaulay Lecture given by Sir Frederick Holliday, Chairman of Northumbria Water, 'The Cost of Clean Water', is presented in full.

In the first article 'Meeting Land Use Research Needs and Delivering Output to End Users' I examine the factors which determine the relevance, usefulness and value to society of the Institute's research and how our programme matches up to the Government's Technology Foresight priorities and recommendations, how we are seeking to involve end-users in identifying research needs, how we are exploring ways in which information, knowledge and understanding derived from our research can be delivered to the variety of end-users served by MLURI, and ultimately how we can engage their participation in the research process itself. The second article, 'Environmental Standards for Soils' is based on our submission to the Royal Commission on Environmental Pollution, in which Ed Paterson emphasises 'the need for environmental standards' and in particular the selection of relevant criteria for measurement, the issues inherent in spatial and temporal variability, and the requirement to understand the relationship between analytical presence and biological significance. Sir Frederick Holliday's 19th Macaulay Lecture complements both the opening articles in the Report within the context of the fundamental issues which determine the cost of clean water, ie the standards set for clean water and the research and development needs that are required to both justify and achieve these standards.

The reports on progress demonstrate continued evolution of our interdisciplinary programme as well as its widening international relevance. Collaboration with our colleagues in Eastern Europe, USA, China, New Zealand, Canada, Chile, Africa and elsewhere as well as those in the European Union has continued to develop and it was both a privilege and pleasure to sign a Twinning Agreement with the National Institute for Agricultural Research (INRA, France) in April of this year to facilitate co-operation in plant science, herbivore foraging and agroforestry research.

In July 1995, our first Chairman, Professor Ian Cunningham, retired from the Board of Governors. Ian Cunningham has served the Institute's interests and those of its staff with distinction. He has provided wise counsel, and guided the early development of the Institute with assurance, and an unswerving commitment to its objectives. While demanding high standards, his warm personality and friendliness, combined with a clear sense of purpose, provided a quality of leadership which was so vital to the success of the Institute in its early years.

Professor Cunningham's concern for the welfare of staff, the importance he attached to postgraduate education in the Institute, and his commitment to finding ways to increase the income of the Institute through the commercialisation of some of its activities were just some of the developments with which he has been involved. It was fitting, therefore, that the new premises, funded by the Macaulay Development Trust containing the administrative offices of Macaulay Research and Consultancy Services (MRCS), the student accommodation and the creche should be named the Cunningham Building as a token of our appreciation for all that he has accomplished on our behalf. We thank him and wish him well in his retirement. Following Professor Cunningham's retirement, Professor Janet Sprent, a member of the Governing body since September 1989 and a Vice Principal of Dundee University was appointed to the Chair.

At the time of writing the outcome of the Government's Prior Options Review of the Institute has just been announced; the review is a part of an on-going, wider review involving some 50 public sector research establishments in the UK. Its purpose was to examine their function and to establish whether there was a case for privatisation or rationalisation. The Government has expressed confidence in the work of the Institute and has decided that its function will continue to be needed and that it should retain its separate identity. However, it wishes the possibility of moving the Institute fully into the private sector to be considered further.

Notwithstanding, the relatively short period of its existence, the Institute has established a growing national and international reputation in land use research. Some 28% of our income during 1995-96 was derived from sources other than the grant-in-aid from SOAEFD, (e.g. the EU, the SOAEFD Flexible Fund, other national and local government departments and agencies, and industries and commerce) much of it from competitively tendered contracts. We are confident that a continuation of our policy to commercialise a greater proportion of our activities, to set clear research priorities relevant to user needs, and to continue to develop our strategic underpinning research strengths, will secure the long term viability and future of the Institute. It will also secure the long term future of land use research in Scotland.

We look forward to developing the Institute, whatever its status, to ensure that the investment made by the Scottish Office and the Macaulay Trustees in creating the Institute in 1987, and the commitment and achievements of the staff over the last nine years, can be fully exploited and built upon well into the next century.

T J Maxwell
May 1996

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MEETING LAND USE RESEARCH NEEDS and DELIVERING OUTPUT to END USERS

T J Maxwell

PREAMBLE

Questions about the amount of funding made available to support research either from the public sector or industry, and the appropriateness of the organisational structures in place to undertake this research, are central to the debate as to how the UK research community can most effectively deliver imaginative ideas and new technology towards wealth creation and improvements in our quality of life.

In "Realising Our Potential - a Strategy for Science Engineering and Technology" (HMSO, 1993), the Government stresses the importance of "the need to apply rigorous standards and impose strong criteria to maintain quality whilst giving much greater emphasis to relevance". It also states that research funders "should take more fully into account the extent to which outcomes could be taken up by potential users". Indeed, technology foresight has been a major initiative of Government "to achieve better communication, interaction and mutual understanding between the scientific community, industry and Government departments".

INTRODUCTION

At the Macaulay Land Use Research Institute (MLURI) we believe that the relevance, usefulness and value to society of our research depends upon three things: the ability of our scientists to work in partnership with our potential customers to determine need, (technology foresight), to do excellent science and relevant research, (as judged by independent peer review and the satisfaction of customers and their willingness to pay), and develop effective ways of maximising the impact of our findings on end users, (achieve effective technology transfer).

This article demonstrates the way in which we are meeting these challenges. It looks at our current programme in relation to the priorities and recommendations of the Government's Technology Foresight programme, how we are seeking to involve end-users in identifying research needs, how we are exploring ways in which information, knowledge and understanding derived from our research can be delivered to the variety of end-users served by MLURI, and ultimately how we can engage their participation in the research process itself. But first how does the Institute programme measure up to the priorities and recommendations set by Technology Foresight?

TECHNOLOGY FORESIGHT

The various sector reports of Technology Foresight were published in May 1995, under the title "Progress Through Partnership" (HMSO, 1995 a), and their recommendations not only provide a context for the setting of priorities and developing new initiatives but also provide a measure of the extent to which existing programmes match up to future needs. We have found that our current programme at MLURI (pages 52 to 56 of this report) closely matches the areas of priority identified by the Technology Foresight Report Number 11, on 'Agriculture, Natural Resources and Environment'. Those areas of priority relevant to the MLURI remit are as follows:

> "environmental research programmes encompassing monitoring surveys, further development of data and information systems, process studies, and impact evaluation studies"
>
> "integrated ecosystem management" particularly in relation to the "maintenance, restoration and utilisation of terrestrial and freshwater aquatic systems", and towards
>
> "the realisation and understanding of the full value of biodiversity in natural and managed ecosystems",
>
> "remote sensor and survey systems, predictive modelling in the presence of uncertainty, artificial intelligence and expert systems",

"technologies for soil/site remediation, landfill management, exploitation of domestic and industrial wastes",

"life cycle evaluation and management" (specifically in MLURI's case to) "evaluate the vulnerability of natural resource production and socio-economic systems to climate, pollution and land use change".

MLURI's AIMS

Primarily, the work undertaken in the Institute aims to provide a better understanding of the biophysical and socio-economic systems related to land use and land use change. Our research addresses questions such as, for example,

- What happens to the land, and the quality of water draining from that land, when it is converted from agricultural use to forestry?
- What happens to the wildlife and landscape ecology of the area?
- Does the local community benefit from the change?

Other examples would be:

- What is the impact of the utilisation of sewage sludge on agricultural land?
- What needs to be done to alleviate the impact of the industrial contamination of land by toxic chemicals?
- What are the measures that need to be taken to retain or enhance the attractiveness of hill and upland areas against the background of CAP reform?

These are all questions, and there are many others like them, which act as a focus for the Institute's research programmes and the strategic soil, plant, animal, geographic and socio-economic research which is undertaken. The aim is to produce information which will improve our ability to manage and use land in a predictable and sustainable manner.

So, what is this information? It takes many forms and a useful and simple classification would be:

i) **resource information**, *that is, quantitative and qualitative descriptions of, for example, soils, vegetation, wild and domestic animals, freshwater lochs and rivers, climate, population distribution, and a range of other socio-economic parameters.*

ii) **information which quantitatively or qualitatively describes the relationships between the components of rural ecosystems** *at varying levels of biological, chemical, physical, economic and social organisation, e.g. the relationships between fertiliser use on agricultural output, river water quality, and the regional economy; the relationship between impact of domestic and wild herbivores (sheep, cattle, deer, goats) grazing natural and semi-natural vegetation on wildlife habitats and landscape and agricultural output.*

iii) **qualitative and conceptual knowledge and understanding** *derived from the experience of end users e.g. farmers and other local experience in the utilisation of land resources and impacts on soil, vegetation and wildlife; knowledge derived from gamekeepers in relation to the factors influencing grouse and deer populations in the countryside.*

The challenge is how best to utilise and integrate these various forms and sources of information within the framework of different policy scenarios. One of the central aims of the research of the Institute is to interpret and add value to resource information. Against the background of CAP reform and the UK strategy on forest policy, it is an essential part of our activity to be able to determine the technical suitability of using land for different agricultural and forestry options as well as being able to evaluate the long term environmental and socio-economic impacts of these options. Similarly, with respect to European and UK legislation and guidelines on pollution control we regard it as crucial to be able to quantify the geochemical and biological impact of industrial pollution emissions on land and freshwater bodies and the socio-economic costs of such pollution. These are just two generalised examples of the kinds of topics with which the Institute deals and for which information is sought.

By whom, you may ask?

Our customer base can be divided broadly into two groups: land use managers and land use policy advisers. Much of our research is geared ultimately towards providing land managers (farmers, foresters, conservation/estate managers and factors) and their advisers, and site remediation and waste management engineers, with management protocols which give a greater precision and predictability to their operations. For farmers and foresters these protocols are designed to control not only levels of output in terms of yield per hectare or liveweight gain per day but also to control for example, among other things, the leaching of nutrients to rivers, soil erosion, and habitat diversity. Similarly, site remediation engineers and waste utilisation and disposal managers require information about the likely transport and fate of pollutant metals and organic materials. Our research addresses these issues at various scales. For the farmer or forester, for example, it is important to provide management prescriptions which are relevant to the scale of the field, farm and estate. However, in the UK and Europe, land use is much influenced by the Common Agricultural Policy, the instruments that implement this policy, and by legislation which controls pollution and protects the rural, as well as the urban environment. A substantial part of our research in the Institute is focused, therefore, on providing information relevant to government policy advisers, to the heritage agencies, the water industry and the statutory environmental protection agencies at the catchment, regional and national level.

MEETING LAND USE RESEARCH NEEDS

THE NATURE of LAND USE RESEARCH

The conventional ways used to transfer information from research institutes like MLURI is to publish results from our research in international, peer reviewed and refereed journals. This is an important, high quality form of output restricted largely to fellow-researchers but much valued by them. It is doubtful, nevertheless, if it is the most appropriate or effective way to transfer information to the end-user. The latter has been done often more successfully through conferences and consultancies and by extension agencies. Rural land use and management rarely deals with single issue, technologically driven solutions. It is not, for example, simply a matter of identifying a gene or even a number of genes which through recombinant technology can confer protection against a pest or disease, or improve the flavour of an agricultural or horticultural product. Such vertically integrated research and product development is highly valued and can be 'sold-on' to industry relatively easily, but delivering the output from research on land use and land management is much more complex than that - it is less about products and more about novel management systems which aim to deliver the multiple benefits of economic, social and environmental sustainability.

This complexity and the cross-disciplinary nature of land use research was recognised by a team of experts who undertook a review of land use research in the UK on behalf of the Scottish Office Agriculture, Environment and Fisheries Department, (Birnie *et al.*, 1995). They concluded that 'the present economic reality in much of rural Britain is that agriculture's significance is declining, as other, particularly service sector and leisure opportunities increase'. The review suggests 'that the well-being of the rural economy is a much more complex policy objective, than is, for example, the well-being of agriculture'. It raises issues such as rural transport and housing, the impact of macro-economic policy, and recreation as being equally important. Land use management options have therefore to be evaluated in the wider socio-economic context.

It is therefore not surprising, from the perspective of the land use researcher, that wealth creating opportunities in agriculture and forestry need to be examined not only in economic terms but also in terms of their impact on the environment as a whole, as well as identifying the social consequences of implementing such technology. Furthermore, there is an increasing acceptance of the notion that the production of environmental goods, such as the maintenance of biodiversity, and the enhancement of wildlife habitats and the landscape, is a legitimate activity for which land holders should receive some form of financial incentive or payment. This requires the development of multi-objective and sustainable land management systems and an ability to carry out analyses of the kind, by way of example, described in Table 1 (Maxwell and Milne, 1995). However, such analyses

Model component and factors affecting herbivore performance	**Relative importance**		**Impact on environmental integrity**	**Economic viability**
	Intensive system	**Extensive system**		
Pasture productivity				
Size of unit	xx	xx		
Climate	x	xxx		Sets limit on output
Soil	xx	xxx		
Plant species selected	xx	-	Biodiversity	Depending on level
Plant species present	x	xx	Habitats	of inputs will
Fertilisers	xxx	-	N and P leaching and eutrophication	generally improved economic performance
Irrigation	x	-	Salination	
Pasture utilisation (feed intake)				
Forage physical and chemical composition	xx	xx		
Sward structure	xx	xxx	Biodiversity	
Distribution and abundance of biomass (heterogeneity)	x	xxx	Wildlife habitats Landscape	
Herbivore behaviour	x	xxx	Plant cover	
- type, eg browser, grazer			Soil erosion	
- weather			Return of dung and urine	
- topography			- nutrient cycling	
- water availability and quality	x	xxx	(leaching and eutroph.)	
Stock numbers			- NH_3/CH_4 emissions	
			Competition with wildlife herbivores	Sets limits on output
Winter forage conservation/ Supplementary feeding policy	xxx	x		
Health				
Endoparasites	x	xx	Use of agro-chemical for control	Cost of inputs to
Ectoparasites	x	xx	of parasites	maintain health
			Impact on other invertebrates and wildlife	Assessment in relation to risk

Table 1.

Box 1

Strategic gaps in current UK land use research effort. (Review of land use research in the UK - (Birnie *et al.*, 1995).

- **The need to create and nurture interdisciplinary groups to produce a coherent body of relevant knowledge, theory and expertise.**
- **The need for underpinning theoretical or methodological land use research that seeks either to develop a framework for integrated research, or to develop a fundamental understanding of process.**
- **The need to assess how understanding of farm household decision-making can be scaled up to provide regionally-sensitive predictive tools.**
- **A general need to improve the process of user participation and technology transfer.**

need to be explained ultimately, as far as possible, in quantitative and explicit terms so that the synthesis of new systems can be undertaken. This suggests strongly that an holistic approach to the analysis, synthesis and presentation of information is needed.

The review of land use research (Birnie *et al.*, 1995) recognised this explicitly when identifying significant strategic gaps in the UK land use research effort, (see Box 1). It recognised that the 'challenges presented by management concepts like integrated pollution control, integrated catchment management and multiple-objective land use planning suggests that there is a need to find ways of creating and nurturing interdisciplinary groups, if a coherent body of relevant knowledge, theory and expertise is to be developed'. One of the other gaps identified by the Review team and one which the MLURI is actively addressing is the recognition that there is 'a need to involve the user community in the research process where the output is specifically designed to support the policy process'. The team concludes 'that there is a general need to improve the processes of user participation and technology transfer'.

Is there an appropriate vehicle by which this can be achieved?

TECHNOLOGY TRANSFER and DECISION SUPPORT

In our Annual Report of 1990-91 an article 'The Role of Mathematical Modelling in Land Use Research', (Birnie *et al.*, 1991) explained how mathematical modelling had the potential to be used to explore the complex biological, economic and social interactions that are inherent in systems of land use. At that time there were sixteen empirical/mechanistic models being developed in the Institute such as modelling upland sheep systems, modelling the effects of climate change on tree crops in Scotland, modelling the effect of land use change and atmospheric acid deposition on water resources,

Box 2

Some examples of Decision Support Tools/ Decision Support Models being developed at MLURI

- Decision Support System for assessing land use options at the management unit level.
  Contact: K B Matthews
- Catchment/district scale model for assessing land use options and their impacts on ecology and conservation.
  Contact: R J Aspinall
- Land suitability/risk assessment in relation to the disposal of wastes rich in heavy metals.
  Contact: W Towers
- Spatio-temporal biophysical resource simulation modelling and representation for quantifying risks and opportunities in land use.
  Contact: G Hudson
- Water resource modelling: the effect of land use, deposition and climate change on soils and waters.
  Contact: R C Ferrier
- Critical loads to natural and semi-natural ecosystems with particular reference to nitrogen.
  Contact: S J Langan
- Modelling chemical behaviour and transport of reactive contaminants in soils.
  Contact: J C L Meussen
- Suitability of whole-tree harvesting of Sitka Spruce as a sustainable land use on different site types in the UK.
  Contact: M F Proe
- Predictive modelling of eutrophication within the river Ythan catchment and the development of an integrated management plan.
  Contact: A C Edwards
- Hill grazing management model.
  Contacts: J A Milne/A R Sibbald
- Development of decision support system for managing the impact of red deer on vegetation dynamics and habitat diversity.
  Contact: I J Gordon
- Geographic Object-Oriented Simulation Foraging Model.
  Contact: K D Farnsworth
- Predicting the dynamics of the intake and burden of *Ostertagia circumcincta* in grazing sheep.
  Contact: J A Beecham

and modelling the interaction between heavy metal pollutants (e.g. from sewage sludge) and fine-grained constituents of mineral soils. The classification, in terms of the application of these mostly deterministic models was described as 'contributing to scientific understanding'. Some, however, were classified as being decision-aids. These included, for example, a forestry investment appraisal model encompassing the environmental and social costs and benefits in relation to regional and national planning; another was the modelling of the agricultural and environmental consequences of sheep and red deer grazing heather moorland. Since that time with the advent of significant advances in information technology the development of models as decision aids has been perceived by us as a practical way of delivering the output of our research in an objective and explicit way. (See Box 2 for current projects). However it was by no means clear to us that our end-users would find this method of delivery useful and acceptable.

In 1995 MLURI and SAC organised a workshop to review the use of decision support tools (DSTs). The workshop was sponsored by the Scottish Office Agricultural, Environmental and Fisheries Department (SOAEFD), and was designed and facilitated by Peter van Beek, a consultant from Australia and Drennan Watson of Landwise, Scotland (van Beek, 1995). The four focal areas which were addressed were

- the role of Decision Supports Tools
- missing elements in the development of DSTs
- the desirability of user involvement, and
- if desirable, how to involve users

As an aid to addressing these areas some 21 case studies of current DSTs were presented over three days to audiences of interested current or potential users in relation to

- managing farms and estates
- developing and implementing policies at regional or district level, or
- at the national level

All together some 50 people contributed their knowledge and experiences. The findings of the workshop are available from the Institute (van Beek, 1995).

We concluded, from the views of the end-users at the workshop, that there is a role for DSTs in delivering the output from land use research. At the farm level (see Box 3) end-users clearly identified their use in terms of resource management, evaluating different technical options and integrating sources of information. At the regional level DSTs were seen to be valuable in understanding complex situations and providing a framework in which to challenge the values and criteria used in decision making (see Box 4) and at the national level as a means of presenting information in more understandable forms and providing a basis for justifying and defending policy; monitoring and validating decisions, and demonstrating accountability (see Box 5).

Several elements were deemed to be missing in relation to the future development of DSTs. These included, for example, the lack of the right data; a lack of understanding of many biophysical processes; the need to design DSTs which could handle nebulous, unstructured issues and incorporate feed-back from end-users; a lack of knowledge about re-scaling; and many technical issues were identified as needing to be addressed, particularly with respect to DSTs which were dependent upon linking biophysical models with geographic information systems and socio-economic data. Issues of quality control, transparency of design, and knowledge of the human-nature interface were also highlighted. Significantly it was concluded that there was a lack of understanding among potential end-users about the kinds of information, data and models DSTs can handle; how they process data, how information is created, and how the needs of users can be determined.

With respect to the provision of the right kind of data and gaining knowledge and understanding of processes to incorporate into DSTs it can be said that the underpinning

Box 3

What is the role of Decision Support Tools at the Farm level?

- *Management role.* Identifying tactical options; determining and testing 'Best practice'; identifying what to monitor and watch out for.
- *Integrative role.* Integrating new technology; linking knowledge from various sources; integrating across enterprises.
- *Testing role.* Testing of new technology and strategies before applying them in reality and running risks.
- *Empowerment role.* Allowing users to set strategies and having experts advise within those; raising awareness in the user communities.
- *Guiding role.* Guiding policy development and implementation.
- *Education, teaching knowledge transfer and demonstrating role.* Transferring knowledge and experience to others.
- *Research role.* Pushing back frontiers of understanding; identifying needs for further detailed research; setting DST objectives at or beyond the cutting edge of current software.
- *Reconciliation role.* Bringing warring parties closer together on the basis of a common and comprehensive overview of the situation.

van Beek 1995

Box 4

What is the role of Decision Support Tools at the Regional level?

- *Understanding role.* Increasing the understanding of complex situations or problems.
- *Value testing, simulation and debate improvement role.* Providing a framework in which to challenge the values and criteria used in decision making; enabling more rigorous testing of decisions, rationality and suggestions.
- *Negotiation role.* Integrating points of view; negotiating between conflicting views; pulling levels of decision making together, showing a range of approaches; providing repeatable and consistent analyses.
- *Justification role.* Justifying what needs to be done now for future benefits; providing confidence in decisions.
- *Research role.* Building knowledge; identifying gaps; bringing out data; turning *ad hoc* policies into action research.
- *Referral role.* Indicating where to go for help.
- *Social engineering role.* Creating equity/ disequity; potentially reducing freedom to manoeuvre; potentially restricting decision making 'on the ground'; reducing or increasing *ad hoc* decision making?

van Beek 1995

Box 5

What is the role of Decision Support Tools for Policy Development?

- *Informing role.* Dealing with data beyond the realms of human capability to take in; harnessing and converting information and data from a range of sources; structuring this in a rigorous way; widening the range of perspectives; acting as 'guardians of systems';
- *Clarifying role.* Helping to prompt, think, teach, relate and share concepts; identifying and evaluating problems, options and information sources.
- *Communication role.* Presenting information in more understandable forms; informing interest groups; providing background information in support of policy; demonstrating that all aspects in a decision have been covered.
- *Negotiation and justification role.* Providing a basis for negotiation with the European Union, users and third parties; justifying and defending policy; monitoring and validating decisions; demonstrating accountability;
- *Simulation role.* Answering 'what if' questions; showing factors involved; identifying desirable objectives (*e.g.* critical loads) based on hard data; providing quantification.

van Beek 1995

fundamental and strategic research undertaken in the Institute and elsewhere is geared to do just that. However, the process of constructing models and DSTs is a crucially important part of the systems approach to land use research, which proceeds through a continuous cycle of analysis, synthesis, testing, re-analysis, and so on. Such an approach determines the context, relevance and priorities of our fundamental and strategic research.

Many other strategic issues raised with respect to what's missing in developing DSTs are fundamental to the processes of information technology and technology transfer. These include those that have been clearly identified as matters of priority in the Government's Technology Foresight exercise *viz* 'predictive modelling in the presence of uncertainty', and 'the use of artificial intelligence and expert systems' which are currently included in projects at MLURI such as the creation of a catchment/district scale model for assessing land use options and impacts with special reference to ecological modelling, and in an approach to modelling wildlife dynamics in hill grazing systems with reference to grouse.

In relation to the question as to whether users should be involved in the development of DSTs, all end-users participating in the workshop regarded user involvement as being essential. 'Users act as champions and create new ideas'. 'Users provide understanding about the decision making situations and processes, highlight different and difficult decisions, can imagine how DSTs will be used, help to set priorities.....' 'Involving other people changes power balances and control. Is control with the user or developer?'

How should users be involved?

The approaches identified by each of the groups in the workshop had, in common, the idea of active group participation. Several 'emergent models of communication' were identified, *viz* workshops, steering groups, rapid appraisals, focus groups, local best practice groups.

Furthermore, it was recognised that it was important to have relevant participation across a spectrum of stakeholders, and that when assessing the costs of participative methods, the right question to ask is: what is a reasonable percentage of the total cost of a project or programme to spend on ensuring that the goals and questions are right, given the high spend involved in getting the answers right?

So far, the Institute's experience has involved rapid appraisal workshops, one-to-one open interview techniques, and user groups, but the ultimate design and construction of the DSTs have been left largely to scientists. As yet, we do not have examples whereby the DST has been designed and developed from 'scratch' by the active involvement of the user community such as that described by Bosch *et al.* (1995). This is a very real challenge and one which is particularly relevant to the objectives set by the recent White Paper on Rural Policy ' Rural Scotland: People, Prosperity and Partnership', (HMSO, 1995 b), one of which is 'to provide a focus for promoting and responding to community-led initiatives', particularly in relation to issues of land use planning and the most sustainable use of the natural resources of an area.

Bosch *et al.* (1995), working in the South Island high country of New Zealand, outlines the development of a community based research initiative which emphasises the maximisation of both scientific and local knowledge and its usefulness in land management decision making. A major component of such a participatory research approach involves the development of a comprehensive decision support system (DSS). The DSS provides a focal point through which land users can access both local and scientific knowledge to evaluate the implications of different management options and strategies.

As Bosch and his colleagues have pointed out this requires a DSS development framework which is capable of,

- integrating existing local and scientific knowledge into accessible and user friendly DSS;
- incorporating tools for monitoring and interpretation of the outcomes of management action;
- continually capturing new information gained through research (scientists), and the adaptive management and monitoring process (land managers);
- transferring new data and information into useful knowledge.

(Bosch *et al.*, 1995)

The traditional linear approach to DSS development requires that the complete specifications of the system are known prior to design and construction. However, given that our knowledge of natural systems is, and always will be incomplete, a more flexible approach is needed. This is especially so when the technical improvement of DSS development is seen as a process that can be enhanced by on-going feedback and learning. It produces a system which can be used at a much earlier stage than in the case of DSSs and DSTs that are developed through more traditional linear approaches.

This does not mean that DSTs and DSSs produced from such an approach are not useful or relevant: it does mean, however that once exposed to user communities they inevitably require adaptation and refinement. Within MLURI we are continually adapting and refining our DSTs and using new technologies to construct and improve the presentation and output from DSTs. The next, most immediate challenge is to engage and empower potential end-users in the design and construction of DSTs to enhance the capability and objectivity of local community land use planning and management decision making.

CONCLUSION

This article demonstrates that the Institute continues to be acutely aware of the need to develop its programmes of research in response to changing policies and the changing requirements of its wide customer base. We are establishing a variety of ways by which end-users can and do influence and ultimately benefit from the research that is undertaken. We plan to continue to develop ways which facilitate their participation in the design and construction of decision support tools so as to maximise the effective delivery and use of information arising from our research.

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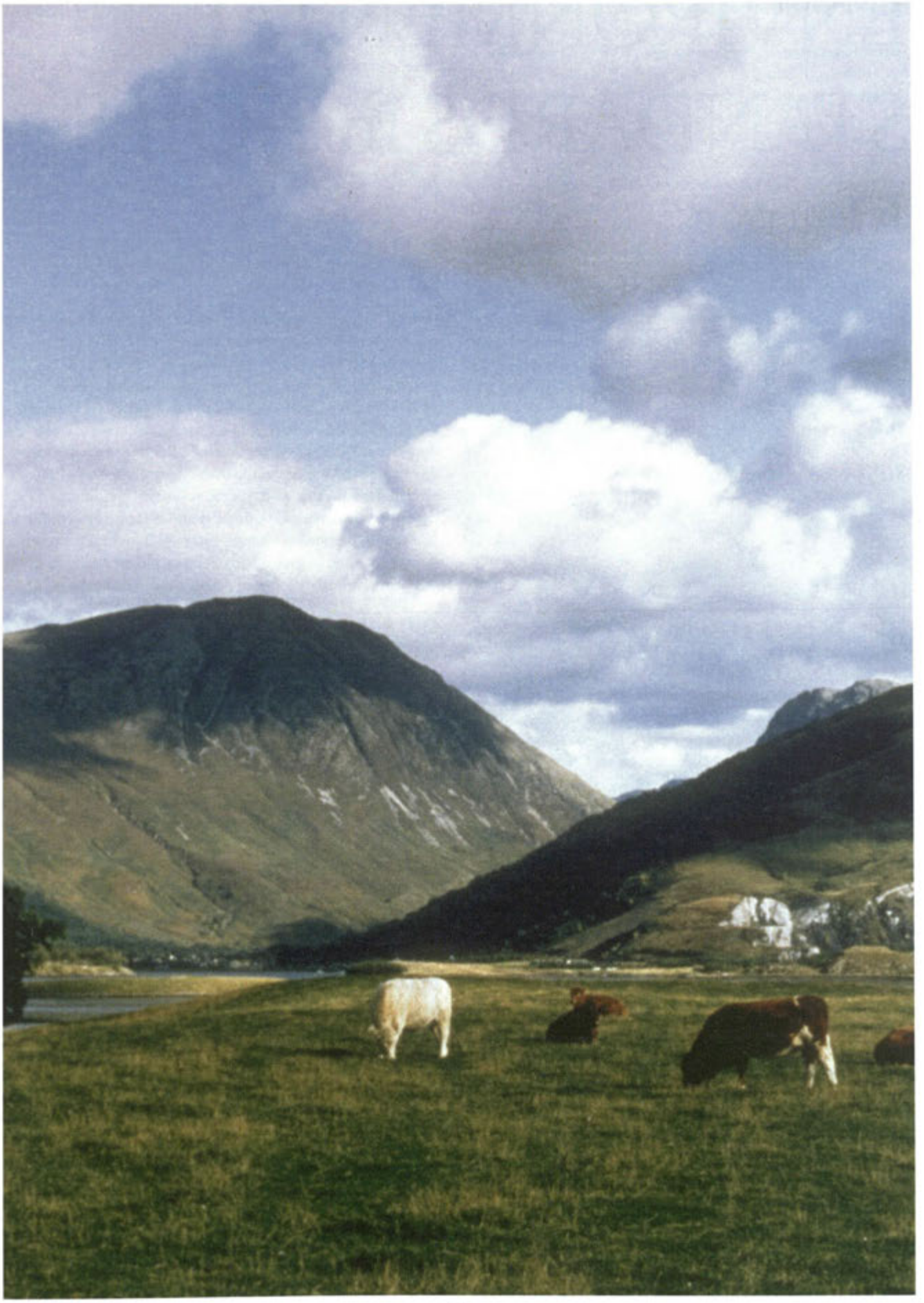


ENVIRONMENTAL STANDARDS for SOILS

E Paterson

INTRODUCTION

It is now widely recognised that the environment is not infinitely resilient and, as a consequence, environmental protection, whether by legislation or voluntary codes of practice, has a key role to play in the development of a national strategy aimed at sustainable development (HMG, 1994). Thus, the assessment of methods whereby environmental standards may be set, implemented and validated is a matter of considerable interest, particularly in view of the opportunities for a more integrated approach than hitherto with the establishment of the Environmental Protection Agencies. Against this background, the standing Royal Commission on Environmental Pollution has initiated a review of the setting of environmental standards within the UK. As was the case in the recently published Nineteenth Report on the Sustainable Use of Soil (Royal Commission on Environmental Pollution, 1996), the Institute has submitted written evidence and, although it is not possible to reproduce the entire document here, it is useful to focus attention on some of the questions posed by the Commission that have particular relevance in the context of the research programme of MLURI.

THE NEED FOR ENVIRONMENTAL STANDARDS

The primary purpose of environmental standards is to protect the environment from changes that may have a deleterious effect on living organisms. Thus, although standards may be defined on the basis of chemical measurements the ultimate objective is to define levels at which biological impacts may be felt. Of the three major environmental media, air, water and soil, the success of the approach decreases as the complexity of the medium increases, from the relatively simple and homogeneous cases of air and water, to the most complex, that of soil. In soils, difficulties can arise from

- selection of relevant criteria for measurement,
- inherent spatial and temporal variability, and
- the requirement to understand the relationship between analytical presence and biological significance.

The approach generally taken enables considerable analytical rigour to be applied to the determinations but the linkage to biological impacts is frequently much less robust.

BIOLOGICAL IMPACTS

One major area of inadequacy in our present knowledge base is concerned with the linkage between the analytical measurements frequently made and their biological significance. However, it is important that this area is addressed using an integrated approach because, although the development of specific biosensors (Paton *et al.*, 1995; Forge *et al.*, 1993) is superficially attractive, any measurements must be related to the underlying chemistry of the system. Only in this way can the boundary conditions described by chemical thermodynamics (Lumsdon *et al.*, 1995) and the rates of change obtained from kinetic studies be incorporated to give a truly ecotoxicological knowledge base on which to develop environmental standards.

CRITICAL LOADS OF POLLUTANTS

One approach which attempts to achieve an integrated view is the concept of "critical loads" which, at its simplest, states that where inputs of a pollutant to a receptor exceed a certain threshold level (the critical load), then inevitably adverse consequences on a target organism will follow (Figure 1). As such, it attempts to account for the causal chain of events implicit in the setting of environmental standards for various media and requires quantitative information on the relationships and reactions between inputs, receptors and targets.

The actual critical load will depend upon the capacity of the receptor and the sensitivity of the target. Some

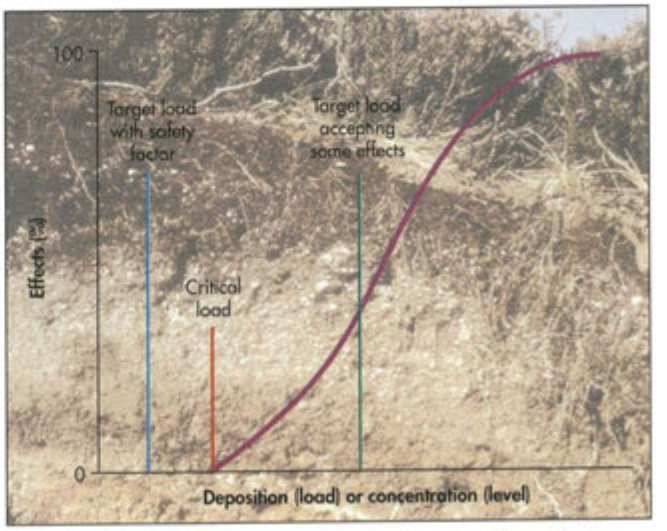


Figure 1. Theoretical dose-response curve showing alternative 'target loads' compared with 'critical load'.

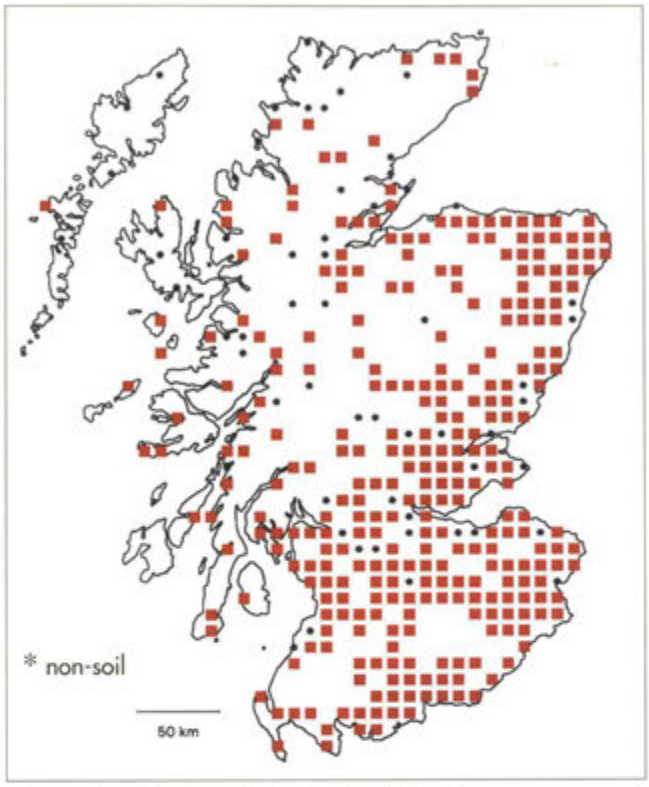


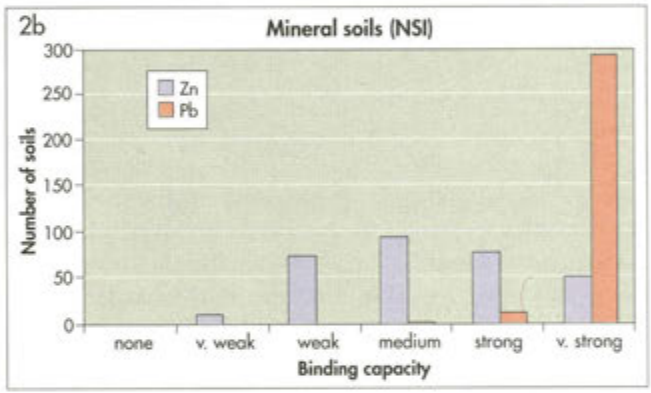
Figure 2a. Sites with mineral surface horizons

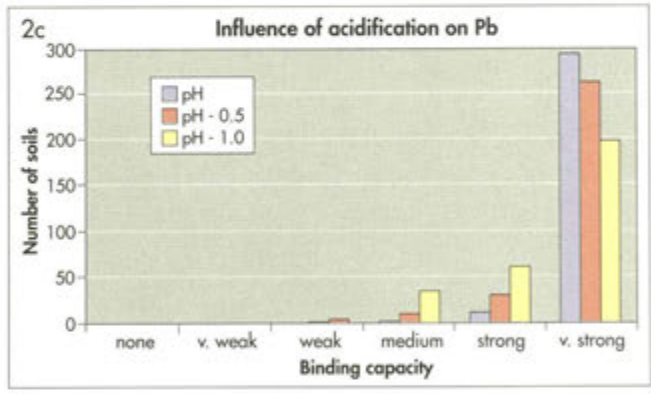
receptors will have a capacity for neutralising or coping with large inputs of pollutants, thus attenuating the impact on the biological target and therefore, the system will have a high critical load. Other receptors will have an exceedingly low ability to cope with pollutant inputs and hence will have a very low critical load. In applying this concept, there are a number of difficulties to be overcome to ensure that

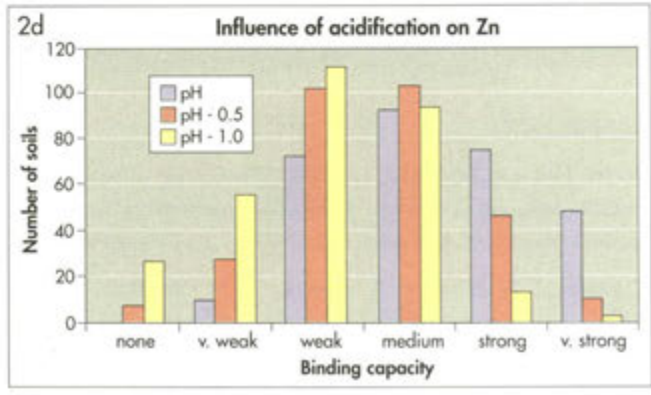
- the biological target is appropriate
- each stage in the causal chain is valid,
- inexact incorporation of expert knowledge is minimised.

A further difficulty is that the concept says nothing about the time element involved in bringing about adverse consequences in the event of critical load exceedance, but merely that these consequences will occur sooner or later. These problems emphasise the point that the critical loads concept can only be applied with confidence when the estimation of the critical load rests on an objective and transparent scientific basis.

In principle, the critical loads concept could be applied to a very wide variety of pollutants, receptors and targets. Perhaps its most extensive application has been in the field of the impact of acid deposition on terrestrial and aquatic ecosystems. For the latter, the linkage between acid inputs, water chemistry and biological status has been quite convincingly demonstrated (Soulsby *et al.*, 1996). For the terrestrial ecosystem the linkage between acid inputs, soil chemistry and biological effect remains to be more firmly established (Langan *et al.*, 1995). Other pollutants to which the critical loads concept could find a ready application (de Vries and Bakker, 1995) include heavy metals (e.g. Pb, Cd, Zn, Cu, Ni), and organic pollutants (e.g. PCBs, PAHs, insecticides, herbicides) providing that a suitable biological target can be agreed. Recent work at the Institute, sponsored by Scottish Natural Heritage, has investigated the sensitivity of Scottish soils to heavy metal inputs (Paterson *et al.*, 1996) using a development of an approach first suggested by Blume and Brummer (1991). This work draws on process-based understanding of the interaction between soils and heavy metals to identify attributes available in the Scottish soils database held at MLURI and then, through the application of a weighting procedure, ranks the binding capacity of soils in the uptake of various metals. Application of the methodology to the mineral soils in the National Soils Inventory (Figure 2a) has shown that while some heavy metals, e.g. Pb, are strongly bound to the soil others, e.g. Zn, are not so tightly bound (Figure 2b). The approach also allows the influence of changing environmental conditions to be assessed and can thus enable some perspective to be obtained on the impact of acidification on heavy metal mobilisation (Figure 2c and d).







DEVELOPMENT AND IMPLEMENTATION OF STANDARDS

Aside from difficulties in the interpretation and implementation of scientific knowledge in setting environmental standards policy makers also face the question of how to balance the advantages (benefits) and the disadvantages (costs) of setting standards at a particular level. By attempting to value these costs and benefits, economists seek to identify a level of pollution which is optimal from the point of view of society as a whole. For example, a standard that is set too low will result in costs to industry and the consumer which exceed the environmental benefits. The optimal value would therefore be at some higher level. The challenge for economics is that, in many cases, the benefits of pollution control are not traded in the market place and cannot be measured directly in monetary terms. Although techniques to value these non-market goods, such as Contingent Valuation and the Hedonic Price Method, are emerging (Macmillan and Ferrier, 1994), they are not, as yet, wholly reliable. However, the economic appraisal of standards-based pollution control strategy will still provide policy makers with useful information regarding the costs of alternative levels of environmental pollution and should be regarded as an important component of standard setting and revision.

The implementation and policing of environmental standards is dependent on two apparently distinct approaches, namely, specific legislation with legally binding standards and the use of Codes of Good Practice, which are not in themselves legally binding but contravention of which may be taken into account in any legal action concerning a specific pollution incident. The statutory approach is more commonly applied to point source pollution of media, such as water and air, produced from individual factories and installations. Thus, in dealing with point source pollution there is little difficulty in identifying the polluter and policing any standards that are applied. It might also be argued that the application of emission and discharge consent, within the concept of integrated pollution control has brought benefits to the environment through reduced pollution and to industry through increased efficiency and minimisation of waste.

Codes of practice are more frequently encountered for diffuse pollution sources and more complex media, such as the impact of agriculture on soils and waters (SOAFD, 1991). This reflects the difficulty of monitoring and policing diffuse sources because of the complexity of the interactions. Research currently under way on integrated catchment management, e.g. in the Ythan catchment (Domburg *et al.*, 1995), is aimed at greater understanding of the relationships between management practices and environmental impacts. One consequence of such an approach will be to produce, for land use and water quality, a methodology which is analogous to the integrated pollution control methods now in common use in the legally enforceable areas. Thus it may be argued that convergence is occurring using two quite different approaches.

CONCLUDING REMARKS

The final point to be made in relation to setting environmental standards is that it is impossible to envisage a situation in which a complete knowledge of the natural environment will be attained. Thus, uncertainty must be viewed not as some indication of woolly thinking or poorly designed experiments, but rather as an inherent characteristic of environmental research. As such, a place must be found for its explicit incorporation in the process of setting standards. Incomplete knowledge must be viewed as normal and we must seek to utilise the knowledge base as it exists in the most effective way possible. As well as continuing to develop the science base in terms of greater understanding of processes and mechanisms, there is a strong case that the objectives of research in environmental standards should be conditioned by the need to integrate contributions from as wide a disciplinary base as possible. The challenge in such a task should not be underestimated but it is one which is vital to pursue.

ACKNOWLEDGEMENTS

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LAND and ENVIRONMENTAL MANAGEMENT SYSTEMS

The aim of our research is the development of spatial decision support systems (DSS) for land use management and planning at a range of scales. By drawing together knowledge of existing enterprises using modelling techniques, and developing understanding of new enterprises (e.g. agroforestry) and new ways of using land (e.g. waste utilisation), the project seeks to develop objective methods for assessing land use options and environmental impacts. These will be of particular value in aiding land use decisions at the local management unit level, and also in informing land use policy at the national level. The project links closely with those on Spatial Data Handling and Information Technology Methods and is developed within a spatial context. It has 4 principal research foci:

- **analysis of resource potentials, particularly in relation to wastes**
- **synthesis of upland management systems and options**
- **assessment of environmental impacts**
- **development of a generic DSS framework.**

This project is specifically tailored to address the needs of the MLURI's research customers who are concerned with land use policy development and evaluation.

Contact: Alan Sibbald

RESOURCE POTENTIALS

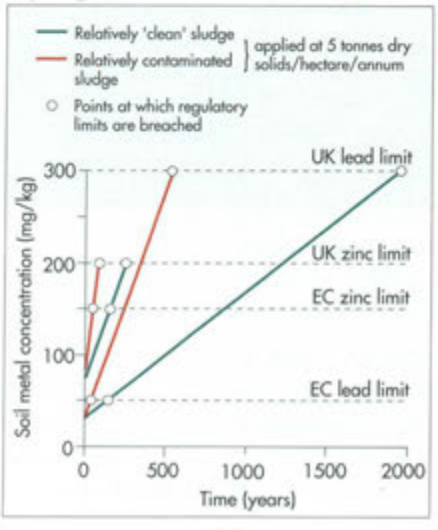
Waste utilisation on land is set to increase dramatically as a result of the cessation of some practices (for example sea disposal of sewage sludge) and the increasing constraints and costs on others such as landfill and incineration. The work on land suitability for sewage sludge utilisation (described in the MLURI 1994 annual report), has been presented to the Scottish Office Agriculture, Environment and Fisheries Department (Towers, 1995).

- the document describing the physical and land use constraints associated with sewage sludge utilisation in Scotland has been well received by the Scottish Office and is being used in policy development at the national level. It is also proving of value to the water industry as the latter goes through a period of considerable restructuring.

Using sludge data from Strathclyde Region and soils data from the MLURI soils database, the rate of build-up of heavy metals from sludge in the soil and the implications for the sustainability of land-based sludge strategies have been assessed. The time before sludge applications must cease is very sensitive to sludge quality, original soil quality (background concentrations of heavy metals in soil and pH), sludge application rate and the statutory soil limit concentration and can vary from a few decades to several millennia (Figure 1). Sludge application would be precluded on one of the soils if the recommended EC limit for lead were implemented.

Sludge utilization impinges on various aspects of farm management such as fertiliser budgeting and waste management planning. The impacts vary between different farm types with the more intensive livestock systems such as dairying, posing the greatest constraints to sludge recycling. MAFF have imposed a guideline figure of 250kg/ha/yr of 'total nitrogen' from livestock and organic wastes which can be applied to land. Approximately 25% of an average dairy farm would be required for farm - derived waste alone, with serious implications for a land-based sludge strategy. This work will be further developed and integrated into a waste-management module within the farm-level DSS.

Figure 1. Impact of sludge quality and regulatory limits on sustainability of sludge recycling on land.



Contact: Willie Towers

SILVOPASTORAL AGROFORESTRY SYSTEMS

Changes in the demands made on the land have resulted in an increasing need to develop land use systems which satisfy multiple objectives. Such land uses are biologically and structurally complex. We aim to gain an understanding of the processes involved in order to define the management strategies and predict the outcomes of such complex systems. Silvopastoralism is a good example of such complex systems.

In collaboration with the Forestry Commission's Research Division, we have set up one of a UK-wide network of silvo-pastoral experiments at our Glensaugh Research Station. The experiment contains a range of tree species and planting densities.

We have shown:

- the extent to which sheep behaviour is affected by the presence of widely-spaced trees (Figure 2).

Figure 2. Linear deviation (%) from the mean location of random movement by sheep in two silvopastoral tree densities (negative values show locations closer to trees than random).

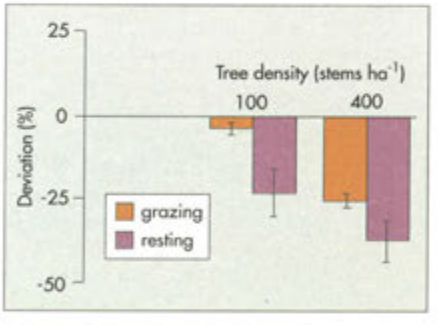
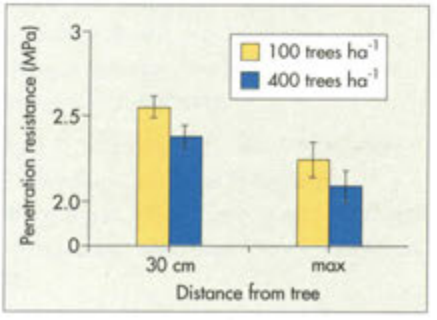


Figure 3. Top soil penetration resistance at two distances from trees at two planting densities.



- soil is more highly compacted close to individual trees than it is at a distance from them as a result of the treading effects of the sheep: we have shown also that the lower the tree planting density, the higher the animal: tree ratio and the greater the compaction (Figure 3).

- that tree survival and growth are a function of soil compaction, the greater the compaction, the lower the survival and growth (Figures 4 and 5).

These results allow the production of better models for the evaluation of alternative land use systems, better prediction of their outcomes and better planning of the future use of the land.

Contact: Alan Sibbald

MODELLING COMPLEX SYSTEMS: RED GROUSE MANAGEMENT

The demand for quality advice on complex land use issues is increasing. Our aim, therefore, is to improve our ability to model ever more complex systems in which land management, economics and landscape ecology are represented. We are developing methodologies, using artificial intelligence, to model such complex systems, particularly in cases where knowledge and data are diverse and sparse. We are adopting this approach to model red grouse management. Red grouse have declined dramatically as a result of changes in ecological and management conditions - the key to their revival is in obtaining an understanding of how the different ecological and management factors interact. A mixed qualitative/quantitative modelling approach is being developed by:

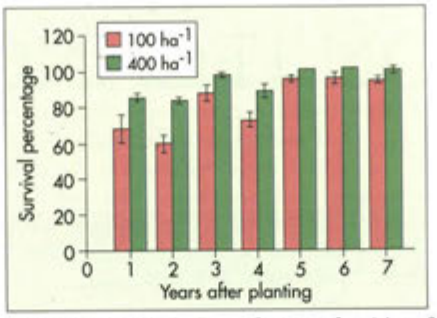


Figure 4. Survival of two planting densities of hybrid larch.

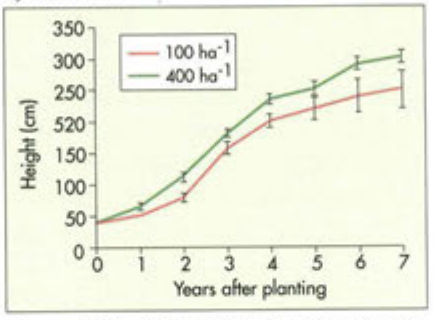


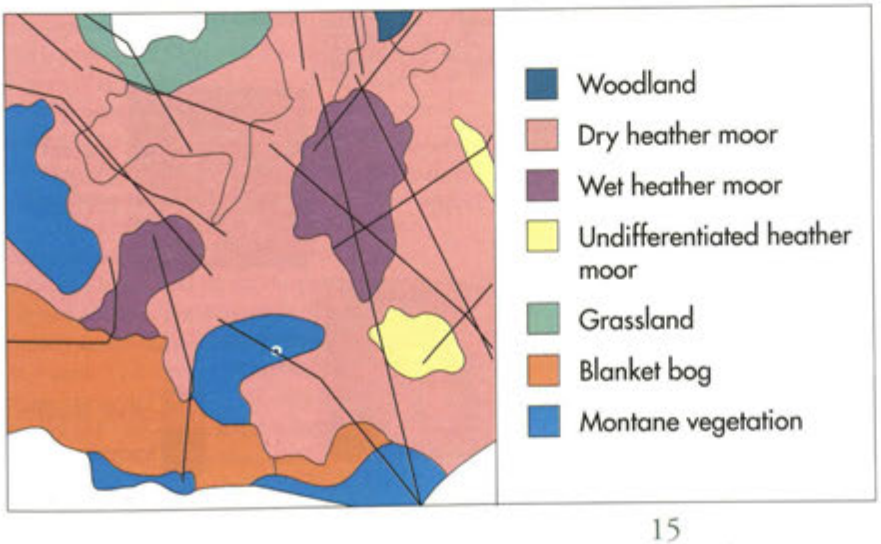
Figure 5. Top height of two planting densities of sycamore.

- integrating and reconciling scientific knowledge and data with the expertise and practices of workers and managers at the estate level,

- creating a heterogeneous knowledge base that can store and use the diversity of information available,

- creating Artificial-Life simulation environments for *in silico* empirical investigation of the nature of the complex behaviour emerging from the interacting ecological and management subsystems,

Figure 6. Knowledge about management practices such as the July count of grouse (the count transects are shown as black lines) is combined with scientific research on land coverage, to add value to the existing body of knowledge.



- linking the knowledge base to a simulation component to fill in the missing knowledge.

This research is being conducted in collaboration with the Computing Science Department, University of Aberdeen, and with the managers of a number of grouse moors.

Contact: Matt Hare

LAND ALLOCATION DECISION SUPPORT SYSTEMS

Land managers are required to make increasingly complex strategic and tactical decisions balancing economic, social and environmental goals within changing regulatory and incentive frameworks. Within the LEMS group innovative computer based decision support systems (DSS) of increasing sophistication are being developed to aid decision making such as multiple objective land use allocation, precision farming and waste management planning. Such systems can disseminate the results of recent research, advise on industry best practice, and provide land managers with opportunities to experiment. This experimentation can be with management regimes or combinations of existing or alternative land uses. This allows responses to legislative changes to be planned with results returned in terms of financial margins, employment and impacts on the rural environment.

Highlights of this research year include:

- establishment of ten land use modules within the G2 expert system.

- creation of a bio-physical resource database prototype for farms and estates within the Smallworld GIS.

- the linkage of the expert system and the GIS via a software bridge to form an integrated land use systems simulation environment.

- setting up an operational protocol for the investigation of methodologies for the optimisation of land use allocations.

Contact: Keith Matthews

Reference - See staff publications

SPATIAL DATA HANDLING and INFORMATION TECHNOLOGY METHODS

This research links closely to that concerned with Land and Environmental Management Systems and shares the same aim in terms of the development of spatial decision support systems (DSS) for land use planning at a range of scales. With the rapid changes in the availability of environmental information and the technology to analyse it, the research addresses some of the strategic scientific challenges relating to the acquisition, analysis and presentation of spatial information. Developing our skills and understanding in these areas is seen as crucial to our effective use of environmental data and the development of land use decision support tools and systems. The foci for current research efforts are:

- **methods for land cover mapping and monitoring, and development of integrated environmental resource databases**
- **improved techniques for spatial interpolation and spatial analysis**
- **measurement and representation of error and uncertainty in spatial data**
- **novel measures for assessing biodiversity**
- **development of integrated environmental impact assessment (EIA) methodology**

Contacts: Richard Aspinall, Alistair Law

LAND COVER MONITORING

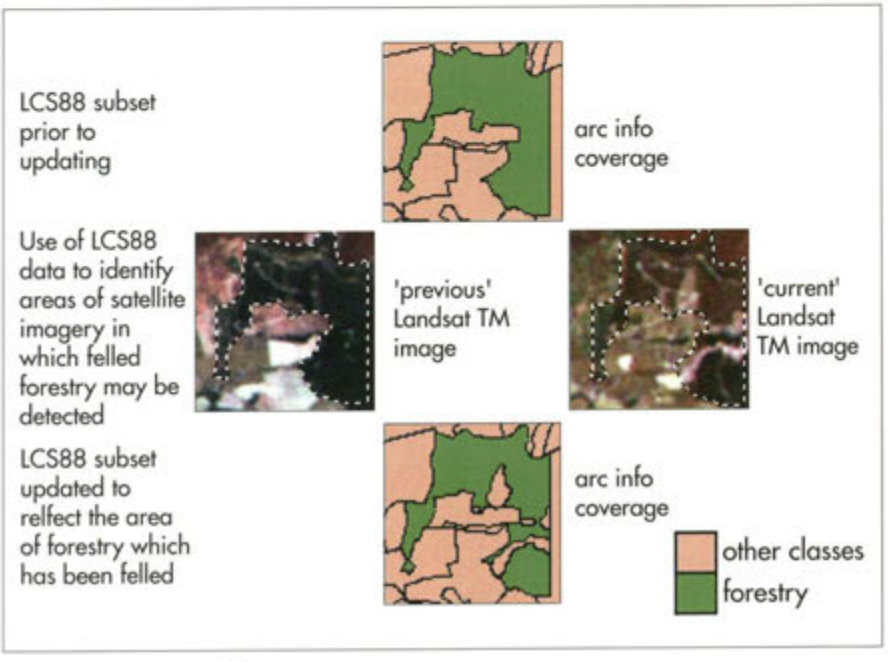
Monitoring countryside change is increasingly a requirement of UK and EC legislation. Current monitoring methods and initiatives in the UK have been recently reviewed as part of a Scottish Office consultancy (Birnie *et al.*, 1995). This showed the fragmentary and uncoordinated nature of much of the current effort, and the relative imprecision of some methods, particularly those which use a limited set of spatial data. Recent research has been concerned with developing an improved system for change detection.

A computer software environment called: SYstem for MOnitoring LAnd Cover (SYMOLAC), has been developed as part of joint project with the Computing Science Department at the University of Aberdeen. Fundamental to SYMOLAC are the concepts of integration and opportunism. Disparate spatial datasets, methods of analysis and qualitative knowledge can be integrated within the environment, enabling geographic, topographic, socio-economic information and other properties of land cover to be exploited, with differing methods of analysis being applied under differing circumstances. Throughout this approach, the choice of the next processing step and of the most appropriate method and requisite datasets is based upon the current state of the solution and upon the nature of the land cover currently being analysed. This lends an 'opportunistic' and dynamic feel to the environment. Figure 1 depicts a simple application of SYMOLAC: a region of felled forestry is detected using multi-temporal satellite imagery, this information being used to update a portion of the Land Cover of Scotland 1988 dataset.

The software components of the SYMOLAC environment are depicted in Figure 2. G2 forms the core of SYMOLAC, an expert system providing blackboard-based reasoning capabilities. The functionality within 3rd-party software can be exploited through communication modules, with the geographical information system Arc/Info and the image analysis package. PV-WAVE software provides SYMOLAC with spatial and statistical functionality.

Contacts: Chris Skelsey, Alistair Law

Figure 1. Diagram showing a before and after subset of the LCS. Landsat TM data also shown is used to identify an area of felling within a forestry polygon, the result used to produce the upated LCS.



A SPATIAL APPROACH to MEASUREMENT of (BIO)DIVERSITY

Diversity is a key element in ecological understanding and measurement of diversity is increasingly important in modelling interactions between human activity and the state of the wider environment. The related concept of biodiversity is also a fundamental component of the set of principles that sustainability provides to land management and planning.

A spatially-based definition and analysis of diversity has been investigated that includes geographic and taxonomic properties of environmental and biological variation as well as models of data-quality that describe heterogeneity in resource maps. The performance of several existing measures of diversity from the ecological literature have been tested using geographic data describing environmental and biological variation in Scotland recorded in a GIS.

The concept of biodiversity is treated hierarchically through taxonomic organisation, and, as the response of an organism to environmental heterogeneity is spatially and temporally variable, our approach considers three properties that are of particular importance:

1. representation of diversity as geographic scale changes (the effect of spatial resolution),
2. representation of diversity in relation to hierarchical changes in taxonomic relations (the complexity of the taxonomic hierarchy),
3. the importance of considering the quality of the geographic data used to measure diversity (incorporating models of heterogeneity in resource data that have been recorded using categorical maps).

The effects of the above properties are displayed in the pattern of diversity of land cover across Scotland which is modelled in Figure 3 using the Land Cover of Scotland (1988) dataset. The Shannon Index has been used as a measure of alpha diversity. The effect of change in spatial resolution is shown between Figures 3 (a)1 km resolution and (b) 3 km resolution. The effect of change in the taxonomic hierarchy between Figures 3 (a) 34 classes and (c) 20 classes. Figure 3 (a) and (d) show the difference in data quality (uncertainty in land classification). In Figure 3 (a) uncertainty in data has not been 'corrected' and (d) the data has been 'corrected' (the error model is included).

The three properties listed, combine to show the importance of different types of scaling in analysis. The use of a stochastic model of data quality has an especially strong effect and shows the importance of data quality as a component of environmental GIS databases. This information is particularly useful for models that predict the likely response of ecological processes to future changes and also has application in environmental monitoring and modelling at landscape and catchment scales.

Contacts: Richard Aspinall, Julia Miller

Reference - See staff publications

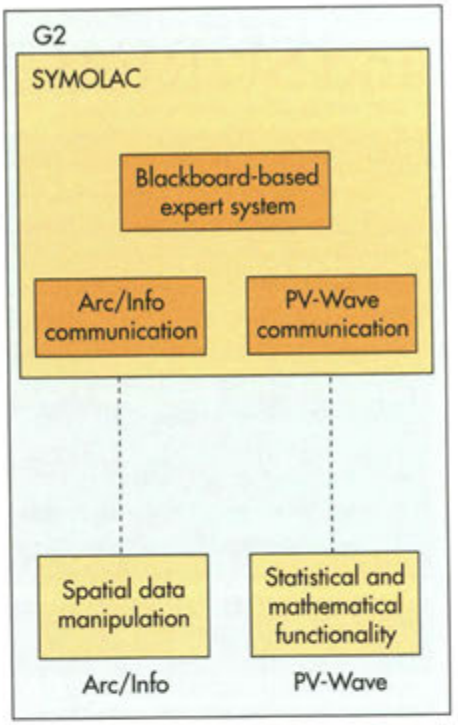
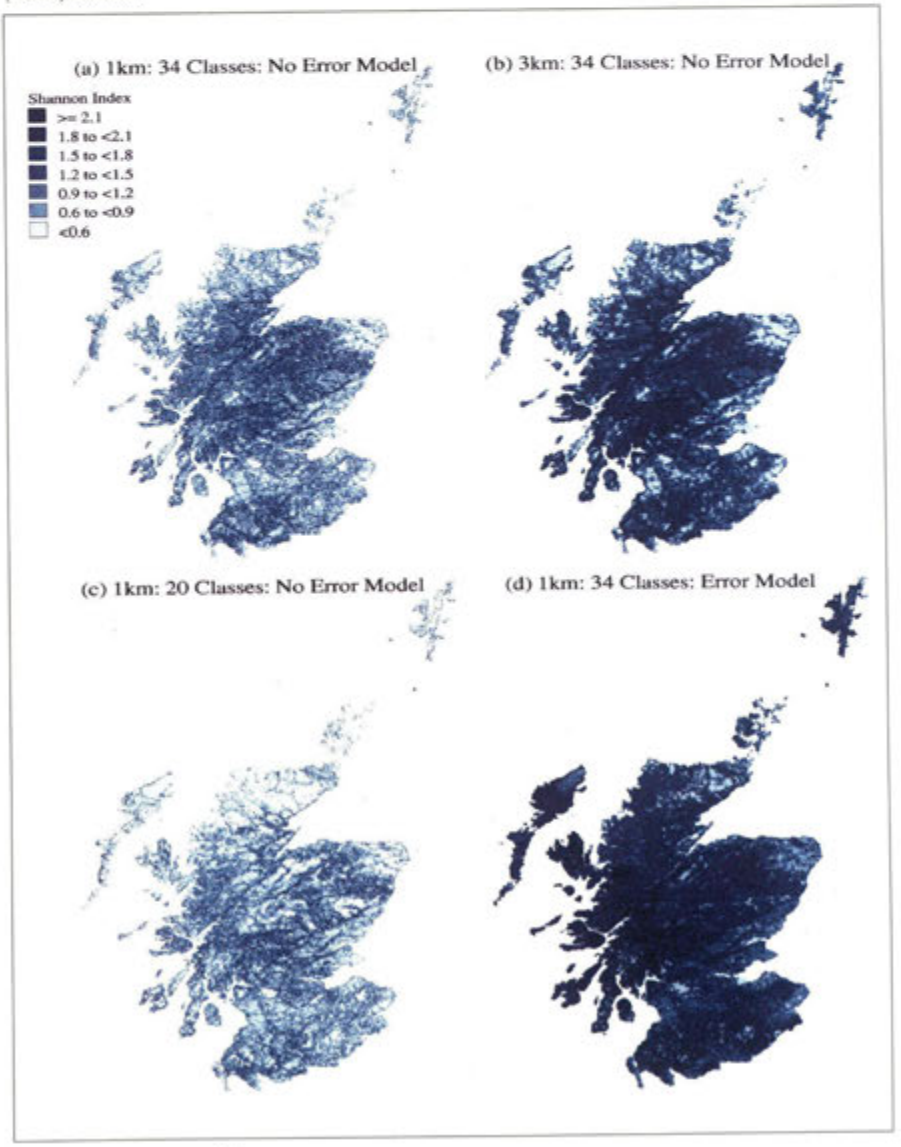


Figure 2 (left). Diagram showing the components of SYMOLAC: a system structure basically.

Figure 3 (below). Land Cover of Scotland (1988) dataset.



ACIDIFICATION of SOILS and SURFACE WATERS

The objective of this programme is to provide strategic information concerning the processes underlying the interactions between land use and atmospheric inputs of components that may lead to acidification of soil and water resources. In upland extensively managed land use systems, catchment budgets provide important data while laboratory studies of processes, such as sulphur dynamics, the decomposition of organic matter and mineral weathering, provide knowledge that can be integrated through modelling. Research has been focused on the following three areas:

- **catchment behaviour**
- **soil processes and catchment acidification**
- **modelling studies and critical loads**

CATCHMENT BEHAVIOUR

Central to the research on soil and surface water acidification is the collection of field data from catchments so that their hydrology and hydro-chemistry can be better understood. The collection of such data throughout the year and in the long term, combined with the development and application of novel instrumentation and experimental approach has enabled several important questions to be addressed.

- A novel soil moisture probe has been developed at the Institute and applied to soils in the Environmental Change Network catchment at Glensaugh. During storm events, the probe clearly demonstrated the phenomenon of "wetting-up" of soils (from the basal horizons upwards) following a drought and helped to explain the observed response of the stream. The soil moisture probe is an excellent example of technology transfer from a research institute to industry. Its manufacture and marketing have been taken up by Delta-T Instruments and it has been sold in many countries across the world. Currently, the MLURI soil moisture probe is in the process of being patented.

Contacts: John Miller, Graham Gaskin

- We have investigated the actual and potential impact of forestry on hydrochemistry. Increases in the hydrogen ion and sulphate concentrations of stream waters of forested catchments, have given rise to fears that proposed afforestation schemes involving catchments may have adverse consequences for the viability of fish stocks. However, the sensitivity of a catchment to such change in principle depends to a large extent on the critical load of acidity of its soils. The Halladale catchment in Caithness was initially assessed as having a low critical load (highly sensitive) giving rise to a conflict of opinion between fishing and forestry interests as to the desirability of afforesting selected parts of the catchment. In collaboration with the Forestry Authority and the Institute of Terrestrial Ecology, base line studies were undertaken involving detailed investigation of the soils. The results showed that the catchment was less sensitive to acid inputs than was originally feared and suggested that it was safe to proceed with afforestation. This outcome was accepted by all parties.

Contacts: John Miller, Hamish Anderson

MLURI soil water probes use a new measuring technique that matches other comparable instruments for accuracy, but is cheap, robust and easily calibrated. The probes use a simplified voltage standing wave method to determine the impedance of a sensing probe wire array, and hence the water content of the soil matrix. This technique has an advantage in allowing sufficient numbers to be used to assess both spatial and temporal changes in soil water behaviour.

SOIL PROCESSES AND CATCHMENT ACIDIFICATION

Many soil processes could be relevant to catchment acidification but attention has been focused on the following:

- Mineral weathering plays a crucial role in neutralizing acid inputs from the atmosphere in the long term and underlies the application of the critical load concept to soils in this respect. Weathering rates were calculated by three different methods in seven Scottish catchments and compared with acid inputs (Table 1). The results for three catchments are generally consistent with their known acidification status. For the others, weathering rates calculated from input-output budgets far exceed those calculated from soils data. Studies are in progress to reconcile these differences.

Contact: Derek Bain

- In environmental studies sulphate is often viewed as a mobile acid anion, and its deposition from the atmosphere and rapid transference through soils is thought to be a major mechanism for surface water acidification. However, the fate of sulphate anions input to organic soils, which are dominant in large areas of Scotland, is not clear. Laboratory incubations of peat spiked with ^{35}S-labelled sulphate under anaerobic conditions have indicated that sulphate-S may be rapidly cycled through both reduced and organic forms. In indigenous bog peat 12% of the label appeared in acid-volatile S (mainly FeS), 47% in pyrite (FeS_2) and 15% in elemental S after 24 hours incubation. After a further 56 days most of the label had been incorporated into an unknown fraction, most probably carbon-bonded organic S. In the same peat under forest, cycling was less pronounced (Figure 1).

Contact: Steve Chapman

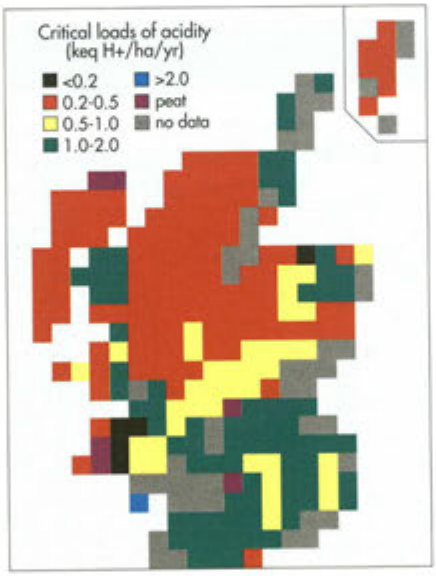
Catchment	Bedrock	Acidic input		Weathering rate		
		pH-based	S&N-based	Long-term	PROFILE	Current
Mharcaidh	Granite	21	46	26	31	82
Glensaugh	Schist	38	108	21	50	212
Sourhope	Andesite	39	110	30	52	662
Chon	Schist	48	144	24	125	44
Kelty	Schist	71	1265	10	58	19
Cairnfore	Greywacke	120	404	12	160	340
Clauchrie	Greywacke	120	404	24	106	185

Table 1. Acidic inputs calculated from pH of precipitation and also from deposition of S and N and weathering rates for base cations in catchments (meq m^{-2} a^{-1}).

MODELLING STUDIES and CRITICAL LOADS

The use of fully researched modelling approaches involving the application of the critical loads concept is essential if realistic assessments and predictions are to be made as to how inputs, land use, and soils interact to influence soil and surface water acidification. This is being done through various steady state and dynamic models.

- PROFILE is a steady state deterministic model and has been used to calculate weathering rates and critical loads for the soils dominant at the 20 x 20 km grid level across Scotland. The results are generally consistent with the UK empirical map of critical loads for acidity to soils (Figure 2).



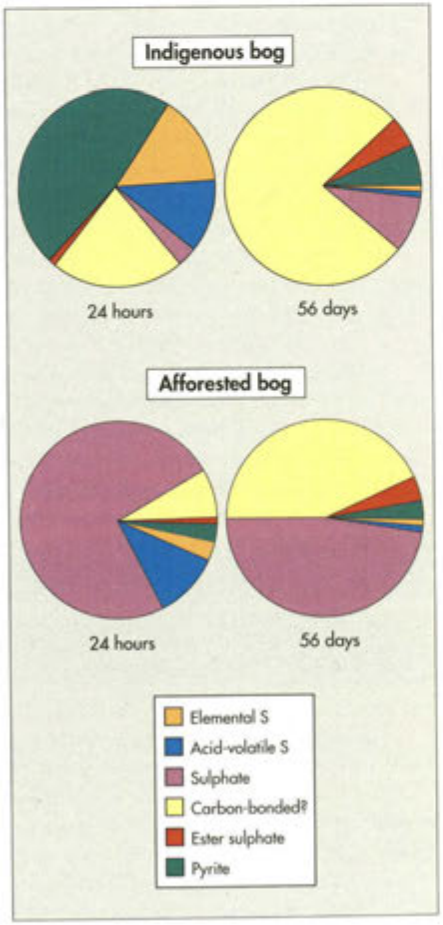


Figure 1. Transformations of ^{35}S-sulphate.

PROFILE was also used to calculate critical loads for nominal forest and moorland type vegetation for each grid square and it appeared from this that the areas of critical load exceedance were likely to be located mainly in the uplands of eastern Scotland.

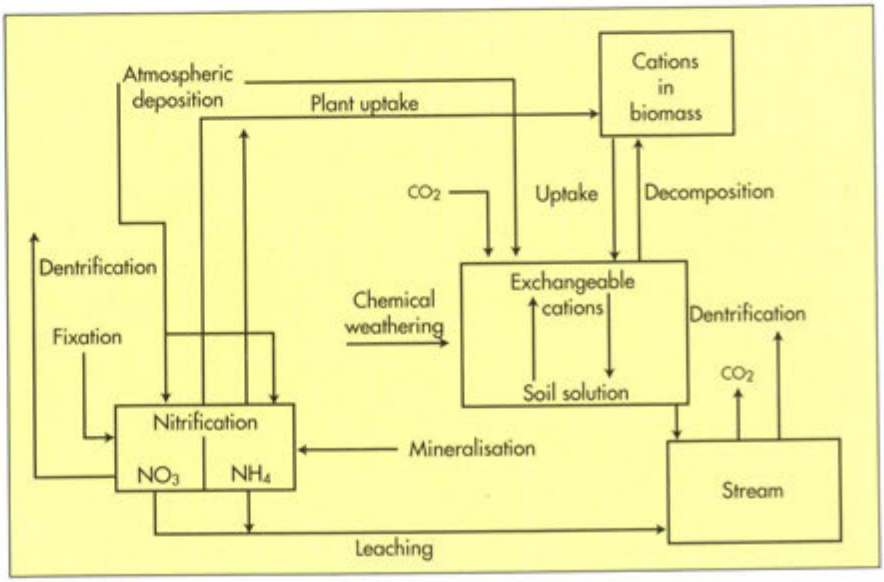
Contact: Simon Langan

- a Model of Acidification of Groundwaters in Catchments - With Aggregated Nitrogen Dynamics (MAGIC-WAND) has been developed collaboratively with the Institute of Hydrology and the University of Virginia. It incorporates all the major fluxes of nitrogen through time (Figure 3) and is designed to enable assessment of future surface water chemistry response to given scenarios of nitrogen deposition and land use change. It is fully coupled to the existing sulphur-driven model. The model has been coded, calibrated and validated against two sites in south west Scotland and has enabled a preliminary regional assessment to be made, highlighting the importance of spatial mosaics of afforestation and the possibility of regional nitrogen breakthroughs to surface waters under current emission scenarios.

Contact: Bob Ferrier

Figure 2 (left). Critical loads as determined from profile weathering rate.

Figure 3 (below). Schematic diagram of the MAGIC-WAND model.



SOIL POLLUTION

The primary objective of the soil pollution programme is to provide strategic information on the content, behaviour, impact and fate of pollutants in the soil environment. Of the various contaminants likely to be relevant to Scottish soils, most of our work has been concerned with the heavy metals, lead, cadmium, zinc, copper and nickel, although we are also carrying out work on the behaviour of radionuclides in highly organic soils and the content of organic micropollutants in Scottish soils.

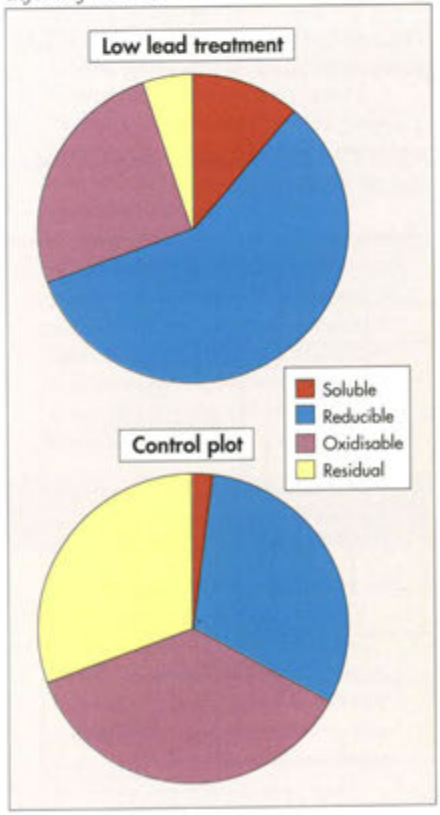
Our research has been structured to address three distinct areas:

- **experimental characterisation of contaminated soils**
- **redistribution and transport of contaminants within the soil environment**
- **assessment of the biological impacts of contaminants.**

CHARACTERISATION of CONTAMINATED SOILS

In January 1989, a sewage sludge trial was established at the Craigiebuckler site of MLURI. Four years later, soil samples, taken from a depth of 0-5cm and 5-15cm in the control plots and the plots to which Pb had been added, were analysed using isotopic analysis. This revealed the presence of at least four different components. The dominant one was that associated with inorganic salt used to 'spike' the sewage sludge which had a much lower $^{206}Pb/^{207}Pb$ ratio than that found in the other Pb sources in the soil. Sequential extractions of the soil samples showed that in the control soils the lead was equally associated with the reducible (organic matter), oxidisable (iron and manganese oxides) and residual fractions of the soil whereas in the amended plots most of the lead was associated with the reducible fraction (Figure 1). Isotopic analysis confirmed that this fraction was a more effective sink for the added lead than the other fractions of the soil.

Figure 1. Partition of lead in operationally defined fractions.



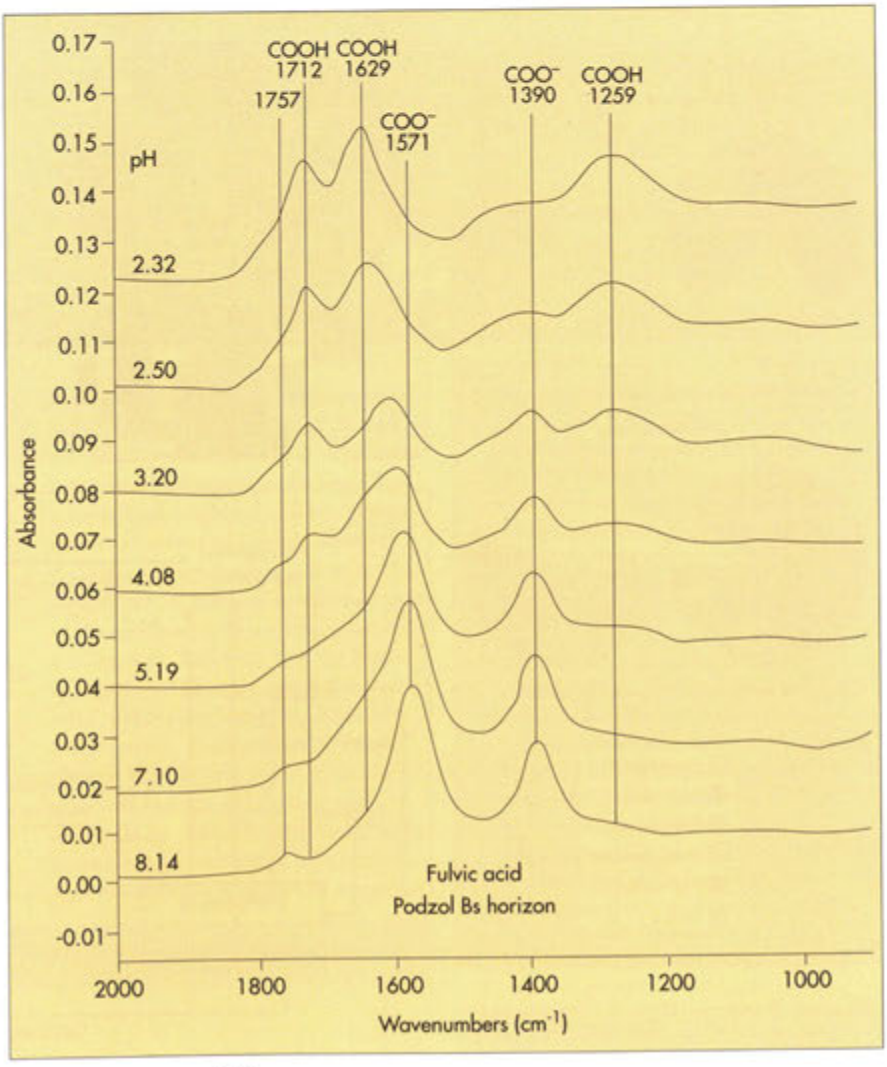
Contact: Jeff Bacon

REDISTRIBUTION and TRANSPORT of CONTAMINANTS in the SOIL ENVIRONMENT

Soil organic matter, in particular, humic and fulvic acids, can play an important role in the behaviour of heavy metals in soils, and many studies have been undertaken on the adsorption of metals by these ubiquitous soil components. However, adsorption studies alone cannot reveal the mechanisms of interaction and recent work has used horizontally attenuated total reflectance Fourier transform infra-red spectroscopy of humic substances in solution to study the molecular changes that occur during protonation (Figure 2). Parallel studies of a model dicarboxylic acid, oxalic acid, has shown that the infra-red observations may be reconciled with calculations from the type of chemical speciation models used to study metal uptake (Figure 3).

Contact: David Lumsdon

Figure 2. Influence of pH on IR spectra of dissolved fulvic acid.



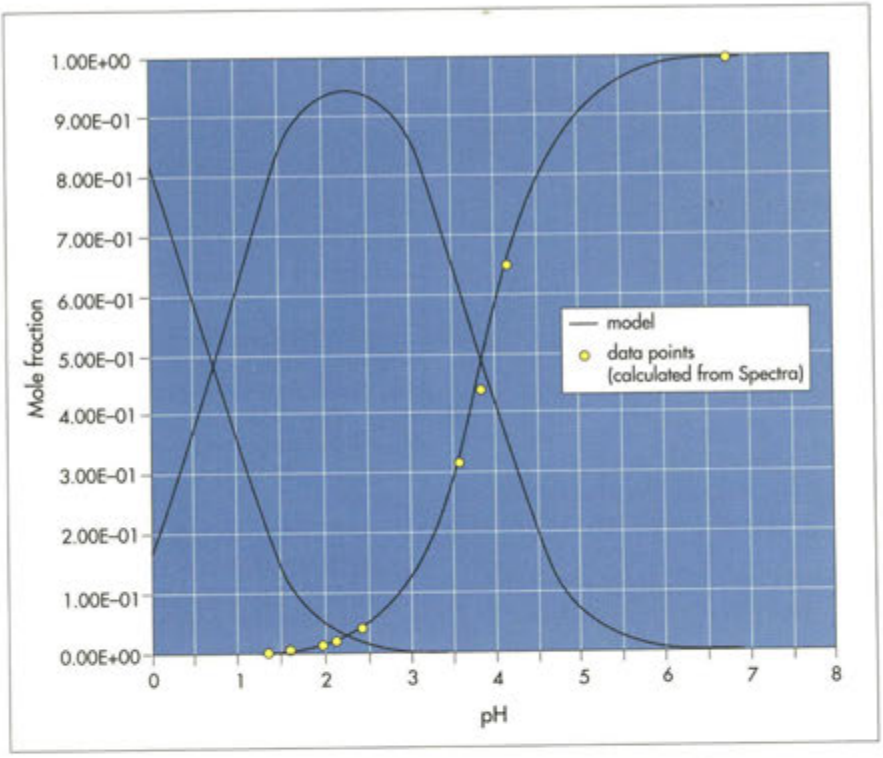


Figure 3 (above). Observed and modelled dissociation of oxalic acid.

The transport of contaminants from soils to ground and surface waters is determined by the physical movement of water through the soil and by the chemical partition of the contaminant between the solid and liquid phases. Implementation of this framework within a computer model facilitates prediction of pollutant migration in porous media and, by using a mechanistic approach rather than an empirical one, a very wide range of conditions and types of material can be simulated. For example, extremely good agreement has been obtained for the transport of fluoride through sand coated with goethite using literature values for the complexation constants (Figure 4) and has subsequently been extended to the leaching of sulphate through the same matrix using independently determined adsorption data.

Contact: Hans Meeussen

BIOLOGICAL IMPACTS of CONTAMINANTS

The mechanism of heavy metal tolerance in the ectomycorrhizal fungus *Thelephora terrestris* has been studied using direct techniques, scanning electron microscopy, electron microprobe analysis, electron spin resonance spectroscopy and Fourier transform infra-red spectroscopy (FTIR). The fungus is able to sequester metals such as Zn and Cu in the extra matrical hyphae when in symbiosis with trees and enhance the trees' ability to survive metal stress (Figure 5). FTIR results have shown that, when grown in the presence of Cu, the chemical composition of the fungus is altered with a greater amount of carbohydrate being produced.

Contact: Colin Campbell

The combination of skills and expertise encompassed in the areas within our programme will provide new and integrated data suitable for the ecotoxicological approach implicit in many current risk assessment procedures.

Several other priority areas have been defined:

- the use of chemical modelling techniques to develop and understand the concept of bioavailability (Paton *et al.*, 1995),
- the application of spectroscopic methods to validate adsorption reaction mechanisms (Lumsdon and Fraser, 1995) and
- the development of rule-based assessments of soil sensitivity to heavy metal inputs through the use of recently acquired chemical data (Towers and Paterson, 1995) and process-based knowledge.

References - See staff publications

Figure 4 (below). Observed and modelled breakthrough curves for H^+ and F^-.

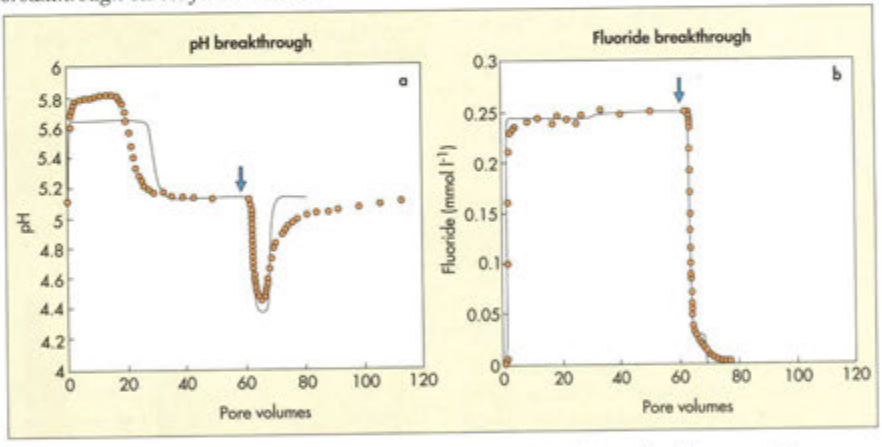
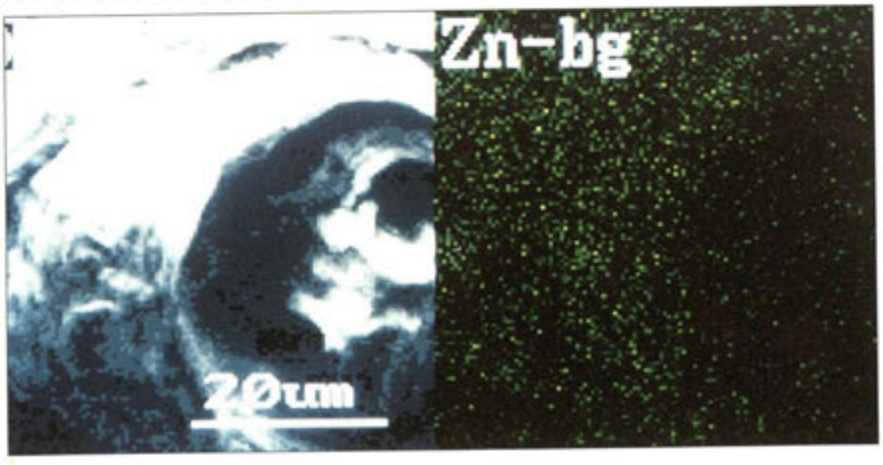


Figure 5. Scanning electron micrograph of tree root and microbe analysis image of Zn concentrations associated with T. terrestris.



SOIL NUTRIENT DYNAMICS and ENVIRONMENTAL IMPACTS

We are studying the dynamics of both nitrogen and phosphorus in soils, the mechanisms of their utilisation by plant roots and the environmental consequences of nutrient losses from soils contributing to eutrophication of waters. Since we are studying mainly acid, organic soils covering a range of fertility, the nitrogen and phosphorus present in soil solutions is predominantly in an organically-complexed form. Our strategic research aims at quantifying the impact of both pollution and changing patterns of land management on soil nutrient dynamics by considering:

- **the impact of atmospheric N deposition on N dynamics of peat soils**
- **the chemistry of soil solutions**
- **mechanisms of organically-complexed P utilisation by plant roots**
- **impacts of patterns of land use on nutrient losses from soils to waters**

Contact: Pete Millard

SOIL NITROGEN DYNAMICS

We are investigating the impact that inorganic nitrogen in atmospheric deposition has on the nitrogen and carbon dynamics in peatland ecosystems. By examining the response of the peat vegetation and microflora to additions of NH_4NO_3 we have shown that:

- production of dissolved organic nitrogen varies between moss species and also between habitats on the bog surface.
- the process shows a marked seasonal variation which may be determined by factors such as the nitrogen content of the rain and the height of the watertable (Figure 1).
- nitrogen added to the surface increased the concentrations of molybdate reactive phosphate and microbial phosphate at 20 to 30 cm depth in the peat.

It has become important that we can determine the fate of the organic nitrogen because it could have important consequences for movement of nitrogen in drainage waters and for changes in the composition of the vegetation on upland soils.

Study of a wider range of mineral and organic soils has also shown that:

- vegetation cover influences the amount and composition of extractable soil nitrogen.
- the proportion of dissolved organic nitrogen is greater in soil under grass than clover, contributing >90% and 60% of the total soluble nitrogen, respectively.

Contacts: Berwyn Williams, Tony Edwards

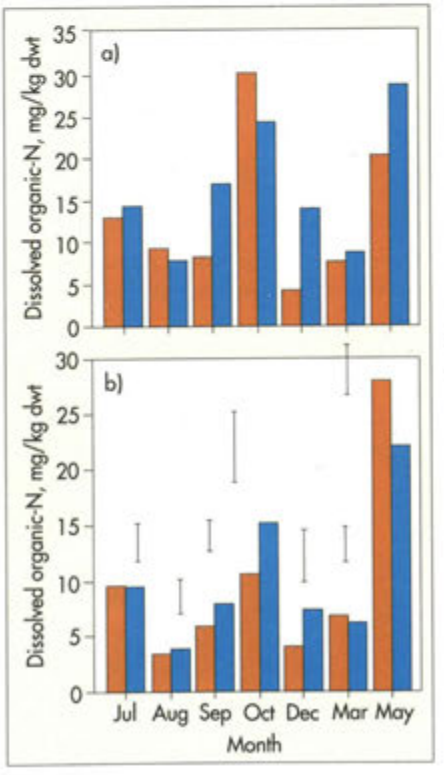


Figure 1 (left). Concentrations (mg N kg^{-1} dry weight) of dissolved organic-N in the water expressed from two species of Sphagnum *moss,* a) S. recurvum, *a pool coloniser, and* b) S. capillifolium *a hummock former, untreated (■) and treated with NH_4NO_3 (■) every two weeks at a rate equivalent to 30 kg N ha^{-1} $year^{-1}$.*

SOIL SOLUTION CHEMISTRY

One of the key mechanisms regulating the bioavailability of organically complexed phosphorus may be enzymic degradation to release phosphate. The potential bio-availability of phosphorus in soil solution from a peaty podzol was measured by the release of molybdate reactive phosphate (MRP) following treatment with acid phosphatase. We have shown that:

- model substrates with phosphate bonds of the type thought to exist in soil solution (e.g. inositol hexo-phosphate and ribonucleic acid) were quantitatively hydrolysed.
- only part of the total dissolved organically-complexed phosphorus was cleaved (Figure 2).

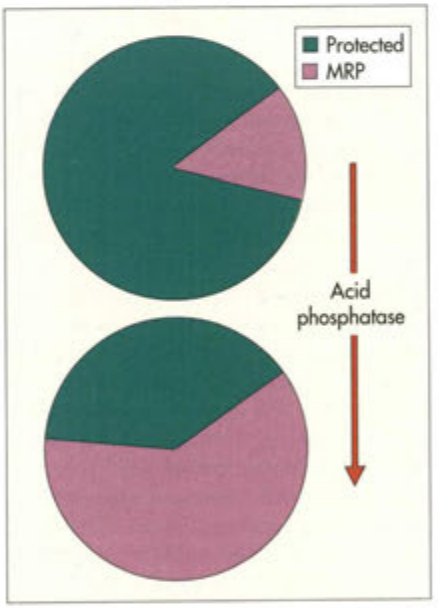


Figure 2(above). The effect of acid phosphatase on molybdate reactive phosphorus in soil solution.

- phosphate compounds in the colloidal state are protected from enzymic degradation. Field flow fractionation (Figure 3) was used to determine the distribution of colloidal P in soil water extracts.

Contact: Charlie Shand

PHOSPHORUS UTILISATION by PLANTS

We are studying the mechanisms by which upland grasses utilise organically complexed phosphorus from soil solution. We have:

- shown that both ^{14}C and ^{32}P from labelled ATP are taken up by roots and transported to the shoots of seedlings of *Agrostis capillaris*.
- prepared ^{32}P labelled compounds from upland soils by incubations and making soil water extracts
- improved the specificity of labelling by culturing *Pseudomonas* sp. isolated from upland soil with ^{32}P, and using an ultrasonic disintegrator to make a microbial preparation.
- after dialysis to remove orthophosphates and molecular size filtration, used the microbial preparation in time course and exchange experiments where root surface phosphatase activity can be monitored.

Contact: Alan Macklon

NUTRIENT LOSSES FROM SOILS

We are developing a predictive understanding of nitrate leaching and phosphorus loss from the Ythan catchment in north-east Scotland. The catchment has an area of 68000 ha and a predominantly agricultural land use. We are working in a collaborative, multidisciplinary study with the Scottish Agricultural College, the Institute of Hydrology and the North-East River Purification Board. In order to develop a management plan for the catchment we have:

- collated comprehensive and wide ranging data sets within a geographic information system and a database (Figure 4).

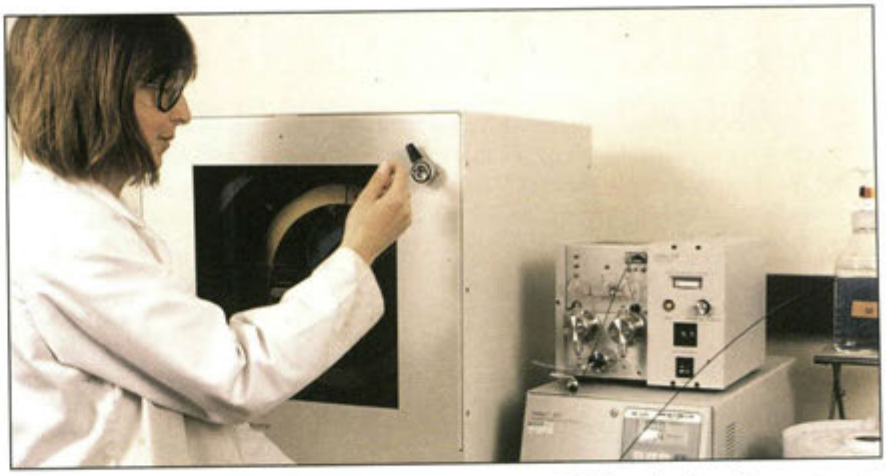


Figure 3. Field flow fractionation equipment used to separate colloidal phosphorus from soil solutions.

- developed an integrated representation of the water flow routing within the Ythan catchment (Figure 5).
- compared current and historical (1960) Agricultural Census data to determine recent changes in the extent and range of crops grown and livestock enterprises in the catchment.
- circulated a questionnaire which has been completed by over 60% of the land holders in the catchment, with help from the Scottish Agricultural College, to provide detailed information on current cropping, fertiliser and manual practices.

Contact: Tony Edwards

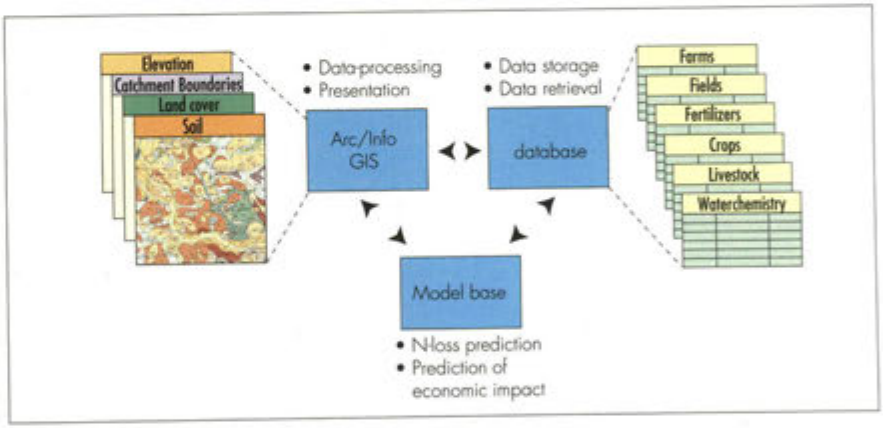


Figure 4 (above). Producing an integrated management plan for theYthan catchment.

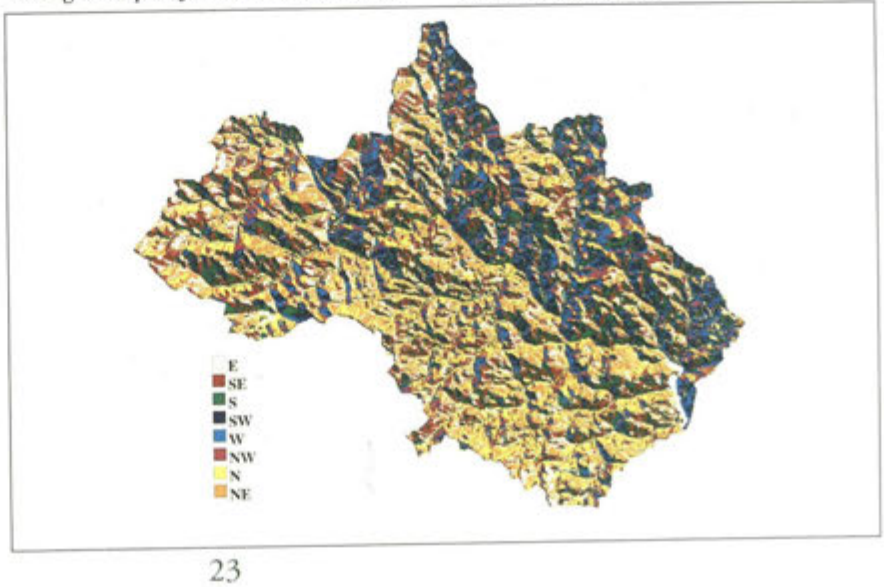


Figure 5 (below). Water flow routings within the Ythan catchment.

ASSIMILATE PARTITIONING and INTERNAL CYCLING

In extensive systems of land use and systems which aim to minimise environmental impacts of agricultural fertilisers are used sparingly or not at all. Instead the majority of nutrients used by plants for growth come from the decomposition of soil organic matter and leaf litter by soil microbes, or the internal cycling of nutrients stored within the plants themselves. Management of plants can have a large impact on assimilate partitioning, which in turn can alter soil nutrient cycling via carbon loss from roots stimulating soil microbial activity. Our aim is to enable the consequences of different management strategies to be assessed in the context of sustainable land use. To achieve this we are studying the impact of nutrient supply and other management inputs on:

- **assimilate partitioning in trees**
- **storage and internal cycling of nitrogen**
- **rhizosphere carbon flow in relation to soil microbes**
- **the relationship between plants and soil microbial diversity and activity**

Contact: Pete Millard

ASSIMILATE PARTITIONING

We have studied the effect of pruning on the partitioning of nitrogen and magnesium within *Pinus radiata*, in collaboration with the Department of Plant Science at Lincoln University and the New Zealand Forest Research Institute Laboratories in Christchurch and Rotorua. We have:

- manipulated assimilate sink/source relations within the trees by pruning and partial defoliation treatments (Figure 1).
- introduced stable magnesium and nitrogen isotopes to the trees using stem injection techniques.

- started a detailed sampling programme of foliage and other tissues which will enable the movement of nutrients within these trees to be studied over several years and which will allow the mechanisms causing pruning to affect tree nutrition and growth to be better understood.

Contact: Mike Proe

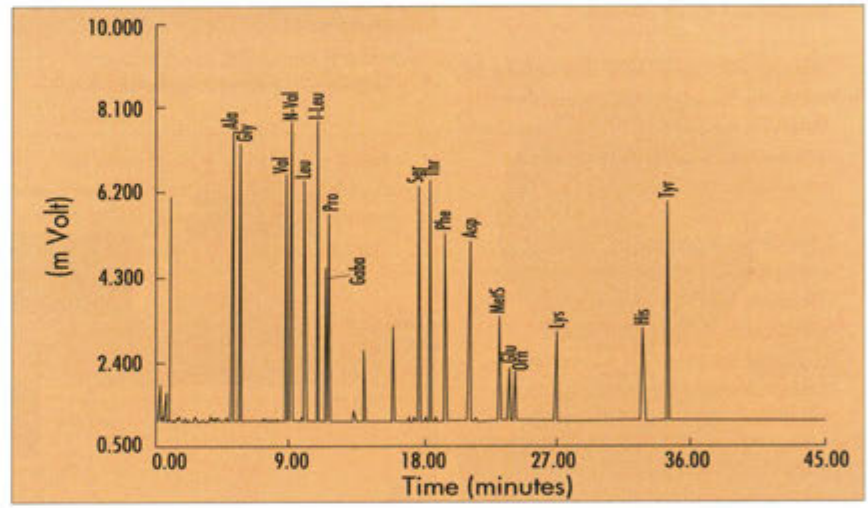


Figure 1 (left). A field experiment in collaboration with Lincoln University and the New Zealand Forest Research Institute to study the effects of pruning of radiata pine on assimilate partitioning.

Figure 2 (above). Amino acid analysis of tree xylem sap exudates.

INTERNAL CYCLING

We are measuring nitrogen translocation patterns in a range of tree species to determine their seasonal storage and remobilisation of nitrogen for growth. We have:

- developed mass spectrometry techniques to measure amino acids in small xylem sap samples (Figure 2).
- applied these techniques to trees grown with ^{15}N, and determined N translocation from storage and that from root uptake.
- run a field experiment with alder, ash, birch, poplar and sycamore trees to determine species specific amino acids in xylem saps due to nitrogen remobilisation from storage (Figure 3).
- established collaborative experiments with the University of Bologna to determine the effects of the timing of N supply on the growth and internal cycling of nitrogen in peach trees (Figure 4).
- shown that N storage during winter by gorse is unaffected by the plants capacity to fix atmospheric N_2 if soil N is available for uptake by the roots.

Contact: Pete Millard

RHIZOSPHERE CARBON FLOW FROM GRASSES

We are collaborating with the Scottish Agricultural College and Aberdeen University to quantify rhizosphere carbon flow from grasses and its impact on mycorrhizal fungi and their ability to take up organically-complexed phosphorus. We have:

- used contrasting levels of atmospheric carbon dioxide and nitrogen availability as experimental tools to manipulate carbon flow within the plant and subsequent release of carbon into the rhizosphere (Figure 5).

Figure 3. Field experiment measuring nitrogen translocation patterns in trees.

Figure 4. A collaborative experiment at the University of Bologna studying the effects of the timing of nitrogen supply on peach trees

- determined both quantitative and qualitative differences in the exudation profile of grasses after manipulation of carbon flow.
- compared the impact of contrasting levels of CO_2 upon carbon flow in soil versus sterile microcosm systems.
- investigated changes in the carbon utilization profile of soil micro-organisms extracted from the rhizosphere of rye-grass seedlings grown under ambient or elevated atmospheric CO_2 levels.

Contact: Sue Grayston

SOIL MICROBIAL DIVERSITY

Soil microbial community structure has important consequences for plant growth because microbial activity is the primary influence on soil nutrient availability. We are:

- collaborating with five other research centres in a coordinated programme to develop a range of molecular and physiological techniques to determine the biodiversity of soil microflora and their relationship to plant community structure (Figure 6).
- using carbon substrate utilisation profiles to assess the metabolic diversity of microbial communities from the rhizospheres of a range of grassland types (Figure 7), at ten sites throughout Britain.

Initial results have shown that discrimination between the microbial communities is associated with differences in their utilisation of some carbohydrates and amides.

Contact: Sue Grayston

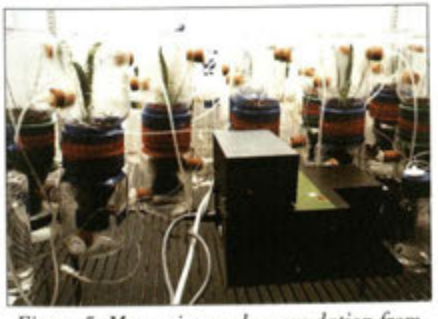


Figure 5. Measuring carbon exudation from plants under sterile conditions.

Figure 6. Location of research centres and study sites of the coordinated programme studying soil microbial diversity (SOAEFD Micronet).

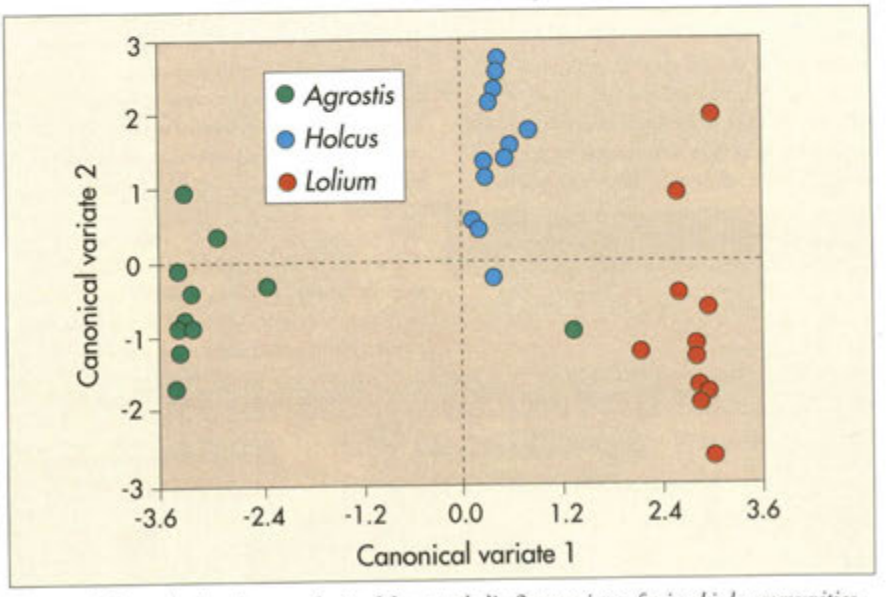


Figure 7. Canonical variate analysis of the metabolic fingerprints of microbial communities from different grasslands, showing separation between unimproved Agrostis *dominated, semi-improved* Holcus *dominated and improved* Lolium *dominated.*

VEGETATION DYNAMICS

We aim to understand and predict the impacts of large ruminants, (such as sheep, cattle and red deer), grazing semi-natural vegetation and the extensive grasslands of the UK, on changes in plant productivity and botanical composition. Such knowledge is required to achieve multiple objective land use management of the upland areas of the UK, viz agricultural output, wildlife conservation and landscape value.

The approach to the research is to:

- **understand the mechanisms and processes, particularly those associated with defoliation at a plant level, which influence competition between plants and hence lead to plant community change**
- **describe and understand the outcome of different grazing pressures on the spatial and temporal changes in vegetation**
- **develop computer models to increase understanding of the underlying mechanisms and to predict the impact of grazing pressure on vegetation change**

Contacts: John Milne, Pete Millard

Results and progress arising from each of these research approaches are given below:

NEIGHBOURING GRASS PLANTS INTERACT with FREQUENCY of DEFOLIATION IN INFLUENCING NITROGEN UPTAKE

When plants of perennial ryegrass (*Lolium perenne*) or red fescue (*Festuca rubra*) are defoliated either weekly or monthly, the presence of neighbouring plants reduces the N uptake per plant. The reduced uptake in the presence of neighbours is affected by the frequency with which the neighbour is defoliated. Increasing the defoliation frequency of the neighbour, results in increased N uptake of the defoliated plants (Figure 1). These findings are of importance in determining how defoliation by grazing animals may influence plant competition.

Contact: Barry Thornton

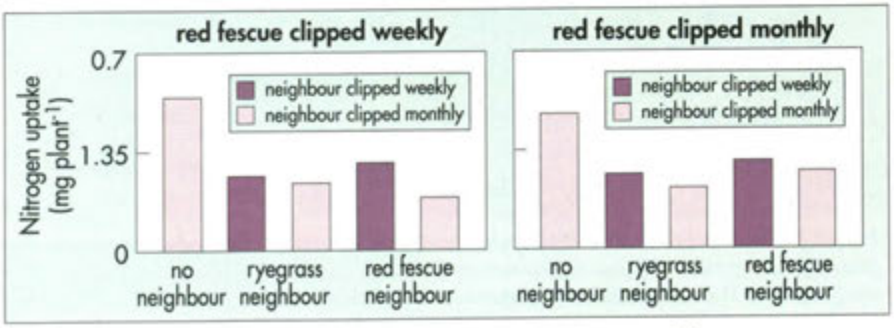


Figure 1. Nitrogen uptake of red fescue in 7 days following defoliation grown either without neighbours or in the presence of neighbouring plants of either perennial ryegrass or red fescue.

SHEEP GRAZING for 6 YEARS INFLUENCES SPECIES COMPOSITION of ACID GRASSLAND COMMUNITIES ACCORDING to HEIGHT at WHICH PASTURE GRAZED

Upland grassland communities dominated by *Festuca* and *Agrostis* species were grazed by sheep for 6 years during each summer at two sites at three pasture heights, 3, 4.5 and 6 cm, to determine how pasture height influenced species composition. A number of species decreased in abundance during the first year as an initial response to the imposition of controlled grazing. Subsequently, the principal grasses (*A. capillaris* and *F. ovina*) maintained or increased their abundance at all heights, mat-grass (*Nardus stricta*) increased,

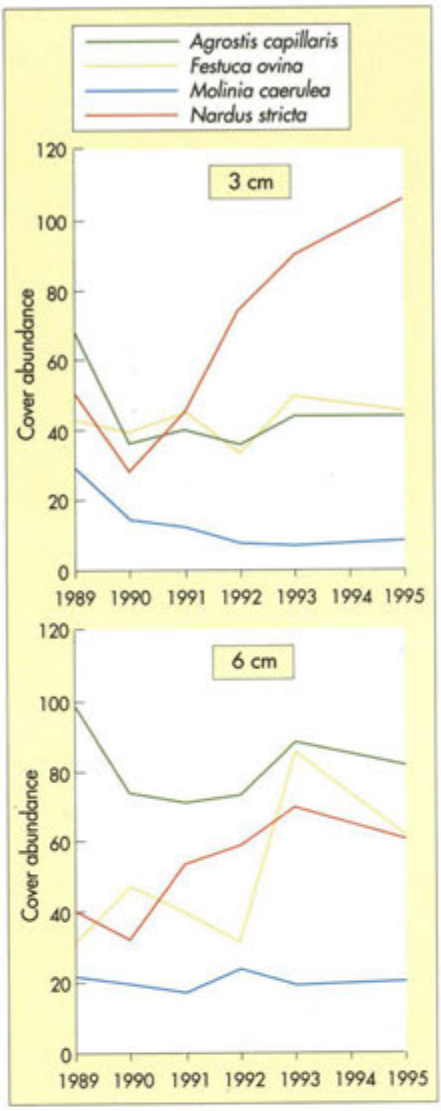


Figure 2. The effect of grazing of Festuca-Agrostis *pastures by sheep for 6 years on the cover abundance of four of the main plant species.*

particularly at 3 cm, and purple moor-grass (*Molinia caerulea*) declined under the heavier grazing of the 3 cm pasture (see Figure 2 for data on pastures maintained at 3 and 6 cm). This experimental site is being used for a new initiative to understand how genetic diversity may influence vegetation change.

Contact: Peter Hulme

The CURRENT HILL GRAZING MANAGEMENT MODEL (HGMM 2) is to be SUPERSEDED by a NEW DECISION SUPPORT TOOL (HGMM 3) with ADDED FEATURES

HGMM 3 will describe the impact of sheep, cattle and red deer grazing on upland plant communities over long periods of time and will be of value in helping land managers, policy makers and policy implementers in their decision making on the use of upland land resources. A list of the new features and outputs of the decision support tool is given in Table 1. It has been designed in an object-oriented manner (see Figure 3 for example) to give it flexibility and is being developed with the involvement of potential users.

Contacts: John Milne, Alan Sibbald

New features

Incorporate feed back effect of grazing in plant productivity
Includes effect of patchiness of heather on its utilisation rate (Figure 4)
Increase on-screen help
Extensive interpretive documentation

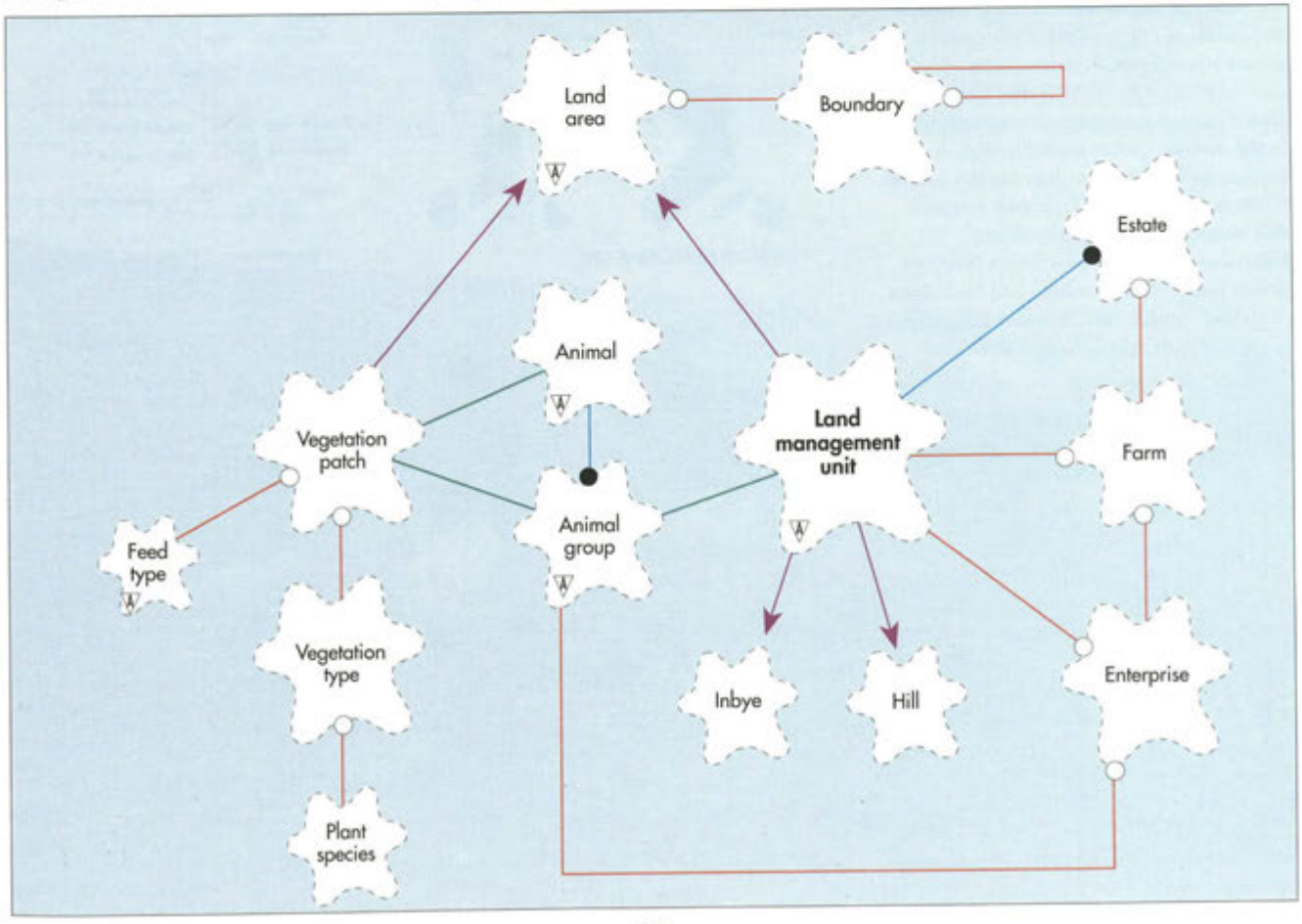
Outputs

Productivity of main vegetation types
Vegetation change
Biomass and height of main vegetation types
Productivity of sheep
Productivity of cattle
Productivity of red deer

Table 1. New features and outputs planned from Hill Grazing Management Model 3.

Figure 4 (right). Sheep grazing in a grass/ heather mosaic.

Figure 3 (below). Schematic diagrams of object-oriented structure of Hill Grazing Management Model 3.



HERBIVORE FORAGING

Our objective is to understand how domestic and other large wild herbivores, such as sheep, cattle and red deer, forage in heterogeneous ecosystems, typified by the semi-natural vegetation and permanent pastures of upland Britain, in order to determine the impact of these animals on plant species and plant community change and to provide information on the nutrient intake of these herbivores.

The approach being taken is:

- **to undertake research to develop a theory of herbivore foraging which takes into account the effects of microclimate, social behaviour, learning and the distribution and chemical composition of the vegetation and**
- **to apply our understanding to the development of decision support systems to aid and inform land managers and policy advice and implementation.**

Contact: John Milne

RED DEER BROWSING on SITKA SPRUCE SAPLINGS

Red deer can have a major impact on both plantation and natural woodlands, exerting a strong influence on vegetation dynamics and forest production. Recent work has shown that, although environmental factors such as soil nutrients and shade affect the nutrient and chemical composition of young sitka spruce trees, the main determinant of red deer feeding preferences is tree size. However, high monoterpene concentrations in the needles lead to earlier cessation of feeding by the deer thus limiting the damage to the tree (see Figure 1). Future research will investigate the nutritional and behavioural basis for selection of different woody plant species by browsing herbivores as part of an integrated research programme to predict their role in natural woodland development.

Contacts: Glenn Iason, Alan Duncan

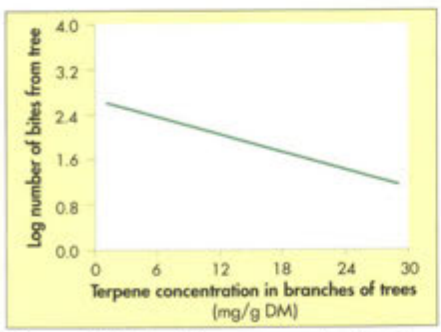


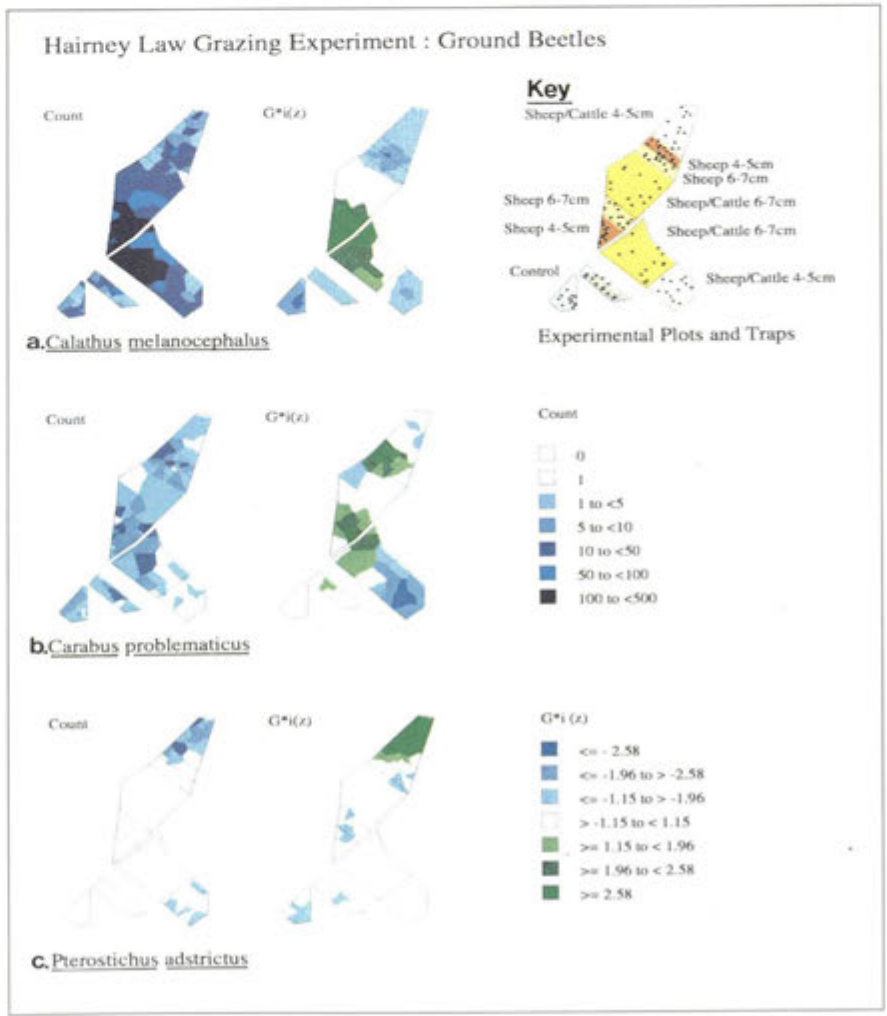
Figure 1. Effect of Terpene concentration in Sitka spruce saplings on the number of bites taken by red deer from a tree.

IMPACT of LARGE HERBIVORE GRAZING on INSECT TAXA

Grazing by large animals on indigenous, upland vegetation can affect the assemblages of insect species, in addition to the vegetation composition that visually most characterizes these upland habitats. The functional groups of insects in relation to their response to various environmental factors has been investigated. A geostatistical technique was developed to analyse the spatial distribution of individual species of rove and ground beetles in relation to the small scale structure of the vegetation, the grazing management and the large scale topography. Three functional groups of beetles were defined on an experimental area of *Nardus stricta* grassland on the Cheviot Hills, Borders Region (Figure 2). Significant aggregations of species corresponded to a sensitivity to either altitude and aspect, grazing regime or soil type (Figure 3). The technique defined those species most vulnerable to changes in grazing regime and this contributes to our understanding of the effects of changes in grazing management on upland biodiversity.

Contacts: Peter Dennis, Iain Gordon, Richard Aspinall

Figure 3. Hairney Law Grazing Experiment : Ground Beetles.



DEVELOPMENT of DECISION SUPPORT SYSTEM for RED DEER MANAGERS

A decision-support system is being developed to allow red deer managers to assess the long-term grazing impact of different sizes of red deer populations on the vegetation communities of upland Scotland and of culling management on deer performance and deer population dynamics (in collaboration with BioSS). Figure 4 describes the framework within which the decision support system is being developed. The effects of the presence of sheep and rabbits, human disturbance, supplementary feeding and climate are being incorporated in the model and output is in terms of the performance of deer populations and long term plant species and plant community change.

Contacts: Lucas Partridge, Iain Gordon, John Milne

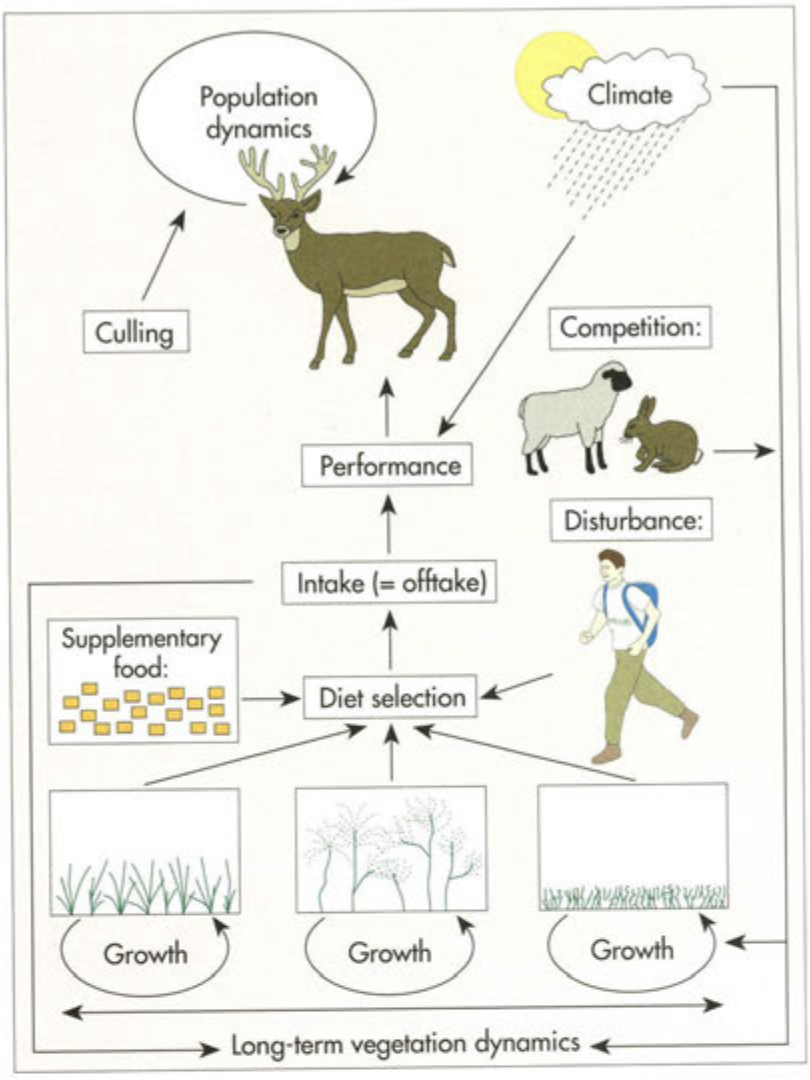


Figure 4 (right). Modelling the impact of red deer on Scottish vegetation communities.

Figure 2 (below). Hairney Law Grazing Experiment

RUMINANT RESOURCE USE

Within the EU there are surpluses of many agricultural commodities, particularly some traditional livestock products which form the basis of output from many hill and upland areas of the UK and the rest of Europe. There is also concern about the impact of agricultural management practices on the environment and on animal welfare. In general, current EU and UK Government policies encourage the extensification of production systems and diversification of the rural economy.

Our aim, therefore, is:

- **to identify options for land use by ruminants and to investigate the biological properties of livestock systems, with respect to agricultural output and efficiency, environmental impacts and welfare.**

Within this context we are concentrating on developing principles concerning the utilization of semi-natural vegetation and permanent pasture resources by populations of traditional and alternative ruminant species. The research focuses on grazing systems, animal fibre production and welfare of novel and extensively managed animals.

Contact: Iain Wright

GOAT GRAZING

If goats are to be incorporated into farming systems, we need to know how to integrate them into grazing systems with other livestock species. When grass/white clover swards are grazed by goats, higher clover contents develop than under sheep grazing, suggesting that grazing by goats could be used as a management strategy to enhance clover growth. An experiment has shown that the reason for the higher proportion of clover which develops under grazing by goats is due to goats selecting much less clover from the surface of swards than sheep (Figure 2).

Contact: Iain Wright

Figure 1. Three month old goat kid.

CASHMERE GROWTH and MOULTING

Research is being conducted to support the developing European cashmere production industry. This covers genetic and environmental influences on fibre growth and quality. Moulting of the fleece is under photoperiodic control and kids born in April shed their birth coat at 2-4 months of age. However moulting is limited to the guard hair, and even when there is cashmere present in the coat at birth, it is not shed until one year old. An experiment in which goat kids (Figure 1), were exposed to controlled lighting, and in particular to long days at different ages has shown that secondary follicles which produce cashmere are not mature enough to respond to photoperiodic cues until the goats are 3 to 4 months old, while the primary follicles which produce the outer guard hair are mature at birth and can respond to photoperiodic cues from that stage.

Contact: Margaret Merchant

WELFARE of DEER DURING TRANSIT and LAIRAGE

Red deer are a relatively new farmed species (Figure 3) and because they have not undergone centuries of domestication, may be more sensitive to the stresses imposed by many routine management and husbandry practices. For example, there is little information available on which to base guidelines and codes of practice for the transport and pre-slaughter handling of red deer to ensure high standards of animal welfare. A major research project is aimed at providing such information. Some preliminary results suggest that the physiological and behavioural effects of food and water deprivation (as occurs during transport and in lairage) for up to 6 hours is relatively minor and that space allowances during transporting of 0.5 m^2/head for yearling males and 0.4 m^2/head for yearling females are adequate.

The latency for deer to enter races and the speed at which they subsequently travel through raceways is altered by the width of the race (Table 1). To facilitate the movement of deer these results suggest that raceways should be 1.5 m wide.

Contacts: Pete Goddard, Phil Grigor

Figure 3. Farmed red deer

	Race width (m)	
	0.5	1.5
Latency (seconds)	6.9	2.7
Speed of movements (m/seconds)	1.0	1.3

Table 1. Effect of race width on latency to enter and speed of movement of deer.

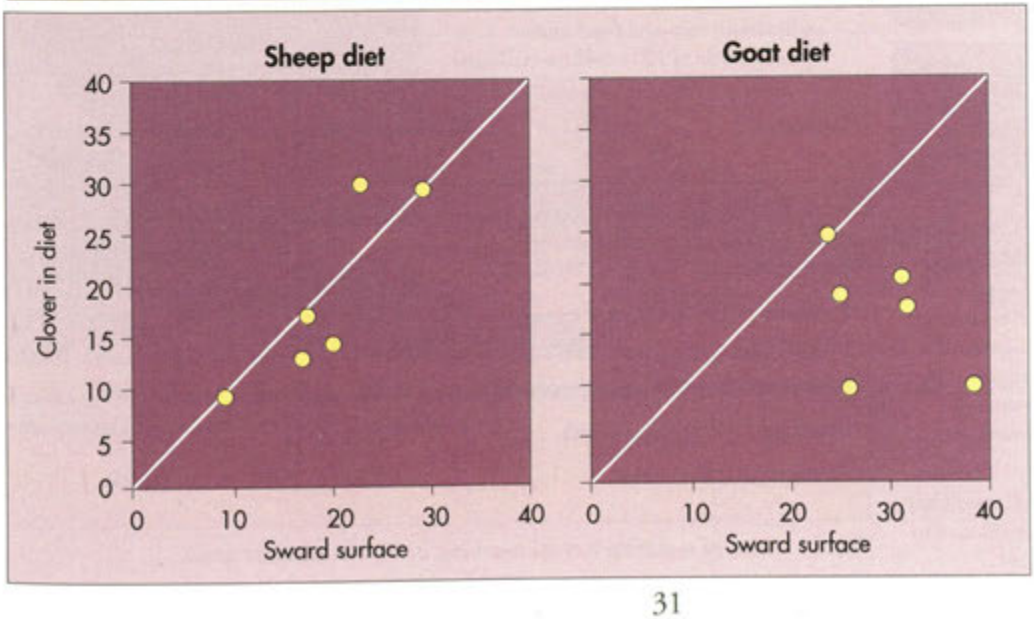


Figure 2. Proportion of clover in the diet of sheep and goats in relation to that in the surface of grass/white clover swards.

ENVIRONMENTAL and SOCIO-ECONOMICS

In rural areas land is principally managed for producing agricultural or forestry products. However, it is the indirect impacts which are increasingly of concern to the public - the effect on landscape, wildlife habitats, water quality and public access. We have investigated the costs and benefits of improving the environmental output from land and reducing agricultural pollution. In particular, we have examined barriers to change in land use (e.g. tenure arrangements) and incentive schemes designed to improve the rural environment.

DESIGN of CONSERVATION INSTRUMENTS

A variety of mechanisms can be used by government and countryside agencies to improve the environmental balance in land use. These include incentive payments, regulation, cross-compliance and auction or tendering systems. We have investigated alternatives for achieving the major conservation objectives on farms in the Cairngorms: these include, enhancing broadleaved woodland, extending wetlands, and maintaining arable stubble over the winter. Investigation of farmers' responses to different instruments has shown that:

- there is very large variability in the conservation responses of farmers to incentive payments.
- that incentives, when used in isolation, have limitations for habitat protection or for widespread habitat enhancement.
- habitats protected under current agri-environmental measures may not be those most at risk of damage.

Contact: Bob Crabtree

COST-EFFECTIVENESS of POLICY MEASURES for REDUCING NON-POINT GROUNDWATER POLLUTION

We have examined the various options made available to farmers under the Pilot Nitrate Sensitive Areas Scheme, established in areas with high groundwater nitrate levels. Farmers were offered incentives to modify land cover and reduce fertiliser inputs. We have assessed the cost-effectiveness of alternative measures and concluded that:

- conversion to grassland with limited N fertiliser inputs (less than 150 kgN/ha) gave the highest potential reduction in N leaching per £ expenditure.
- reductions in fertiliser level were very cost effective but failed to reduce potential N leaching sufficiently to meet the Scheme's objectives.
- conversion to unfertilised grassland was an expensive option (Table 1).

Contact: Bob Crabtree

LAND TENURE and FORESTRY

Woodland planting and management is an aspect of land use which in Scotland has traditionally been closed to tenants of land. Research began by investigating whether any tenants had become active in woodland management in recent years and, if so, in what circumstances. It found that few agricultural tenants are involved as yet, due to legal barriers and to more general cultural constraints on farm woodland. A substantial number of crofter tenants, however, have initiated woodland schemes since 1992, the year in which the Crofter Forestry Act took effect. By means of interviews, this phenomenon of crofter forestry has revealed that:

- schemes are proceeding on over 150 individual crofts and the common pasture lands of 15 townships (villages). Most crofter forestry is at a very small scale, involving planting or natural regeneration of native broadleaved species such as willow, alder and rowan. This reflects the changing emphasis of public grants.
- crofters are encouraged by a variety of motivations: to provide shelter for live-stock or buildings, to improve the appearance of their land, to increase soil fertility, to make use of areas which would otherwise lie unused, and generally to benefit the environment.
- despite the availability of grants on a par with all private foresters, very few crofters regard their forestry as a commercial venture. Many crofters are deterred by the cost of fencing, particularly where there is a deer problem.
- collective township projects are slow to develop, particularly where common pastures are smaller in size, where the community is generally older and less active, or where the legislative requirement to obtain a landlord's consent is difficult to achieve.
- there is still considerable resistance to more forestry in many areas due to the perceived threat to the sheep economy associated with large-scale conifer plantations.

The main thrust of the research consists of exploring the legal and sociological issues arising from the crofter forestry legislation. How in practice does the law balance the rights of common and individual property, the rights of landlords and tenants, and the desirability of agriculture and alternative land uses? At first sight, the law has little bearing on forestry and agriculture, but we have found that this is not the case. The study therefore provides a basis for research on other aspects of the effect on land use of legal intervention, for example, in relation to pollution control or nature conservation.

Contacts: Alison Brown

Option	Nitrogen leaching (£/1kg/ha/year)	Nitrate concentration (£/1mg/1/ha/year)
Basic Option (good agricultural practice with some restriction on fertiliser levels)	1.94	1.10
Premium A (no fertilizer, manure or grazing)	4.59	2.59
Premium B (no fertiliser or manure)	4.34	2.45
Premium C (< 150kg N/ha)	3.49	1.97
Premium D (plant trees)	4.23	2.39

Table 1. Costs of reducing nitrate leaching in nitrate sensitive areas.

VALUING the BENEFITS from GRAZING EXTENSIFICATION

Policies that encourage extensive grazing systems are now being promoted as part of the reform of Common Agricultural Policy and can benefit botanical diversity by increasing the area covered by species-rich grassland, wet meadows, heather and scrub.

In order to quantify the landscape benefits derived from extensified grazing with particular reference to extensification in the Central Southern Uplands, an environmentally sensitive area, a survey of 1,500 residents in Southern Scotland was conducted. In addition, questionnaires were despatched to visitors and interest groups (birdwatchers and ramblers). Responses indicated that:

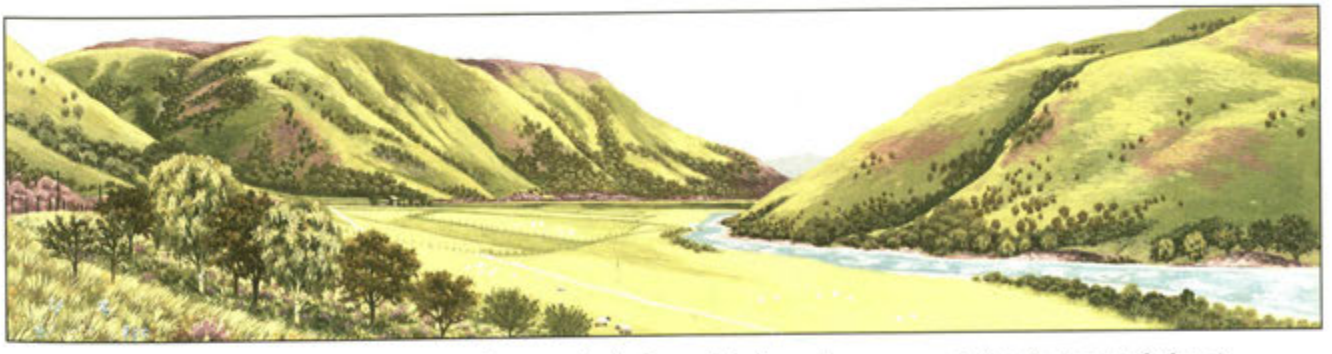
- over 65% of respondents were willing to pay for these policies, with the average annual household willingness-to-pay (WTP) being £55.
- the respective WTP values for visitors, birdwatchers and ramblers were similar at £49, £56 and £57.
- amongst all groups there was a clear preference for more deciduous tree cover. The median WTP for extensification policy was £47, but rose to £54 where respondants wanted 'many more' landscapes such as 2 (Figure 1).
- 43% of respondents considered an open landscape to be "most typical" of the area and these people were also willing to pay the highest average amounts for policies that brought about more tree cover.

This economic evaluation strongly supports current expenditure to encourage extensified grazing. In contrast to some studies, no strong attachment to the status-quo was apparent in this survey, especially where people disliked or were indifferent to the open landscape.

Contact: Craig Bullock

Figure 1. Valuing the benefits of grazing extensification. Two of the landscapes used in the survey.

Landscape 1. A landscape with levels of grazing at the higher end of current practice. There is very little heather or scrub and evidence of erosion on steep hillsides and in gullies.



Landscape 2. In this scenario there has been a much greater level of extensification and some removal of stock. As a result there is considerable regeneration of heather, trees and scrub.

The COST of CLEAN WATER

Professor Sir Frederick Holliday, CBE, D.Sc., F.R.S.E., F.I.Biol. CHAIRMAN, NORTHUMBRIAN WATER GROUP

The 19th Macaulay Lecture, 22 November 1995

The Macaulay Land Use Research Institute is devoted to the science of land use, but we all realise that the division of environmental considerations into land, water and air is an arbitrary one. Indeed some of the most interesting situations are at the interfaces of land and water, water and air.

Agenda 21 of the Earth Summit states that "By the year 2000 all states should have national action programmes for water management, based on catchment basins or sub-basins, and efficient water use programmes. These could include integration of water and other resource planning with land use planning development and conservation, demand management through pricing, regulation, conservation, re-use and recycling of water."

The presence of water on a planet is generally taken as indicating the potential for life. That is because on this planet life originated and evolved in water. In this context life means those biochemical processes which are generated by molecules that can self-replicate and have the potential to change. Viewed from space the earth is a watery planet, but 97% of that water is salt water and is unsuitable for drinking by man and unsuitable for many other human uses. Of the 3% freshwater, two-thirds is locked up in the polar icecaps and other glaciers. The 1% available to man is found in part in lakes, rivers and other 'wetlands' and in part in subterranean 'fossil-water', some of the latter having accumulated many thousands of years ago. There is water within the tissues of all living organisms; this 'biological water' is in a dynamic state, passing into and out of the organisms often at specific sites and by both active and passive mechanisms. The water molecules a human aged 60 has, are not those they had at 59 or will have at 61. Water is constantly on the move and when we refer to the water cycle, driven by solar energy and gravitation forces, we should remember that we are included in that cycle. The knowledge that we ourselves are 'interruptions' in the cycle may be one reason why water is often given such a special place in philosophical thinking and why emotional as well as rational considerations have to be taken into account in considering how water is used, paid for and owned.

Although this paper concentrates mainly on the management of water in Britain, water in other countries limits human life and endeavours much more dramatically than here. World-wide, 2 billion people lack access to safe water and 3 billion people lack effective sanitation (WaterAid figures). A recent report from the World Bank (August 1995) states that water scarcity, not shortage of land, will be the main constraint of agriculture in developing countries. Whilst less than 1% of abstracted water is used by agriculture in Britain, 80% of all water used worldwide each year goes for irrigation, producing up to 40 per cent of world food crops from 17 per cent of all arable land.

The World Bank estimates that $600 billion must be spent over the next 10 years on water-related investments. A very considerable cost for clean water. Worldwide the factors most influencing water use are: the growing world population, especially in urban areas; the restriction on supply of safe water due to pollution from domestic wastes,

industry, agriculture etc; the escalating costs of the engineering and environmental technologies involved in harnessing new resources.

Very often it is not the basic supply that is the problem, but inefficient usage. Global demand for water has increased by about 2.3 per cent a year, doubling every 21 years. Such a rate of growth cannot be sustained. In particular Fossil water resources are being depleted as rapidly as oil reserves. This led to Press headlines responding to the World Bank report, such as 'Future wars will be fought over water'. Certainly there have been threats made from some countries e.g. Sudan to interfere with the water supplies of other countries e.g. Egypt.

In 1986 the World Resources Institute produced a classification of water availability per head of population thus

Very Low <1000m^3 per annum per person
Low 1000-5000m^3 per annum per person
Medium 5000-10,000m^3 per annum per person
High > 10,000m^3 per annum per person

England and Wales, with 1,400m^3, is indeed low, and some regions e.g. East Anglia, South East England are very low. Scotland, overall, is not low but parts of East Scotland are low. The figure for the UK as a whole is 2,090m^3. Table (1) puts the UK figure into context.

Selected Water Abundant Countries	Annual Renewable Fresh Water Available Per Person for Early 1990s (cubic metres)
United Kingdom	2,090
China	2,427
India	2,464
Germany	2,516
Spain	2,849
Italy	3,243
France	3,262
Mexico	4,226
Japan	4,428
The United States	9,913
Brazil	46,631
Equatorial Guinea	85,227
Norway	97,268
Canada	108,900
Congo	359,803
Iceland	666,667

Source: The World Bank

Table 1

Water Scarce Countries Today (less than 1,000 cubic metres of water per capita per year)	Annual Renewable Fresh Water Available Per Person for Early 1990s (cubic metres)
Djibouti	23
Kuwait	75
Malta	85
Qatar	117
Bahrain	179
Barbados	195
Singapore	221
Saudi Arabia	306
United Arab Emirates	308
Jordan	327
Yemen	445
Israel	461
Tunisia	540
Cape Verde	551
Kenya	636
Burundi	655
Algeria	689
Rwanda	897
Malawi	939
Somalia	980

Source: The World Bank

Table 2.

Whilst the WaterAid figures and the World Bank report underline that whatever problems we face here in Britain they are relatively small by comparison, the problems of water availability in Britain are real and are dealt with later on in this article.

England and Scotland differ in one important fashion so far as calculating the cost of clean water is concerned - in England the water authorities were privatised in 1989 and ownership passed from the state to the private sector. Ownership is important, as we shall see, not least because in England the interest of customers is guarded by a Regulator - the Director General of Water Services and his Office (OFWAT for short) rather than, as in Scotland, by the Secretary of State and Parliament.

So the subject of this paper, 'The cost of Clean Water' has a political and administrative dimension to it. It is important to note that a great deal of our science is applied science i.e. applied to the human condition. It is

commissioned and constrained by the workings of the government machine. That machine is fuelled by political considerations which are generally highly subjective, based on feelings rather than objective considerations.

Water as a resource is best considered within catchment areas. The shape and structure of the land determines the nature and supply of our water. In Northumbrian Water's region we have embellished and modified it by building reservoirs such as Kielder. The water from Kielder is used to regulate three rivers, the Tyne, the Wear and the Tees. Important water supplies are drawn from those regulated rivers. The water is technically owned by The Crown administered by Parliament through its Agent, at present the National Rivers Authority, soon to be the Environment Agency. There will be an equivalent Scottish Environment Protection Agency.

Selected Water Scarce Countries, 2025	Annual Renewable Fresh Water Available Per Person (cubic metres)
Djibouti	8
Kuwait	42
Qatar	65
Malta	66
Bahrain	83
Saudi Arabia	108
Jordan	115
Yemen	147
Barbados	154
United Arab Emirates	164
Singapore	172
Cape Verde	224
Kenya	224
Israel	237
Burundi	252
Rwanda	284
Tunisia	290
Algeria	309
Libya	329
Malawi	333
Somalia	337
Oman	396
Morocco	549
Comoros	572
Egypt	584
South Africa	644
Syria	685
Haiti	761
Iran	776
Ethiopia	784
Cyprus	921
Zimbabwe	952
Tanzania	955
Peru	983

Source: The World Bank

Table 3

Northumbrian Water is permitted (for a price) to capture, treat and distribute water. We are licensed for those activities and subject to a number of Regulators. The quality of water at the tap is monitored by H.M. Drinking Water Inspectorate. It is a criminal offence to provide water unfit for human consumption. Our own staff every year do 160,000 tests, 80,000 of which are done at the customers taps. We meet over 99% of those standards (as indeed do most UK water suppliers), which are determined by UK law and the EU Directive.

Behind those tests lie the collection, treatment and distribution facilities of a major industry. Producing clean water produces a sludge, various organic and inorganic substances that settle out during the purification process. Those sludges from clean water are disposed of in landfill sites.

We do our best to inform our customers just what is in their tap-water, but it is not easy to get across the scale of the units used. For example, some substances e.g. coal-tar derivatives, must meet standards at the nanogramme per litre level, others e.g. lead, copper, zinc at the microgramme per litre level and yet others e.g. nitrate at the milligramme per litre level. As a rough guide we use the swimming pool analogy. One mg/l is equivalent to one pint in a typical recreational pool; one microgramme per litre is 10 drops in the pool; one nanogramme is one hundredth of a drop in the pool. In projecting costs and risk to the public, it is important to seek for an understandable reference frame, because big numbers of small units can be alarming.

There are a number of sensitive issues on which we are often called to respond e.g. the addition, or not, of fluoride to the water supply; the presence or not of oestrogenic substances in the water supply; the presence of lead derived from pipes in the water supply. Two of those issues raise points of either principle or payment. We add fluoride to some of our water supplies and the Regional Health Authority wishes us to extend the Fluoridation programme. But it is the decision of the Board of Northumbrian Water Plc to take and the Board no longer contains elected representatives: we are a Plc, we cannot resort to a democratic mandate. Cost is not an issue; feelings and legal consequences are issues. Welsh Water has withdrawn Fluoridation and our neighbours (Yorkshire and North West) have decided not to embark upon it. Any decision by the Board of Northumbrian Water will not be taken lightly, the consequences of our action will be far-reaching, our lawyers are uneasy.

To meet the likely European Standards on lead in tap-water will not be easy. Many older houses in the region, as in Scotland, have lead plumbing and the ability and willingness to pay for the replacement of pipes is a

challenge. After consultation and publicity we are experimenting on Teesside with the addition of phosphates to the water, which react with the lead to form an insoluble phosphate coating to the pipes. We hope at least to buy time for our domestic customers by this method. But low-lead water as specified by the EU will cost households more money than many can afford to pay.

In relation to the question of returning water once it has been used to the environment, water in means water out, whether it be home, hospital or factory. In addition, once rain has fallen on roads, car parks, roof-tops and so on it has been dirtied and should not be returned to the water cycle without passing through some form of treatment. Once treated, the water is discharged into either inland or estuarial waters. Northumbrian Water has 409 sewage treatment works; 168 of them have discharge standards determined by the environmental Regulator at present the NRA. We monitor our own compliance and typically achieve figures of over 99%. For the future, compliance with the Urban Waste Water Directive will dominate both our technical and our financial thinking. Another EU Directive that we must comply with is the European Bathing Water Directive. It is rather hard to believe, but there are 34 designated bathing waters along the coast of N.E. England. Our discharges are closely monitored, once again by the NRA. Major investments have been made (e.g. at Saltburn, Seaham, Whitley Bay); and we are spending £1m per week on such schemes.

Attempts are made to control what is accepted into our sewers. Consent criteria for substances in List 1 of the European Dangerous Substances Directive are determined by Her Majesty's Inspectorate of Pollution. On that list we have substances such as those below:

A major challenge is coping with any list 1 and list 2 substances that come from rainfall draining from uncontrolled sources such as road surfaces, and from domestic drains. Levels far greater than any approved from industry can find their way into our sewers from those sources. Another dimension of the control problem is that of wrong or illegal connections to sewers. 7-20% of properties in sampled areas were found to have connection defects - a startling proportion if it is representative of the nationwide problem.

CONSENT CRITERIA FOR LIST 1 SUBSTANCES
Determined by HMIP
Total consented loads of List 1 substances discharge to NWL's sewers in 1994:

Parameter	Quantity (g)
Mercury	8,395
Cadmium	80,300
Dichloroethane	511
Carbon Tetrachloride	<1
Pentachlorophenol	7,665
Tetrachloroethane	272,000
Chloroform	1,500,000

Northumbrian Water determines standards for accepting list 2 substances.

CONSENT CRITERIA FOR LIST 2 SUBSTANCES
Determined by Northumbrian Water
Total consented loads of List 2 substances discharge to NWL's sewers in 1994:

Parameter	Quantity (kg)
Copper	9,125
Chromium	6,205
Lead	3,139
Nickel	4,380
Zinc	11,680

Of course, underground sewerage pipes must be regularly surveyed for leakage especially if they are in the vicinity of ground-water boreholes.

The discharge of the cleaned water is, of course, only half the story. The sewage and other sludges present a major challenge for disposal now, and even more so in the future. Northumbrian Water Plc produces about 33,000 dry tonnes of sludge to be disposed of in an environmentally acceptable manner and at present the main disposal routes are to the sea, to agriculture and to landfill. The complex chemistry associated with disposal remains an area of fruitful research. The total will rise to 76,000 dry tonnes by 2005 as a result of implementing the Urban Waste Water Treatment Directive. Also, in accordance with that Directive, sludge disposal to sea will cease by 1998. That decision, not based on sound scientific principles, will result in greater environmental detriment to the air and to the land. The energy costs of driving our treatment works will substantially add to the generation of CO_2. After 1998 we shall de-water the sludge, condition and dry it (again using energy) and form a product to be used positively as a soil conditioner, a raw material in manufacturing and possibly as a fuel. But cleaning the seas will burden the air. And we have only three disposal media - Air, Water or Land (Figure 1).

As was described earlier, we are moving to new Environmental regulatory regimes. The Environment Agency in England and Wales and the Scottish Environment Protection Agency, will soon have more comprehensive powers than the present agencies. The stated objective is to achieve a holistic approach to environmental protection to prevent problems being moved around, a hoped for 'one-stop-shop' for commerce and industry. That last objective looks over-optimistic, given that other agencies e.g. Scottish Natural Heritage and English Nature, have statutory powers over much important land. There is scope for yet further change in the future.

Having talked about the regulators of the quality of drinking water and the regulators of the quality of discharged water let me turn now to those who have to pay the costs and the regulator of charges. Reconciling the areas of public health, environmental protection, costs of operating and price to customers is a major conundrum. Add to it a dividend policy for shareholders and you find yourself confined somewhere in a pyramid (Figure 2).

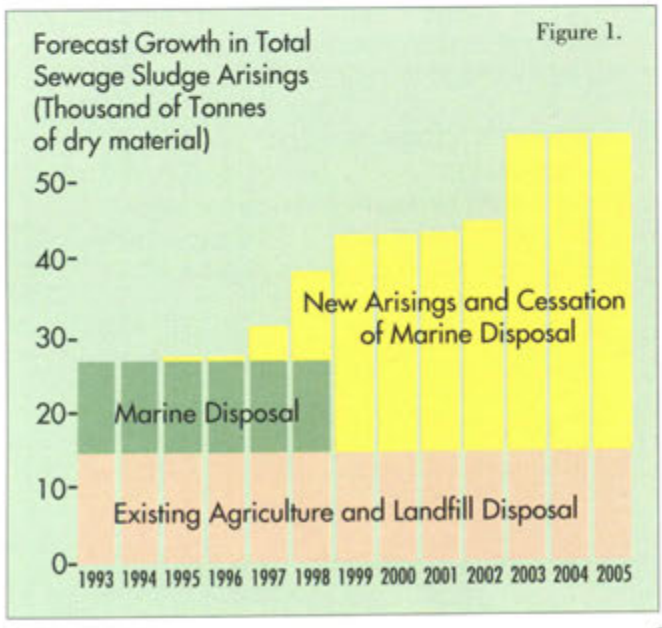


Figure 1.

In a privatised system the price-base supports the rest, and it is the job of the Director of Water Services (OFWAT) to make sure that the pyramid is properly based.

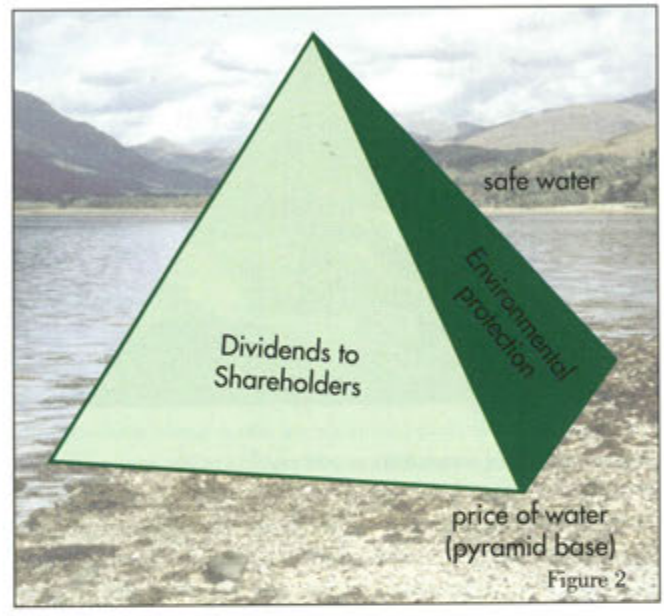


Figure 2.

While scientists may find other things more interesting, unless we are prepared to marry our science and technology with economics and social policy we shall not do justice to our subject.

Water supply to the public has been in and out of the private sector for many years. The history of the water industry in Britain has been well recorded (e.g. Water, the Book, 1992) and private water companies, established for both public good and for profit motives, are not new. But in the lifetime of most of us the supply of water and the treatment of sewage have been local authority functions. It is in the last 5 years or so that local government reorganisation, and the social restructuring policies of national governments, have focused attention and debate on how drinking water and waste water are best to be owned, managed and paid for.

At first sight it may seem that the privatised companies in England and Wales and the new Authorities in Scotland are very different systems. In my view, the differences are large in principle but small in practice. The reason is simple - the two Kingdoms and the Principality that make up Britain are all subject to EU Directives, none wants to have standards lower than its neighbours. Safe drinking water, a protected environment and an affordable price are common to all. It is my contention that 'affordability' will dominate the agenda throughout the UK, indeed throughout the EU. For someone must pay either a market price or a tax.

The Office of Water Services and the Director of Water Services control the price regime in England and Wales. The Scottish equivalent of OFWAT is the Secretary of State for Scotland. Both OFWAT and the Secretary of State for

Scotland have advisory committees that represent the voice of the consumer. Both OFWAT and the SOS must balance the consumers' viewpoint with the well-being of the industry and the well-being of the environment. The customer will wish to keep prices low, the industry needs money, the environment needs protection. That is why the systems are essentially the same - they are in tension.

Investment in the water and sewerage industry has lagged behind need; past governments have not been great investors in infrastructure. When that under-investment is then placed in the context of new EU Directives and standards there is a demand for funds that is, by any standards, substantial. Is it affordable? It is too early to say in Scotland, but we have some clues from England.

To quote from a letter dated 13 July 1993 sent to the Secretary of State for the Environment by the Chairman of the OFWAT Customer Council:

"The Council is firmly of the view that Affordability must be the key issue in setting new price limits..... It would be socially and economically unacceptable for new prices to be set on the basis of what some but not all customers can afford to pay".

Ian Byatt, the regulator, reacted by saying in his publication 'The cost of quality' (1993). "Bills are becoming substantial in relation to the income of some households- about 25% of households have incomes of less than half the average, and water and sewerage bills already represent 2% or more of households income for them".

He went on to discuss the effects on customers bills of Environmental legislation. He gave two environmental scenarios, 'progress maintained' and 'pure and green'. The latter he judged unaffordable, so in England and Wales since 1994 prices have been kept lower than they might have been by reducing capital and operating expenditure on environmental improvement works. The environmental Regulator (the NRA) and the Green lobby groups have not been pleased with the outcome of that conflict of interest between consumers and the environment.

The same problem will face the Secretary of State for Scotland when, as inevitably he will have to, he sets price regimes for the three new statutory water authorities. Already the Chairman of his Customers Council (Dick Douglas Esq) has issued a warning statement about keeping costs to customers down.

Affordability becomes a key issue in the supply of clean water and in the protection of the environment, for someone must pay, via market or taxes. If prices are set to match the purse of the poorest then the environment can suffer and the rich enjoy cheap water. If prices are subsidised by the State then taxation policies need to be in place to raise the money.

Is the metering of domestic water supplies the answer? Logically it has many attractions, giving the opportunity to set one price for a basic household allowance, with an escalating price for higher usage. Account could similarly be taken of households with special needs e.g. kidney dialysis. But it is difficult to justify the use of meters in a region such as Northumbria with abundant supplies held in Kielder and high levels of rainfall in the catchment. And it has proved hard to find general public acceptability to the principle of metering even in areas such as East Anglia, less well endowed with rainfall. Metering is favoured by the Director of Water Services but opposed by the Labour party. The dry summer of 1995, coupled with high usage that modern lifestyles now require (e.g. car-wash, recreational -grass watering, high investment in garden plants), resulted in drought orders and restrictions in many areas of Britain, whether served by privatised companies e.g. Yorkshire or local authorities here in Scotland. Leakage from the pipe networks (around 28% in England, Scotland and Wales) and the needs of the environment for optimal water flows and levels, were balanced against the often conflicting needs and demands of customers. Difficult decisions needed to be taken and are still being taken e.g. in parts of Yorkshire and in the Lake District. Investment levels were criticised and became the subject of public and political debate. The debate was hostile and acrimonious, especially when considered in the context of privatisation (although Scotland was in a similar situation). Whilst the dividends paid to shareholders are to some an easy target, it grossly over-simplifies the supply and demand equations to seek solutions or found accusations on what is a small part of the total flow of money in the industry. In any event, the major beneficiaries of the dividends are the pension funds which constitute the business of our largest shareholders. To diminish pension funds, given the present demographic trends, would seem inadvisable. Similar arguments apply to a windfall tax. The money can only be spent once and can money raised from English regional water companies properly be spent outside those English regions? If there is indeed a fundamental change in the level and distribution of rainfall in Britain then it may be necessary to consider the price and practicalities of some form of national water grid or grids. If human needs for domestic, agricultural and industrial water are to be reconciled with the needs of habitats and species then scientists, engineers, economists, politicians and social-policy determinists in general will all need to find common purpose. Once social and political priorities have been decided upon then, and only then, can the wisdom and ingenuity of science and technology be effectively applied.

Getting the right answers is important. The new industries based upon electronics and biotechnologies, need large and reliable supplies of clean water just as much as the older industries based on heavy engineering and bulk chemicals. Agriculture, forestry, fisheries, watersports, tourism all need adequate water supplies. Although only 4% of the rain that falls on Britain is put into public supply, much of the rest is profoundly altered by roads, rooftops, agricultural chemicals, etc, and the needs of other species that rely on clean water e.g., amphibia and wading birds deserve our consideration and our protection regardless of their value to the economy of mankind.

MACAULAY RESEARCH

Macaulay Research and Consultancy Services, (MRCS), was established in December 1994 as the commercial arm of the Macaulay Land Use Research Institute (MLURI). Its mission is to develop the commercial research and consultancy expertise of MLURI and in so doing to enhance the transfer of knowledge and the products of research to the user community. External contracts awarded to MLURI staff (except EU and SOAEFD Flexible Fund contracts) are managed through the MRCS Research Division. In addition MRCS has a Consultancy Services Division with a small group of permanent staff. In a successful first year of operating, MRCS has achieved a turnover of £660K.

MRCS has a strong customer base which includes local and national government departments, government agencies, international funding agencies and private industry and commerce. The broad discipline base of MLURI provides MRCS with an impressive range of research and consultancy skills. These skills, combined with full access to MLURI's analytical facilities, data sets (e.g. soils, land cover, vegetation, climate,) geographic information systems (GIS) and information technology capability, gives MRCS an ability to offer research and consultancy in key areas of land and environmental management. For further details of the full range of services offered, contact Dr Sue Bird, External Affairs Officer. (Telephone (01224) 318611. Fax (01224) 324880). Summaries of some of the research and consultancy services within the Research Division and Consultancy Services Division of MRCS are given below.

RESEARCH SERVICES DIVISION

Catchment Management and Water Quality Control

MRCS has an acknowledged capability and expertise in water catchment modelling in relation to land use and management, and water quality. Contracts have been undertaken for the Scottish Association of Directors of Water and Sewerage Services; Scottish and Northern Ireland Forum for Environmental Research and Purification Boards. MRCS looks forward to developing relationships with the Scottish Environmental Protection Agency and the new Water Authorities.

Contacts: Jeff Wilson, Bob Ferrier

Air Pollution Impacts and Controls

With a well established record of research within MLURI on the impact of anthropogenic pollution on soils and water, MRCS can advise customers on what impact their activities or those of others can have on soil and water resources. MRCS has expertise in the measurement of the effects of pollutants derived from atmospheric deposition on soils, vegetation, streams and rivers and the critical load concept has been developed to be used as a tool in national and international abatement protocols. Work is being undertaken for National Power, the Department of the Environment, the Forestry Commission and the National Environment Research Council.

Contacts: Jeff Wilson, John Miller, Simon Langan

Management and Utilisation of Waste on Land

With MLURI's unique soils databases and international reputation and expertise in soil science, MRCS has access to resources to undertake risk and suitability assessments for a wide range of waste materials. MRCS has carried out, for example, some unique work to classify the suitability of land in Scotland for the disposal of sewage sludge and has contributed to an objective, independent assessment for policy advisers at the national level. This has led to several contracts being commissioned by Regional Councils as they work towards implementing a land-based sludge recycling strategy - (see Figure 1).

Contact: Willie Towers

Contaminated Land

Again, based on MLURI's expertise in soil science and chemical analysis MRCS provides a service in the identification of particular chemical compounds, (inorganic and organic), and minerals in contaminated soils and landfill sites and in chemical and pollutant transport modelling. This expertise is of particular value in assessing the stability of contaminated sites and in developing remediation protocols for such sites. A specialist service in biological monitoring of contaminated sites is also available.

Contact: Ed Paterson

Vegetation and Habitat Management

MLURI has an international reputation for research in livestock grazing (sheep, goats, cattle, deer and camelids) and its impact on vegetation dynamics, wildlife habitats and landscape. This has led to a significant amount of business being undertaken through MRCS, especially for government agencies such as Scottish Natural Heritage, English Nature, and Countryside Conservation for Wales who have a concern for the protection, enhancement and management of the natural environment. The Hill Grazing Management Model (HGMM), a computerised decision support tool, has been used widely and is available through MRCS.

Contacts: John Milne, Alan Sibbald

ANALYTICAL SERVICES

Chemical and Physical Analysis

The state-of-the-art and comprehensive analytical services of MLURI are available for commercial contract work through MRCS. The analytical laboratories are operated to the highest standards of quality control and staffed with technicians dedicated to a multidisciplinary approach to chemical analyses and interpretation. Work has been undertaken for a wide range of industrial and commercial interests, (e.g. OIS Ltd., Freshwater Fisheries Laboratory, RTD UK Ltd., government bodies, farmers).

& CONSULTANCY SERVICES

Analysis of pollutants in contaminated land, minerals, oilfield and surface waters, and corrosion products, as well as a full range of chemical and physical parameters for soils are just some of the procedures available.

If you have a problem with the analysis of a sample - bring it to us - we have probably seen them all!

Contact: Alistair Smith

Animal Fibre Analysis

There is a suite of specially designed laboratories dedicated to the measurement of animal fibres, (wool, hair, cashmere) to international standards. The following measurements can be made:

- fibre diameter
- fibre yield
- staple length and drawn length
- histological assessment of fibre follicles

Contact: Hilary Redden

MRCS CONSULTANCY SERVICES DIVISION

The staff of the Division are qualified scientists with years of experience in the field but, where appropriate, multi-disciplinary teams incorporating MLURI staff and expertise can be assembled to tackle complex problems and apply advanced technological approaches to land use issues and environmental management.

SERVICES AVAILABLE

Resource information and surveys

- soils, peat and vegetation surveys at a variety of scales.
- soil maps and field survey documentation with consultancy services.
- land cover of Scotland (1988) dataset - census of landcover available for land use and environmental management consultancy and research.

Interpretative Services

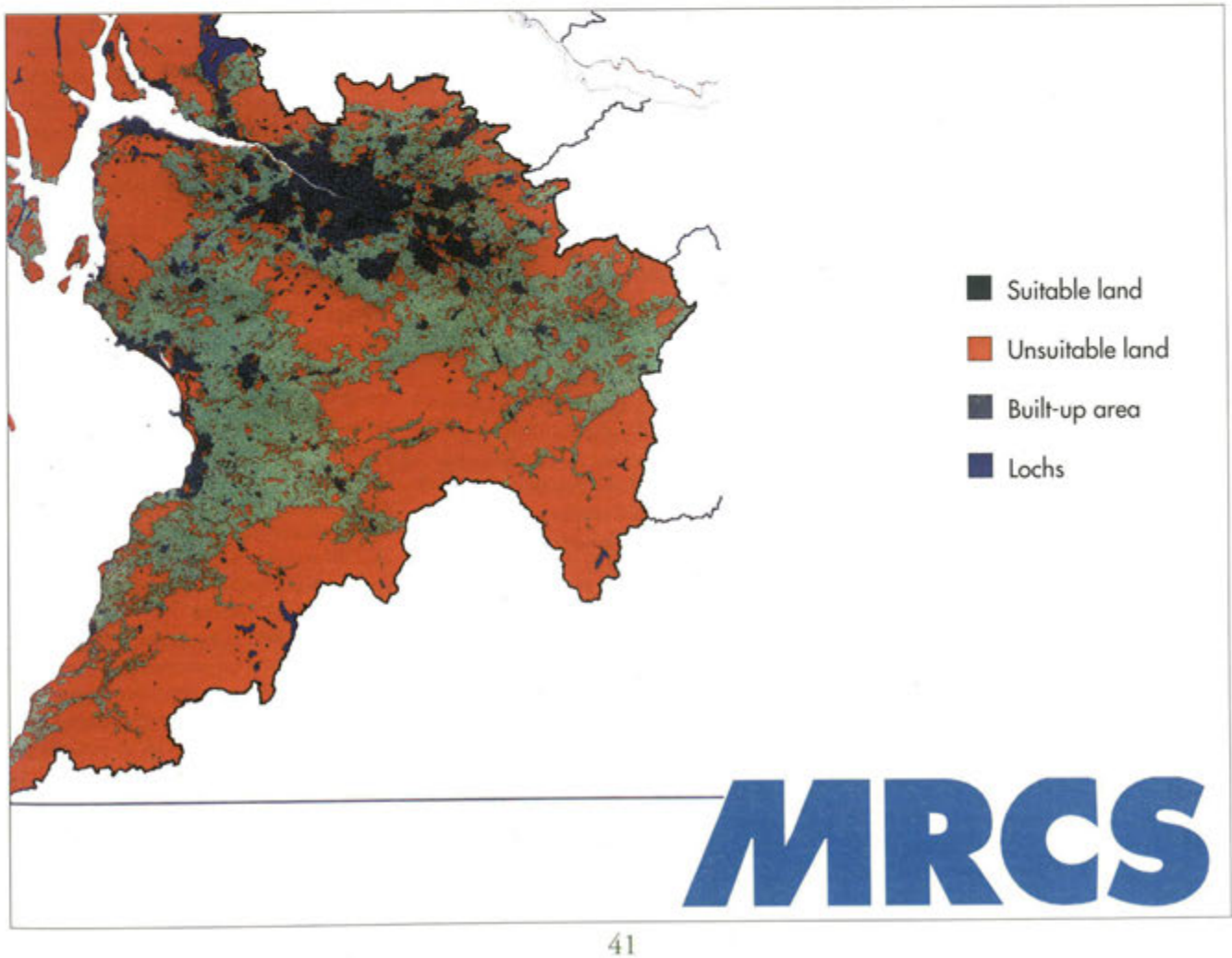
- interpretative maps and expertise to appraise land quality, and suitability for crops and utilisation of waste (e.g. sewage sludge, paper waste)
- land capability for agriculture and forestry.
- systematic interpretation of the Land Cover of Scotland (1988) dataset in conjunction with data on soils, climate and socio-economic information.

Specialist Expertise

- environmental impact studies.
- GIS and digitising services.
- interpretation of aerial photography and remotely sensed satellite imagery.
- indicative strategies for forestry and agriculture.

Contacts: Jim Gauld, Ann Malcolm

Figure 1. Land suitability for sewage sludge utilization on agricultural land in Strathclyde Region.



BIOMATHEMATICS and STATISTICS SCOTLAND

Director of BioSS, Rob Kempton, addressing the BioSS staff at a meeting at MLURI

Biomathematics and Statistics Scotland (BioSS) contributes research, consultancy and training in statistics and mathematics to agricultural and biological organisations in Scotland. Its 30 graduate staff are based at BioSS Headquarters in the University of Edinburgh and in units in Aberdeen (at both MLURI and Rowett Research Institute), Dundee (at Scottish Crop Research Institute), and Ayr (at SAC and Hannah Research Institute).

BioSS has particular expertise in the areas of Environmental Modelling, Image Analysis, Mathematical and Systems Modelling, Molecular Biology, Plant Breeding and Variety Testing, and Food and Nutrition. Major projects in these areas call on the services of the relevant BioSS specialists.

In Aberdeen, there are 9 BioSS posts, 5 of which are based in the Environmental Modelling Unit at MLURI. The primary duties of the Unit are:

- to provide a consultancy service to MLURI scientists
- to engage in collaborative research with scientists from MLURI and elsewhere
- to develop programmes of applied statistical research
- to undertake related contract work

The consultancy service is operated through a well publicised open door policy whereby a member of staff is available each afternoon of the week. Primary responsibility for the MLURI Divisions is divided amongst the BioSS staff involved. The consultancy service was well-used throughout the year, with over 100 scientists, visiting workers and research students seeking advice on the application of a wide range of statistical and mathematical methods to a variety of scientific problems.

Collaborative projects arise out of contacts initiated through the consultancy service and lead to joint publications with MLURI and BioSS co-authors. In 1995, BioSS had productive collaboration with staff in the following MLURI Divisions:

- Animals and Grazing Ecology Division - development of censored analyses for fitting a log-ratio model to selection data containing zero utilisations; estimating the effect on fecundity of introducing the Thoka gene into Cheviot sheep; developing statistical methods for comparing the spatial distributions of deer counts on the island of Rhum;
- Land Use Division - developing non-linear regression models to estimate mean willingness to pay using data from contingent valuation studies;
- Plants Division - estimating differential growth rates in plant material growing at the edges and centres of patches, and studying the dynamics of roots of growing plants;
- Soils Division - estimating trends over time in water chemistry data.

The joint research programme between BioSS and MLURI to develop a decision support system for management of red deer has seen rapid progress. The main BioSS contribution has been to build a population dynamics model to integrate prior knowledge about closely studied deer populations with counts made at the locality for which management decisions are to be made. A questionnaire has been sent to deer managers to establish the management strategies currently in use and to ascertain the types of information the managers could supply for the decision support system. A pilot study has also tested the cost and accuracy of counting deer using the line transect method from a helicopter.

Further areas of research include the application of errors-in-x regression methods to improve predictions made using covariates stored with error in a Geographic Information System and the assessment of different sampling strategies for estimating annual discharges of waterborne pollutants using data on water chemistry and river flow rate.

BioSS provides training to scientists, both formally through computer-based short courses in Statistics and Mathematical Modelling, and also informally through discussions with individuals and small groups. This training raises the level of statistical awareness and abilities amongst scientists, allowing the statistical consultants to spend a greater proportion of their time on those projects which require the use of advanced statistical methods. During 1995, MLURI staff attended 11 different BioSS courses and received a total of 94 person-days of training.

About 20% of the income of the Unit comes from external sources. BioSS provides a consultancy service under contract to ITE Banchory and has acted in partnership with scientists at MLURI and ITE on projects to monitor and evaluate the Scottish Environmentally Sensitive Areas, to assess the misclassification rates of interpretation of air photographs in SNH's National Countryside Monitoring Scheme and to relate tree regeneration to deer numbers in the Cairngorms.

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1 January, 1996

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1. Vegetation dynamics

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Claire Souchet, B.Sc., M.Sc.
Glynn Stanworth, B.Sc., PG Dip.
Ben Werkman, B.Sc., Ph.D.
Nicholas Outram
Patricia J Wilson, B.Sc.
Andrew Ferguson, B.Sc.
Elaine Foreman, HNC
Loraine Shellard, B.Sc.
James L Small, HNC (S)
Iain L Thomson, HNC
Sheila A Young, HNC

Postgraduate students, (Ph.D.),
Jane Cooper, B.Sc., University of Aberdeen
Miguel Bugalho, M.Sc., University of Aberdeen

Staff undertaking doctorate,
Angela M Sibbald, MA

PU15 Manager,
Iain A Wright, B.Sc., Ph.D.

Ruminant resource use

Project leader,
Iain A Wright, B.Sc., Ph.D.

Research objective leaders,
Stewart M Rhind, B.Sc., Ph.D.
Angus J F Russel, B.Sc., M.Sc., Ph.D. (H)
Peter J Goddard, B.Vet.Med., Ph.D., MRCVS
Jonathan A Beecham, BA
Pamela Dicks, B.Sc., Ph.D.
Philip N Grigor, B.Sc., M.Sc., Ph.D.
Margaret Merchant, B.Sc., Ph.D.

Other staff,
Patricia M Colgrove, HND (H)
Robbie Hetherington, B.Sc.
Alastair J Macdonald, SDA, NDA
Stuart R McMillen, HNC
Alberto Melacini, M.Sc
Hilary L Redden, B.Sc.
Grant C Davidson, B.Sc.
Carol A Littlewood, HND (G)
Siobhan Abeyesinghe, B.Sc., M.Sc.(G)
David J Riach, HNC
Brenda Copland
Audrey R Stephen

Postgraduate student, (Ph.D.),
David Villar, University of Aberdeen

Visiting workers,
Maria Bakker, MSc, Universidad del Centro de la Provincia de Buenos Aires, Argentina
Ignacio Pérez Ferre, Estacion Agricola Experimental - CSIC, Leon, Spain
Pilar de Frutos, Consejo Superior de Investigaciones Cientificas, Spain
Sylvie Lebocey, University of Bordeaux, Perigueux, France
Javier Pérez-Barberia, Dpto. Biologia de Organismos y Sistemas, Spain

Staff who have left Animals & Grazing Ecology Division since the last Annual Report
Richard H Armstrong, B.Sc. (Agric.) (H)
William J Hamilton, BA, NDA, NDD, C.Biol., M.Biol. (G)
David E Suckling, JP, HNC, C.Biol., M.Biol. (H)
Alison J Hanlon, B.Sc., M.Sc.
Anna H Murray, B.Sc., M.Phil
Alison J Smith, HNC (H)
Thomas K Whyte, HNC, SDA (H)

Analytical Division

Head of Division,
Alistair Smith, B.Sc., Ph.D., C.Chem., FRSC

Divisional secretary,
Lynda M Keddie

1. Inorganic element analysis

Gareth Newman, B.Sc.
Alistair G Inglis, B.Sc.
Alison M Stewart, HNC
Lesley J Sinclair, HNC
Doris M McCombie

2. Mass spectrometry

Andrew J Midwood, B.Sc., Ph.D.
Jennifer J Harthill, HNC
Keely P Taylor

3. Soil analyses

Jason Owen, B.Sc., M.Sc., Ph.D.
Anne Dickson, B.Sc., M.Sc.
Kathleen H Davidson
June B McAdam

4. Radiochemistry

Terry Atkinson, LRSC (Consultant)

5. Colourimetric analyses and chromatography

Alan Hepburn, C.Chem., MRSC
Pat E Moberly, B.Sc.
Susan M McIntyre, HNC
Arlene M Murray, HNC
Maureen M Procee, HNC
Gillian L Sim, B.Sc.
Anna L Hendry
Gillian Martin
Donna MacDonald
Dawn Morley

6. Technical services

Bert W Stuart, HNC
James S Anderson
Gordon J Ewen, HNC
Graham J Gaskin, HNC
Allan I A Wilson, HNC
Jim A Steinson
David W Clark, HNC
Gordon W Stott

Outdoor staff,
Brian N Kemp (head groundsman)

Staff who have left Analytical Division since the last Annual Report
Bill J McHardy, B.Sc., Ph.D. (transferred to Soils and Soil Microbiology Division)
Evelyn M McMurray, HNC (transferred to Soils and Soil Microbiology Division)
Lorna Black

Computing & Information Services Division

Head of Division,
Christopher H Osman, B.Sc., M.Sc., Ph.D., C.Phys., M.Inst.P.

Divisional secretary,
Carol A Smith

INSTITUTE STAFF

Computing Support,
Geoffrey A Reaves, B.Sc., MBCS (network manager)
Lindsay Robertson, B.Sc. (database manager)
Tony H Sunman, HND (systems manager)
Jane D Stebbings, B.Sc., M.Sc.
Ann M Teale

Publications and Graphics,
Patricia R Carnegie
Caroline C Milne
David J Riley

Staff who have left Computing & Information Services Division since the last Annual Report
Chris Scott
Alexander D Moir (transferred to Land Use Division)
Susan MacLeay, B.Sc. (transferred to Land Use Division)
Ruth A Morrison (transferred to Land Use Division)

Research Stations Division

Head of Division,
Professor T Jeff Maxwell, B.Sc., Ph.D.

GLENSAUGH

Head,
John A Milne, BA, B.Sc., Ph.D.

1. Farm resources

Officer-in-charge,
David L Nelson, B.Sc. (Agric.)

Administrative assistant,
Kim Richardson

Staff,
John W Black (Snr.) (grieve)
Norman G McEwan (head shepherd)
John W Black (Jnr.) (tractorman)
James Scott (shepherd)
Jessie P Black (cleaner)

2. Red deer

Staff,
Duncan Murray

3. Animal house

Officer-in-charge,
A Robson Fawcett, AIMLS

Staff,
Andrew G Brown
Craig A MacEachern

HARTWOOD

Officer-in-charge,
George K D Corsar, B.Sc., MS

Administrative assistant,
Sandra A Denham
Catherine Walsh (typist)

Staff,
Ian Boustead (grieve)
Robert Graham (head stockman-cattle)
W Paul Leonard (stockworker-cattle)
Jim C MacDonald, B.Sc. (stockworker-sheep records)
Betty Farley (cleaner)

SOURHOPE

Officer-in-charge,
Harry M Sangster, B.Sc., Dip.FBOM

Staff,
Geoffrey D Gittus NDA (deputy officer-in-charge)
John L Wallace (head shepherd)
Patricia Gentry (recording officer)
James C Pringle (stockman/tractorman)
T Gavin Rogerson, Dip.FBOM (goats)
Pamela Tapson (shepherd)
Matthew Wilson (shepherd)
Dorothy H Wallace (cleaner)

Staff who have left Research Stations Division since the last Annual Report
William J Hamilton, BA, NDA, NDD, C.Biol., M.Biol.
Robbie A Hetherington, B.Sc. (transferred to Animals and Grazing Ecology Division)
Harry Habblett (head shepherd at Hartwood)
Grace B Welch, HND

Administration Division

Institute Secretary,
Robert B Devine, DPA, MIM

Institute Deputy Secretary/Finance Officer,
David T Wilkinson, MA

Secretary's typist,
Karen J Scott

Personnel administration,
Eileen J Cockburn

Financial and general administration,
Christina M R Burness
Murray G C Mainland
Catherine B Adams
Janice M Laing
Jacqueline S Wales

Secretaries/typists,
Lucy M Burnett
Margaret W Forsyth
Iona M Shand
Aileen Stewart
Julie McKenzie
Nicola G Paterson
Carol A Smith

Library
Lorraine E Robertson, BA, ALA, Dip.Ed.

Telephonist,
Coral Bannister
Roberta M Simpson

Stores,
Lynne Thomson

Cleaners,
Jill Evans
Margaret Kindness
Ruth Penny
Agnes M Rennie
Margaret A Walker

Security staff,
David Burgess
Allan E J Rhynas
Wilfred F Wallace
Ernest Milne

Cunningham Building caretaker,
Catherine Milne

Other,
Graham Thomson

Visiting Worker,
Marjan Middelhoff, Institute of Higher European Studies, The Netherlands

Staff who have left Administration Division since the last Annual Report
William S Shirreffs
Anne H W Dickie, ALA, M.I.Inf.Sc.
James E Price, B.Sc.(Econ) (transferred to MRCS)
Joyce H Pirie
Patricia R Carnegie (transferred to Computing and Information Services Division)
Caroline C Milne (transferred to Computing and Information Services Division)
David J Riley (transferred to Computing and Information Services Division)
James Robertson
John R Ewen
William L W Ross

INSTITUTE STAFF

Kathleen McPherson
Hazel Mutch
Graham A S Davie
John S West

Macaulay Research and Consultancy Services

Head of Consultancy Division,
James H Gauld, B.Sc., Ph.D.

Secretary,
Nicola G Paterson

Finance Officer,
James E Price, B.Sc. (Econ)

Staff,
John S Bell, B.Sc.
Ann Malcolm, B.Sc., DMS
Victoria Gilham, B.Sc., MA
Margaret McKeen, B.Sc., M.Sc.
Marianne Wamser, M.Sc.

Staff who have left Macaulay Research and Consultancy Services since the last Annual Report
Frank T Dry, B.Sc. (H)
Andrew G Richman, B.Sc., M.Sc.
Julia Miller, B.Sc. (transferred to Land Use Division)

BioSS staff based at MLURI

Head,
David A Elston, BA, M.Sc., C.Stat.

Other staff,
David Hirst, B.Sc., Ph.D.
Elizabeth I Duff, B.Sc.
Verena M Trenkel, Dip.Biol., M.Sc.

Staff who have left SASS since the last Annual Report
Jim Kay, B.Sc., B.D., Ph.D.
Gayathree Jayasinghe, Grad.IS, M.Sc.

Honorary Fellows
G Anderson, B.Sc., Ph.D.
Miss E J Dey, MBE
J Eadie, B.Sc.
P Newbould, B.Sc, B.Agr., D.Phil.
Miss E A Piggott, OBE
T S West, CBE, FRS
E G Williams, B.Sc., Ph.D.

Honorary Associates
J F Darbyshire, B.Sc., MSc., Ph.D.
P C DeKock, M.Sc., D.Phil.
V C Farmer, B.Sc., Ph.D., C.Chem., FRSC, FRSE
R Glentworth, BSA (Manitoba), Ph.D.
R Grant, MA, B.Sc.
R H E Inkson, B.Sc., FSS, FIS
R C Mackenzie, D.Sc., Ph.D., FGS, FRSE
J W S Reith, B.Sc., C.Chem, FRSC
R A Robertson, OBE, B.Sc.
A M Ure, B.Sc., Ph.D., C.Chem., FRSC

Honorary Research Associate
Professor H G Miller, B.Sc., Ph.D., D.Sc., FI (For.)

VISITING WORKERS

Land Use Division

Italo Bertocchi, University of Torino, Italy
Hélène Chevallier, FIF-ENGREFF, Nancy, France
Dr Bhupendar Gupta, University of Horticulture and Forestry, Nauni, India
Dr Michael Hill, CSIRO, Pastoral Research Laboratory, Armidale, Australia
Dr Gaetano Pace, University of Naples, Italy

Soils & Soil Microbiology Division

Graham Bach, Rogalandsforskning, Norway
Christophe Blanc, Ecole Polytechnique Fédérale de Lausanne, Switzerland
Mingzhen Chen, Zhejiang Agricultural University, Peoples Republic of China
Camille Dumat, INRA, Laboratoire de Science du Sol, Montpellier, France
Mathieu Guiberteau, Ecole Superieure d'Agriculture d'Angers, France
Dr Jon Petter Gustafsson, Royal Institute of Technology, Stockholm, Sweden
Jussi Heinonsalo, University of Helsinki, Finland
Prof Nikola Kostic, University of Belgrade, Serbia
Fiona McBeath, University of Aberdeen, Scotland
Andrea Oess, Swiss Federal Institute of Technology, Switzerland
Florence Perrier, Ecole Supérieure d'Agriculture d'Angers, France
Dr Maria Jesus Belzunce Segarra, Institute of Marine Sciences, Spain

Plants Division

Sara Adrian, Comett - Auef Euskal Herria, Spain
Mark Munro, Scottish Agricultural College, Scotland
Anna Rigol, University of Barcelona, Spain
Carmen Scarnecchia, University of Turin, Italy
Sari Stark, Oulu University, Finland

Animals & Grazing Ecology Division

Arantza Aldezabal, Instituto Pirenaico de Ecologia, Spain
Maria Bakker, Faculty of Veterinary Sciences, Tandil, Argentina
Luc Chaverot, Ingeniene de lespace rural, Poisy, France
Dr Pilar de Frutos, Consejo Superior de Investigaciones Cientificas, Spain
Yvonne Gordon, Scotland
Candy Heyworth, University of Aberdeen, Scotland
Anna Nilsson, The Swedish University of Agricultural Sciences, Sweden
Dr Javier Pérez-Barberiá, University of Oviedo, Spain
Elise Wack, Ecole Nationale Superieure d'Agronomie et d'Industries Alimentaires, France

Analytical Division

Prof J H Kirkman, Massey University, Palmerston North, New Zealand
Christopher Pearson, Scottish Agricultural College, Scotland

Administration Division

David McGrath, Robert Gordon University, Scotland.
Marjan Middelhoff, Institute of Higher European Studies, The Netherlands

POSTGRADUATE RESEARCH STUDENTS

(Ph.D. students with University and Funding Source) current students, 1 January 1996, are shown thus *

Land Use Division

* Rebecca Badger, University of Aberdeen, MAFF CASE Studentship
* Mario Caetano, University of Lisbon, EC
* Cameron Campbell, Robert Gordon University
  Mike Christie, University of Aberdeen, Aberdeen Research Consortium
* Alessandro Gimona, University of Aberdeen, MLURI
  Rachel Harvey, Herriot-Watt University, MLURI
* Ann Humble, University of Aberdeen, SERC CASE Studentship
* Jason Matthiopoulos, University of Aberdeen, Aberdeen Research Consortium
* Leonard Nwaigbo, University of Aberdeen, Commonwealth Scholarship
* Chris Skelsey, University of Aberdeen, Aberdeen Research Consortium
* Jia-En Sheu, University of Aberdeen, Self-financed
* Joanna Wherrett, Robert Gordon University, Aberdeen Research Consortium
* Julia Wootton, University of Aberdeen, MLURI

Soils and Soil Microbiology Division

* Kirsty MacPhee, University of Aberdeen, DoE
  Rory Maguire, University of Aberdeen, EC
* Diane Mitchell, University of Aberdeen, SNIFFER
* Clara Oyegoke, University of Agriculture, Nigeria, World Bank
  Graeme Paton, University of Aberdeen, Aberdeen Research Consortium
* Bruce Thompson, Robert Gordon University
* Maureen Young, Robert Gordon University, Historic Scotland

Plants Division

* Jenny Claxton, University of Aberdeen, Aberdeen Research Consortium
  Amanda Cook, University of Aberdeen, MLURI
* Helmut Ernstberger, University of Aberdeen, Aberdeen Research Consortium
* Fiona McLeod, Robert Gordon University
* Peter Mulenga, University of Aberdeen, Zambian Government
* Charles Russell, University of Aberdeen, BBSRC
* Vicky Temperton, University of Edinburgh, NERC

Animals and Grazing Ecology Division

Susan Borwick, University of Aberdeen, SERC CASE Studentship
* Miguel Bugalho, University of Aberdeen, Portuguese Government
* Jane Cooper, University of Aberdeen, Aberdeen Research Consortium
  John Hadjigeorgiou, University of Aberdeen, Greek Government
* Fiona Stewart, University of Aberdeen, NERC CASE Studentship
* David Villar, University of Aberdeen, Spanish Government

CONFERENCES and VISITS ABROAD

UK CONFERENCES at which papers were presented during 1995

Land Use Division

GIMONA, A. British Ecological Society Winter Meeting. University of Sheffield, 19-21 December 1995.

HARE, M P. 1st International Workshop on Intelligence and Multimodality in Multimedia Interfaces. Edinburgh University, 13-14 July 1995.

MILLER, D R. GISRUK '95. Newcastle University, 5-7 April 1995.

MILLER, D R. British Computer Society. Robert Gordon University, 26 April 1995.

MILLER, D R. Catchment Databases. Fish Conservation Centre, Stirling, 19 October 1995.

MILLER, D R. Aerial Photographic Interpretation for Environmental and Strategic Planning. Cardiff University, 15 November 1995.

TOWERS, W. The Application of Remotely Sensed Data to Monitoring Coastal Processes. University of Dundee, Dundee, 19-20 December 1995.

WRIGHT, G G. Remote Sensing in Action. Southampton University, 11-14 September 1995.

WRIGHT, G G. Remote Sensing and GIS for Natural Resources Management. Chatham Maritime, Kent, 19 December 1995.

WRIGHT, G G. The Application of Remotely Sensed Data to Monitoring Coastal Processes. University of Dundee, Dundee, 19-20 December 1995.

Soils Division

CAMPBELL, C D. Heavy Metals and Trees. Institute of Chartered Foresters, Glasgow, 10-11 October 1995.

CHESHIRE, M V. Humic substances in Soils, Peats and Waters. University College, Dublin, 18-19 September 1995.

MITCHELL, D. SOILS '95. Reading University, 11-14 September 1995.

Plants Division

CHAPMAN, P. Workshop on P loss from agriculture. Johnstown Castle, Ireland, 27-29 September 1995.

MARRIOTT, C A. British Ecological Society Winter Meeting. University of Sheffield, 19-21 December 1995.

Animals and Grazing Ecology Division

BEECHAM, J A. British Ecological Society Winter Meeting. University of Sheffield, 19-21 December 1995.

BIRCH, C P D. British Ecological Society Winter Meeting. University of Sheffield, 19-21 December 1995.

GRIGOR, P N. International Society for Applied Ethology. London, 28 November 1995.

MILNE, J A. Royal Society of Edinburgh. Edinburgh, 7-8 September 1995.

PALMER, S. British Ecological Society Winter Meeting. University of Sheffield, 19-21 December 1995.

CONFERENCES ABROAD at which papers were presented during 1995

Land Use Division

ASPINALL, R J. Eurocarto XIII. Beligrate, Italy, 1-4 October 1995.

BROOKER, N A. 15th ESRI Annual User Conference. Palm Springs, 22-26 May 1995.

HUDSON, G. Geostatistics. Fontainebleau, France. 15-16 June 1995.

MILLER, D R. European GIS conference. The Hague, 25-31 March 1995

SIBBALD, A R. FAO meeting on Silvopastoral Systems. Avignon, France. 29 May-2 June 1995.

Soils Division

BAIN, D C. 8th International Conference on Acid Deposition. Göteborg, Sweden, 26-30 June 1995.

FERRIER, R C. 8th International Conference on Acid Deposition. Göteborg, Sweden, 26-30 June 1995.

LANGAN, S J. 8th International Conference on Acid Deposition. Göteborg, Sweden, 26-30 June 1995.

MEEUSSEN, J C L. Conference of the Netherlands Integrated Soil Research Programme in The Netherlands. The Netherlands, 18-19 December 1995.

Plants Division

DOMBURG, N. Conference of the Netherlands Integrated Soil Research Programme in The Netherlands. The Netherlands, 18-19 December 1995.

GRAYSTON, S J. 7th International Symposium on Microbial Ecology. Santos, Brazil, 27 August-3 September 1995.

PROE, M. Environmental Guidelines for Developing Sustainable Energy Output from Biomass. Ontario, Canada, 17-23 September 1995.

Animals and Grazing Ecology Division

BEECHAM, J. Novel Approaches to the Control of Helminth Parasites in Livestock. Armidale, Australia, 17-21 April 1995.

DUNCAN, A J. Ungulates in Temperate Forest Ecosystems. Wageningen, The Netherlands, 23-27 April 1995.

GODDARD, P. 2nd Circumpolar Agricultural Conference. Tromso, Norway, 3-7 September 1995.

HESTER, A J. Ungulates in Temperate Forest Ecosystems. Wageningen, The Netherlands, 23-27 April 1995.

IASON, G R. Ungulates in Temperate Forest Ecosystems. Wageningen, The Netherlands, 23-27 April 1995.

MAXWELL, T J. IV International Symposium on the Nutrition of Herbivores. INRA Clermont-Ferrand, France, 11-15 September 1995.

MAYES, R W. IV International Symposium on the Nutrition of Herbivores. INRA Clermont-Ferrand, France, 11-15 September 1995.

RUSSEL, A J F. European Fine Fibre Network Workshop. Bella, Italy, 12-13 October 1995.

WRIGHT, I A. IV International Symposium on the Nutrition of Herbivores. INRA Clermont-Ferrand, France, 11-15 September 1995.

CONFERENCES and VISITS ABROAD

VISITS ABROAD during 1995

Land Use Division

ASPINALL, R J. CSIRO Armidale, Brisbane and Canberra and the Australian National University, Australia, January 1995.

ASPINALL, R J. EC Project meeting. Lisbon, Portugal, 23-27 February 1995.

ASPINALL, R J. Co-ordination meeting for research programmes on GIS. Santa Barbara, USA, 7-13 March 1995.

ASPINALL, R J. 20th World Congress of the International Union of Forestry Research Organisations. Tampere, Finland, 7-12 August 1995.

ASPINALL, R J. GIS-LIS. Nashville, USA, 13-17 November 1995.

ASPINALL, R J. Australian National University and CSIRO Division of Water Resources, Canberra, Australia, 20 November -28 December 1995.

BERGEZ, J E. INRA Avignon, France, 7-8 December 1995.

BIRNIE, R V. Institute of Soil Science and Plant Cultivation, Pulawy, Poland, October 1995.

BULLOCK, C. Conference on Environmental Valuation. Oslo, Sweden, May, 1995.

CRABTREE, J R. International Panel on EU Pollution Project. Brest, France, 13-17 March 1995.

CRABTREE, J R. Institute of Soil Science and Plant Cultivation, Pulawy, Poland, October 1995.

HUDSON, G. European database of measured soil physical properties. Hannover, Germany, 19-21 October 1995.

McMILLAN, D C. British Council funded visit. Barcelona, Spain, March 1995.

McMILLAN, D C. EC COST meeting. Copenhagen, Denmark, 25-25 September 1995.

MILLER, D R. EC Project meeting. Lisbon, Portugal, 23-27 February 1995.

MILLER, D R. Faculty of Agriculture, University of Coimbra, Portugal, February 1995.

MILLER, D R. 20th World Congress of the International Union of Forestry Research Organisations. Tampere, Finland, 7-12 August 1995.

SIBBALD, A R. 20th World Congress of the International Union of Forestry Research Organisations. Tampere, Finland, 7-12 August 1995.

SIBBALD, A R. Committee meeting for the Livestock Farming Systems Symposium. Prague, Czechoslovakia, 5-8 September 1995.

Soils Division

BACON, J R. EC project meeting. Brussels, 22-24 May 95.

BAIN, D C. EC proposal discussion meeting. Uppsala, Sweden, 13-14 February 1995.

BAIN, D C. EC project discussion meeting. Forest Research Institute, Freiburg, Germany, 1-4 March 1995.

BAIN, D C. Euroclay '95. Leuven, Belgium, 20-25 August 1995.

BAIN, D C. University of Umeå, September, 4-6 September 1995.

CHESHIRE, M V. EC project meeting. Evora University, Lisbon, Portugal, 4-9 October 1995.

CHESHIRE, M V. CEC, Brussels, Belgium, November 1995.

HODSON, M. Department of Geosciences, University of Pennsylvania, USA, December 1995.

HODSON, M. Geological Society of America Meeting on Weathering Rates. New Orleans, USA, 4-9 November 1995.

FERRIER, R C. MAGIC modelling meeting. Captiva Island, Florida, 5-15 January 1995.

FERRIER, R C. Model development working group meeting. Charlottesville, USA, 19-27 October 1995.

LANGAN, S J. Geological Society of America Meeting on Weathering Rates. New Orleans, USA, 4-9 November 1995.

PATERSON, E. Institute of Soil Science and Plant Cultivation, Pulawy, Poland, October 1995.

WILSON, M J. Department of Geological Sciences, Seoul National University, Korea, 16-26 May 1995.

WILSON, M J. Institute of Soil Science and Plant Cultivation, Pulawy, Poland, October 1995.

Plants Division

EDWARDS, A C. Institute of Soil Science and Plant Cultivation, Pulawy, Poland, October 1995.

GRAYSTON, S J. Woody Roots Symposium. Ithaca, USA, 9-13 October 1995.

MARRIOTT, C A. British Council visit. Greece, 15-19 May 1995.

MILLARD, P. Agriculture Canada Research Station, British Columbia, February 1995.

MILLARD, P. Interactive Environmental Effects on Forest Stands. New Zealand, February 1995.

MILLARD, P. University of Bologna, Italy, October 1995.

SILCOCK, D. EC project co-ordination meeting. Finland and Estonia, 14-21 May 1995.

WILLIAMS, B L. EC proposal discussion meeting. Helsinki, Finland, 11-13 January 1995.

WILLIAMS, B L. EC project discussion meeting. Amsterdam, The Netherlands, 11-12 March 1995.

WILLIAMS, B L. EC project co-ordination meeting. Finland and Estonia, 14-21 May 1995.

WILLIAMS, B L. EC project meeting. Evora University, Lisbon, Portugal, 4-9 October 1995.

Animals and Grazing Ecology Division

DICKS, P. European Hair Research Society. Brussels, 7-10 October 1995.

DICKS, P. Cashmere Research Project Co-ordination Meeting. Bella, Italy, 10-11 October 1995.

DICKS, P. European Fine Fibre Network Workshop. Bella, Italy, 12-13 October 1995.

GODDARD, P. Swedish Agricultural University. Uppsala, Sweden, 25-31 March 1995.

GORDON, I J. University of Zimbabwe. Harare, Zimbabwe, April 1995 - April 1996.

GORDON, I J. CNRS Laboratory, Chize, France, 11-15 December 1995

IASON, G R. Department of Forest Animal Ecology, University of Agricultural Sciences, Umeå, Sweden, 11-14 February 1995.

LAKER, J. 3rd International Symposium on Speciality Animal Fibre. Aachen, Germany, 18-19 May 1995.

LAKER, J. European Fine Fibre Network Workshop. Athens, Greece, 16-17 June 1995.

LAKER, J. European Fine Fibre Network Workshop. Bella, Italy, 12-13 October 1995.

CONFERENCES and VISITS ABROAD

LAKER, J. European Fine Fibre Network Workshop. Bella, Italy, 23-24 November 1995.

McPHAIL, D. Conference on non-nutritive, protective substances in plant foods. Potsdam, Germany, 14 September 1995.

MILNE, J A. Evaluation of DGVI proposals. Brussels, Belgium, May 1995.

MILNE, J A. European Fine Fibre Network Workshop. Athens, Greece, 16-17 June 1995.

MILNE, J A. European Fine Fibre Network Workshop. Bella, Italy, 23-24 November 1995.

MILNE, J A. CEC contract negotiations. Brussels, Belgium, 5 December 1995.

RHIND, S M. Lecturing. University of Zaragoza, Spain, 2-7 June 1995.

REDDEN, H. Instituto spermentaleper la Zootecnia, Bella, Italy, 15-22 March 1995.

REDDEN, H. 3rd International Symposium on Speciality Animal Fibre. Aachen, Germany, 18-19 May 1995.

REDDEN, H. Consultancy on cashmere sampling. IPEA, Villavicosa, Spain, 8-12 September 1995.

RUSSEL, A J F. 3rd International Symposium on Speciality Animal Fibre. Aachen, Germany, 18-19 May 1995.

RUSSEL, A J F. European Fine Fibre Network Workshop. Athens, Greece, 16-17 June 1995.

RUSSEL, A J F. Cashmere Research Project Co-ordination Meeting. Bella, Italy, 10-11 October 1995.

RUSSEL, A J F. European Fine Fibre Network Workshop. Bella, Italy, 23-24 November 1995.

WRIGHT, I A. EC project proposal meeting. Paris, France, 20 February 1995.

WRIGHT, I A. European Suckler Cow Researchers meeting. INRA Thiex, France, September 1995.

WRIGHT, I A. EC Workshop. Paris, France, 22-24 November 1995.

Analytical Division

MIDWOOD, A J. Collaborative field work. Texas A&M University, USA, 21 October- 5 November 1995.

PROGRAMME OF RESEARCH

January 1995 to December 1995
Research projects in Programme Units 11-17 are funded by SOAEFD

PROGRAMME UNIT 11
LAND USE OPTIONS and IMPACTS on NATURAL RESOURCES

Research projects completed since January 1995

011013 Field testing of low input upland sheep systems (A R Sibbald) [non-commissioned research]

011148 Develop and test land use suitability models (G Hudson)

011150 Assessment procedures in wide area conservation evaluation (R J Aspinall)

011152 Modelling upland sheep systems (N J Hutchings)

011157 Use of GIS techniques with process-based environmental assessment procedures for water quality modelling (D R Miller)

011160 To model effects of rainfall variability on soil water regimes (A Lilly)

011161 Relationships between changes in agricultural intensity and land use on the nitrate and phosphate loadings of Scottish river systems (G G Wright)

011281 Assessment of tourist attitudes to landscape amenity value in Scotland (R V Birnie) [non-commissioned research]

011374 Strategic planning issues associated with windfarm location in the Scottish hills and uplands: a feasibility study (C H Osman)

011408 Review of Land Use Research in the UK (R V Birnie)

011418 Decision making tool kit - a short-term research review (R V Birnie/J A Milne) [SOAEFD Flexible Fund]

011471 Eliciting and mapping the attributes of landscape perception (R V Birnie) [non-commissioned research]

Current research projects

011159 Land suitability/risk assessment in relation to the disposal of wastes rich in heavy metals (W Towers)

011339 An approach to modelling wildlife dynamics in hill grazing systems using grouse as a model (M Hare)

011342 Environmental and socio-economic implication of low-input upland sheep systems (A R Sibbald)

011354 Developing and testing methods for detecting changes in land cover types and configuration using satellite remote sensing (R V Birnie) [non-commissioned research]

011355 Automated detection of land cover change in Scotland (A N R Law) [non-commissioned research]

011371 Decision support system for assessing land use options at the management unit level (K B Matthews)

011372 Assessment and impact of potential conflicts between re-cycled organic wastes from different sources (W Towers)

011373 Application of remote sensing and GIS for predicting nutrition of voles (R V Birnie) [non-commissioned research]

011376 Multiple-benefit upland silvopastoral systems: modelling and experimentation (A R Sibbald)

011401 Integration of land cover and agricultural information from the Agricultural and Horticultural Census of SOAEFD with the Land Cover of Scotland 1988 (LCS88) to provide an enhanced, co-ordinated and multi-temporal Land Cover Database for Scotland (N A Brooker) (Flexible Fund)

011439 A catchment/district scale model for assessing land use options and impacts with special reference to ecological modelling and conservation (R J Aspinall)

011440 Development of a generic methodology for integrated environmental impact assessment within a GIS framework (D R Miller)

011441 Integrating the Land Cover of Scotland 1988 data set with satellite imagery to provide measures of vegetation heterogeneity, structure and examination of regional variation (G G Wright)

011442 Extending and scaling up a model of upland livestock systems (N J Hutchings)

011443 Develop and evaluate the use of pedotransfer functions as a means of providing soil hydraulic data for process-based simulation models (A Lilly)

011444 Nitrate losses to surface water associated with increases in oilseed rape cropping: risk assessment based on satellite mapping and GIS analysis (G G Wright)

011445 Rescaling a grazing model for use within a farm-level land allocation decision support system (A R Sibbald)

011446 Spatio-temporal biophysical resource simulation modelling and representation for quantifying risks and opportunities in land use (G Hudson)

011453 The development of visualization techniques for landscape evaluation (D R Miller) [non-commissioned research]

011454 Computing slope and aspect from different sources and scales of digital elevation data; a critical review (D R Miller) [non-commissioned research]

011464 Modelling vole populations at the landscape scale (R J Aspinall) [non-commissioned research]

011477 Assessing the potential for short rotation coppice in Scotland (R V Birnie) [SOAEFD Flexible Fund]

PROGRAMME UNIT 12
ACIDIFICATION of SOILS and SURFACE WATERS

Research projects completed since January 1995

012169 Factors controlling the dynamics of organic matter decomposition in soil releasing organic acids and plant nutrients (M V Cheshire)

012170 Effects of acidification and metal complexant ligands on chemical speciation and mobilization of aluminium and other toxic metals in soils and waters (D G Lumsdon)

012171 Mineral weathering in relation to the vulnerability of catchments to acidification in Southern Scotland (D C Bain)

012175 Characterise amounts, sources and fate of heavy metals deposited from the atmosphere on Scottish soils and taken up in the food chain (J R Bacon)

012180 Investigate the nature and ion-exchange properties of hill and upland soils (E Paterson)

012327 Use of the Isotope Hydrograph Separation technique to determine hydrological pathways (H A Anderson)

012392 The use of LUX modified soil bacteria as an assay for soil heavy metal toxicity (C D Campbell) [non-commissioned research]

Current research projects

012165 Determine environmental changes at a series of long-term monitoring sites (J D Miller)

012166 Quantify the principal hydrological and hydro-chemical consequences of forestry, in relation to soil type, atmospheric inputs and management practices (J D Miller)

012167 Quantify sources and sinks of acidity under selected hill land uses, and their effects on water quality and quantity (H A Anderson)

012378 Water resource modelling: the effect of land use, atmospheric deposition and climate change on soils and waters (R C Ferrier)

012379 Interaction between the biosphere and the atmosphere in wetlands (S J Chapman)

012385 Critical loads to natural and semi-natural ecosystems with particular reference to nitrogen (S J Langan)

012434 Influence of weathering of calcium-bearing minerals on the sensitivity of catchments to acidification (D C Bain)

012457 Distributed modelling of water quality at the river basin scale (R C Ferrier) [non-commissioned research]

012468 Distributed modelling of the Ythan catchment (R C Ferrier)

PROGRAMME UNIT 13

PLANT-SOIL RELATIONS

Research projects completed since January 1995

013185 Effect of root exudate components on the ecology of specific soil microbial populations (D Jones)

013189 Seasonal internal cycling of nitrogen in evergreen and deciduous trees and the consequences for nutrient use efficiency (P Millard)

013199 Factors affecting nutrient source/sink relations on second-rotation forest sites (M F Proe) [Forestry Commission/SOAEFD]

013290 Influence of management practices on root exudates produced by contrasting tree species and their impact on microbial activity and cation availability in soils (D Vaughan)

Current research projects

013182 Mineral nutrition and assimilate partitioning in trees, including consequences of coppicing (M F Proe) [Central Scotland/ Countryside Trust/SOAEFD]

013194 Organic matter turnover in upland soils and its relationship with N and P transformations and availability to plants (B L Williams)

013322 Root growth and below ground competition between grasses in relation to nutrient availability and grazing (L A Dawson)

013323 Comparison of the phosphorus cycle in natural and managed ecosystems (A C Edwards)

013336 Microbial diversity and activity in the mycorrhizosphere of trees (S J Grayston)

013344 Carbon partitioning: rhizosphere carbon flow regulation of soil microbial activity and diversity in relation to mycorrhizal partitioning and nutrient transfers (A Hodge) [SOAEFD Flexible Fund]

013349 Characterisation of nutrient flows in upland grassland ecosystems using stable isotope signatures (C A Marriott) [SOAEFD Flexible Fund]

013362 Biomass and nutrient allocation in species associations undergoing extensification in relation to defoliation and nutrient supply (C A Marriott)

013363 Remobilization of nitrogen in grasses in relation to defoliation and nutrient supply (B Thornton)

013364 Fractionation of phosphorus in soil solution in relation to bioavailability and leaching (C A Shand)

013365 Availability of soluble and insoluble organic and condensed P sources in soil to *Agrostis capillaris* plants (A E S Macklon)

013395 Predictive modelling of eutrophication within the river Ythan catchment and the development of an integrated management plan (A C Edwards) [SOAEFD Flexible Fund]

013398 Development and application of molecular biological techniques in studies of the interactions between microbes, nutrient cycling and vegetation among a range of agriculturally important pastures, to enable scaling from microcosm to field (S J Grayston) [SOAEFD Flexible Fund]

013435 Development of methods to measure seasonal nitrogen translocation in trees and their application to quantify internal cycling (P Millard)

013436 Suitability of whole tree harvesting of sitka spruce as a sustainable land use on different site types within the UK (M F Proe)

013438 Phenotypic and genotypic basis of population dynamics in heterogeneous species - rich grassland (P Millard) [SOAEFD Flexible Fund]

013459 Application of immobilized algae as biosensors to investigate the consequences and options for control of nutrient enrichment (N&P) in flowing waterbodies (A C Edwards) [non-commissioned research]

013460 Natural abundance of ^{2}H, ^{18}O and ^{13}C in rainfall, soil moisture and plants in a subtropical savanna: implications for plant water use (A Midwood) [non-commissioned research]

013463 Interactions between N status and carbon partitioning on the development of *Vacciniuum* (P Millard) [non-commissioned research]

013466 Supplementary Analytical provision (A Smith) [non-commissioned research]

PROGRAMME UNIT 14

PLANT-ANIMAL RELATIONS

Research projects completed since January 1995

014213 Factors influencing the intake, diet selection and foraging behaviour of goats (I J Gordon)

014215 The effect of the structure of herbage on foraging strategies of sheep (R H Armstrong)

014216 Diet selection and intake by camelids and goats grazing indigenous hill plant communities (I J Gordon)

014217 Prediction of herbage intake by grazing ruminants from a study of physiological factors (A M Sibbald)

014221 Energetic constraints on ruminants: the role of sheltering behaviour, feeding ecology and seasonal energetic variation (G R Iason)

014285 Effect of grazing on the competitive ability of tussock and prostrate species (A J Hester)

014286 Modelling the foraging strategy of herbivores in heterogeneous ecosystems (K D Farnsworth)

014390 Effects of extensive grazing management on soil physical properties and botanical composition of upland mixed sown swards (J A Milne) [non-commissioned research]

014391 The effects of deer browsing on upland woodland dynamics (A J Hester) [non-commissioned research]

014470 Completing Hill Grazing Management Model papers (J A Milne) [non-commissioned research]

Current research projects

014203 The effect of grazing intensity by sheep on vegetation dynamics and diet selection in species-poor *Agrostis-Festuca* grassland (P D Hulme)

014204 Approaches to aiding rehabilitation of degraded heather stands (P D Hulme)

014205 Effects of sheep grazing intensity on

the vegetation dynamics of a range of wet heather moorlands differing in vegetation structure and species composition (A J Nolan)

014208 Changes in floristic composition, diet selection and soil nutrients of grazed swards under nutrient stress (C A Marriott)

014209 Develop and test foraging strategy theories for herbivores grazing mixed hill vegetation (I J Gordon)

014210 Assessment of diet composition and behaviour of ruminants grazing indigenous hill vegetation (R W Mayes)

014214 Diet selection by sheep grazing ryegrass/clover swards differing in the distribution of clover in the sward (R H Armstrong)

014220 The nature and extent of herbivore adaptation to ingestion of plant secondary compounds (G R Iason)

014223 Measurement of energy expenditure in grazing sheep (R W Mayes)

014284 Development of computer models to predict the effects of grazing by herbivores on plant community composition and dynamics (C P D Birch)

014297 Influence of vegetation structure on faunal species diversity in indigenous ecosystems (P Dennis) [SOAEFD Flexible Fund]

014324 Effects of sheep and red deer grazing on the vegetation dynamics of grass/heather mosaics (A J Hester)

014325 Effects of changes in sheep grazing intensity on competitive interactions with rabbit populations and on plant community dynamics (G R Iason)

014332 Impact of variability in the capacity of large herbivores to degrade plant secondary compounds on their foraging behaviour (A J Duncan)

014333 Environmental Change Network: measure long term environmental changes in soils, vegetation and wildlife populations at two upland agricultural sites in Scotland (D J Henderson)

014335 Host/parasite interactions in a herbivore-grazing ecosystem: the behavioural control of helminth infection by sheep (I J Gordon) [non-commissioned research]

014347 Development of a decision support system for managing the impact of red deer on vegetation dynamics and habitat diversity (L Partridge/I J Gordon) [SOAEFD Flexible Fund]

014366 Antioxidant efficacy of dietary polyphenols in relation to diet choice in sheep (D B McPhail)

014396 Representations of time trends and the spatial nature of plant communities on utilization rate in the Hill Grazing Management Model (J A Milne) [SOAEFD Flexible Fund]

014400 Develop a Geographic Object-Oriented Simulation Environment for individual based ecological modelling using GIS data (K D Farnsworth/N Outram) [SOAEFD Flexible Fund]

014447 Develop a theoretical approach to optimal matching between habitat and free ranging ruminants (K D Farnsworth)

014448 Effect of social behaviour on foraging by ruminants in heterogeneous ecosystems (A M Sibbald)

014449 Effect of shelter and food supply on behaviour and energy status of ruminants in heterogeneous upland ecosystems (A J Duncan)

014450 Effects of pre- and post-burning management on the recovery of rehabilitated dry and wet heather moorland (P D Hulme/ A J Nolan)

014455 Development of a new framework for Hill Grazing Management Model 3 (HGMM3) (J A Milne/A R Sibbald) [non-commissioned research]

014472 Effects of grazing by cattle and sheep on semi-natural vegetation and agricultural output (J A Milne/A R Sibbald) [SOAEFD Flexible Fund]

PROGRAMME UNIT 15 RUMINANT RESOURCE USE

Research projects completed since January 1995

015138 Welfare aspects of the catching of wild deer for use in deer farming (P J Goddard)

015222 Impact of exposure on energy expenditure of free grazing animals (R W Mayes)

015224 Seasonal variation in appetite in red deer (S M Rhind)

015225 Hormone control of seasonal coat growth in cashmere goats (S M Rhind)

015229 Effects of grazing management strategies on cattle performance and floristic composition in *Nardus*-dominated swards (I A Wright)

015230 Effects of genetically derived increased prolificacy on efficiency of resource use and welfare of sheep in different nutritional environments (A J F Russel)

015234 Fibre production and characteristics of fibre from camelids in upland environments (A J F Russel)

015389 Immunocompetence as an index of stress in weaned lambs (A J Hanlon) [non-commissioned research]

Current research projects

015226 Fibre growth and energy expenditure of cashmere goats following shearing (M Merchant)

015228 The complementarity of sheep, cattle and goat through the sequential grazing of sown swards (I A Wright)

015232 Cashmere production from goats and its improvement by crossbreeding and selection (A J F Russel)

015287 Effect of social behaviour on the prediction of intake and diet selection by grazing sheep (I A Wright)

015288 Speciality fibres and their role in the future use of land resources (A J F Russel)

015326 Sequential and mixed grazing of grass/ clover swards by sheep and cattle (I A Wright)

015352 The welfare of deer during transport and at slaughter (P J Goddard) [SOAEFD Flexible Fund]

015361 Mechanisms of early life nutritional effects on lifetime reproductive performance in sheep (S M Rhind) [non-commissioned research]

015367 Effect of rearing environment, management and genotype on the stress susceptibility of sheep in extensive systems (P J Goddard)

015368 Relationship between behaviour, hormonal and immune responses to stress in sheep (S M Rhind)

015369 Hormonal and metabolic mediators of seasonal changes in appetite in ruminants (S M Rhind)

015370 Modelling interactions of genotype and nutritional environment in sheep (N J Hutchings)

015397 Effects of pre-natal nutrition, colostral immunomodulators and lamb growth factors on aspects of innate and adaptive immunity in lambs (S M Rhind) [SOAEFD Flexible Fund]

015399 Testing models of nematode larval intake by ruminants (J Beecham) [SOAEFD Flexible Fund]

015402 Object oriented modelling of mixed grazing systems (J Beecham) [SOAEFD Flexible Fund]

015426 Interaction of genotype and nutritional environment in grazing beef cows (I A Wright)

015427 Mixed grazing of structurally heterogeneous swards (I A Wright)

015429 The effect of the presence of other species on the welfare of deer in lairage (P J Goddard) (SOAEFD Flexible Fund)

015437 Identification of sheep carrying the 'Thoka' gene for prolificacy by DNA microsatellite markers (A J F Russel)

015458 The independent and interactive roles of prolactin and the thyroid hormones, at the systemic and receptor level, in the control of hair follicle activity (S M Rhind/P Dicks)[non-commissioned research]

PROGRAMME UNIT 16

LAND USE OPTIONS and IMPACT: ENVIRONMENTAL and SOCIO-ECONOMICS

Research projects completed since January 1995

016156 Economic models in land use planning and policy development (J R Crabtree)

016158 Identify economic effects of acid deposition on water catchments in Scotland with special reference to land use change to forestry (D C Macmillan)

Current research projects

016337 Agricultural policy impacts on socio-economics and environmental sustainability in sensitive rural areas (J R Crabtree)

016338 Measuring the public benefits of environment and landscape change arising from agri-environmental policy measures (C H Bullock)

016383 Social factors in environment and development: Determining private and public interests in land use change (A Brown)

016384 Economic analysis of habitat and ecosystem restoration (D C Macmillan)

016393 Provision and economic impact of access-related recreation in Upland Scotland (J R Crabtree) [non-commissioned research]

016422 The relative importance of agriculture, pollution and climate change in determining biodiversity on Scottish Agricultural Land (J R Crabtree) [SOAEFD Flexible Fund]

016451 Economic appraisal of nitrate management at the catchment level (D C Macmillan)

016452 Preferences in deer stalking - an application of stated preference techniques to environmental change in Scotland (C H Bullock)

016461 The function and role of large estates in rural development (J R Crabtree) [non-commissioned research]

016462 Quantifying and explaining structural change in rural areas with reference to demographic and economic parameters at different scales (J R Crabtree) [non-commissioned research]

016467 Evaluation of Farm Woodland Premium Scheme (J R Crabtree) [SOAEFD Flexible Fund]

PROGRAMME UNIT 17

SOIL POLLUTION

Research projects completed since January 1995

017469 The forms and behaviour of Pb + Zn in organic soils from a former lead mining area in SW Scotland (E Paterson) [non-commissioned research]

Current research projects

017174 Assess the retention of heavy metals and major nutrients following sewage sludge application to acid soils (J R Bacon)

017176 Determine the effects of heavy metal pollution on soil microbial activity, including mycorrhizas, in agricultural and forest soils (C D Campbell)

017328 Effects of sewage sludge applications to agricultural soils on soil microbial activity and the implications for agricultural productivity and long term soil fertility (J R Bacon)

017329 The occurrence, mobility and persistence of organic pollutants in soils (A Smith)

017380 Influence of competitive interactions on the impact and fate of heavy metals in sewage sludge-treated soils (E Paterson)

017381 Cycling and bioavailability of radioisotopes in upland soils, particularly organic-rich soils (M V Cheshire)

017382 Role of fine-grained and colloidal particulate material in transporting pollutants in the environment (S J Hillier)

017386 Modelling chemical behaviour and transport of reactive contaminants in soils (J C L Meeussen)

017431 Effects of mineral-humic interactions in relation to modelling metal retention by soils (D G Lumsdon)

017432 Changes in time in the chemical association of the heavy metals cadmium, copper, lead, nickel and zinc in grassland and forest soils likely to receive sewage sludge (J R Bacon)

017433 Influence of heavy metal pollution on processes involving organic matter which affects soil fertility (M V Cheshire)

017456 The simulation of soil micro-architecture and its value in the study of the interactions between soils and biological systems (E Paterson) [non-commissioned research]

PROGRAMME UNIT 09 EXTERNAL CONTRACTS with source of funding

LAND USE DIVISION

Contracts completed since January 1995

090465 Definition of a system of nomclature for mapping European forests and for compiling a pan-European forest information system (D R Miller) [EC]

Current contracts

090307 Alternative agricultural land use with fast-growing trees (A R Sibbald) [EC]

090412 Silvicultural strategies for predicting damage to forests from wind, fire and snow: integrating tree, site and stand properties with Geographic Information Systems and regional environmental models to evaluate options for forest management (D R Miller/ A N R Law/ R J Aspinall) [EC]

090420 Using existing soil data to derive hydraulic parameters for simulation models in environmental studies and in land use planning (A Lilly) [EC]

CONSULTANCY DIVISION

Current Contracts

099415 Monitoring of Environmentally Sensitive Areas in Scotland (J H Gauld) [SOAEFD]

PROGRAMME OF RESEARCH

SOIL and SOIL MICROBIOLOGY DIVISION

Contracts completed since January 1995

090303 Immobilisation of soil nitrogen by decomposing plant residues and the potential of the forms of immobilised nitrogen for remineralisation (M V Cheshire) [EC]

090304 Phosphate release potential for over fertilised soils of important agricultural areas of the European Community: Implications for the sustainability of agricultural systems and for the environment (M J Wilson) [EC]

Current Contracts

090359 Characterisation, management and utilisation of red soil resources of southern China (M J Wilson) [EC]

090474 Prediction of spatial and temporal variation in the solute chemistry of a major river system from the integration of models of terrestrial and hydrological processes (S J Langan/ R C Ferrier/A C Edwards) [NERC]

090478 Dynamic models to predict and scale-up the impact of environmental change on biogeochemical cycling (R C Ferrier) [EC]

PLANTS DIVISION

Contracts completed since January 1995

090308 Influence of N deposition on the C balance in peatland ecosystems (B L Williams) [EC]

Current Contracts

090353 Biogeochemical cycling in agroforestry systems network (BAFNET) (A C Edwards) [EC]

090387 Soil borne organic phosphorus as affected by different agricultural regimes and climate: leaching and potential contribution to eutrophication (C A Shand/A C Edwards) [EC]

ANIMALS and GRAZING ECOLOGY DIVISION

Contracts completed since January 1995

090301 Transfer of radionuclides in animal production systems (R W Mayes) [EC]

090305 Coordination of research activities in the development of animal fibre production systems (J A Milne) [EC]

090306 Production of high quality cheese from extensive systems of sheep and goat production in less favoured areas (I A Wright) [EC]

090331 The influence of vegetation pattern in diet selection by sheep and red deer (I J Gordon) [EC]

Current contracts

090405 Research on the production of high quality cashmere from goats and its potential for agricultural diversification (A J F Russel) [EC]

090428 The use of grazing as a management tool in natural woodland ecosystems (A J Hester) [EC]

090473 Conservation management of Priority Upland Habitats through grazing: guidance on management of Upland Natura 2000 sites (J A Milne) [EC]

090475 Transfer of heavy metals from feeding stuffs and environmental sources into meats, milk and other foods of animal origin (R W Mayes) [MAFF (ITE subcontract)]

090476 The role of domestic livestock systems in rural development in disadvantaged areas (J A Milne) [EC]

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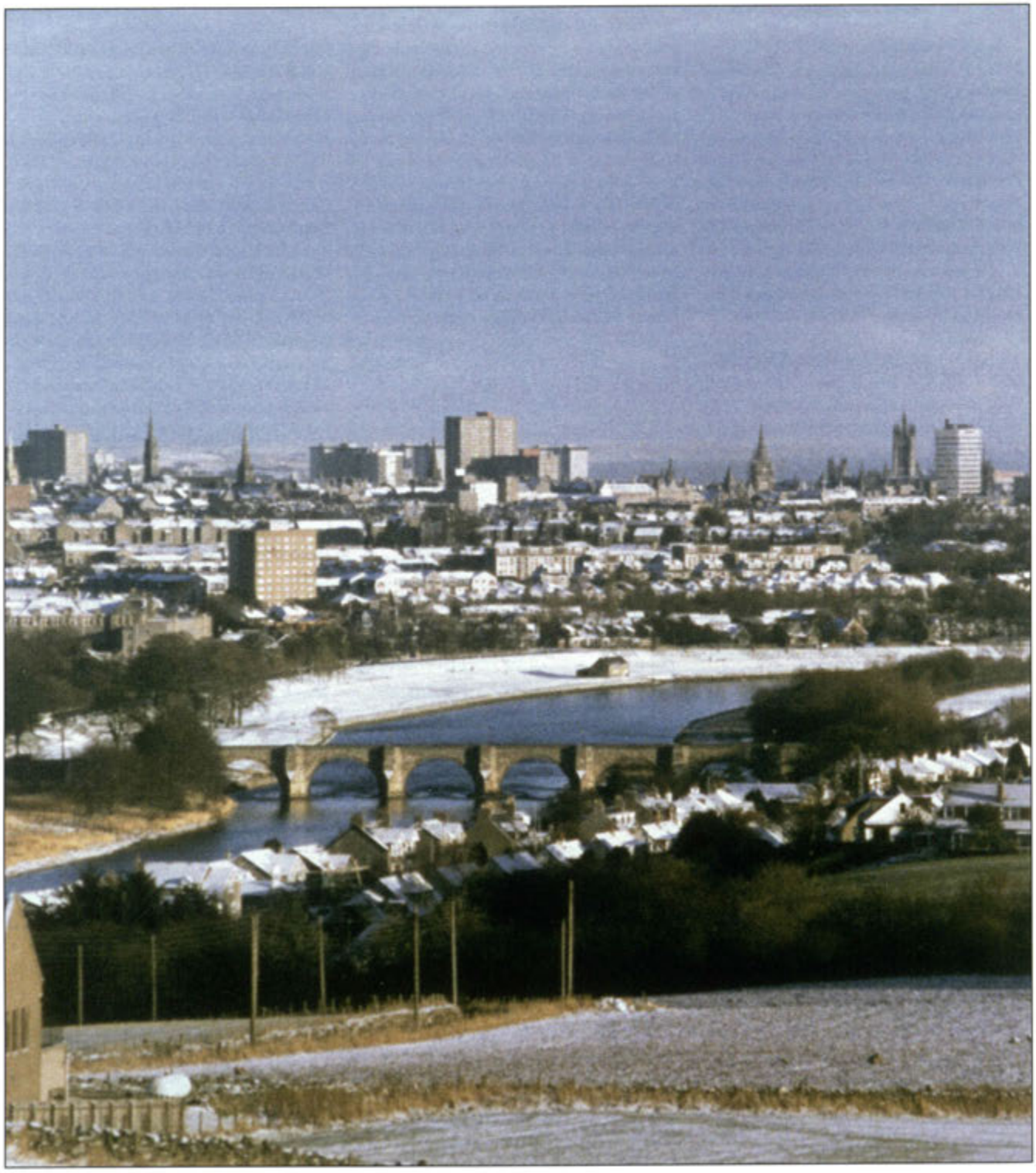
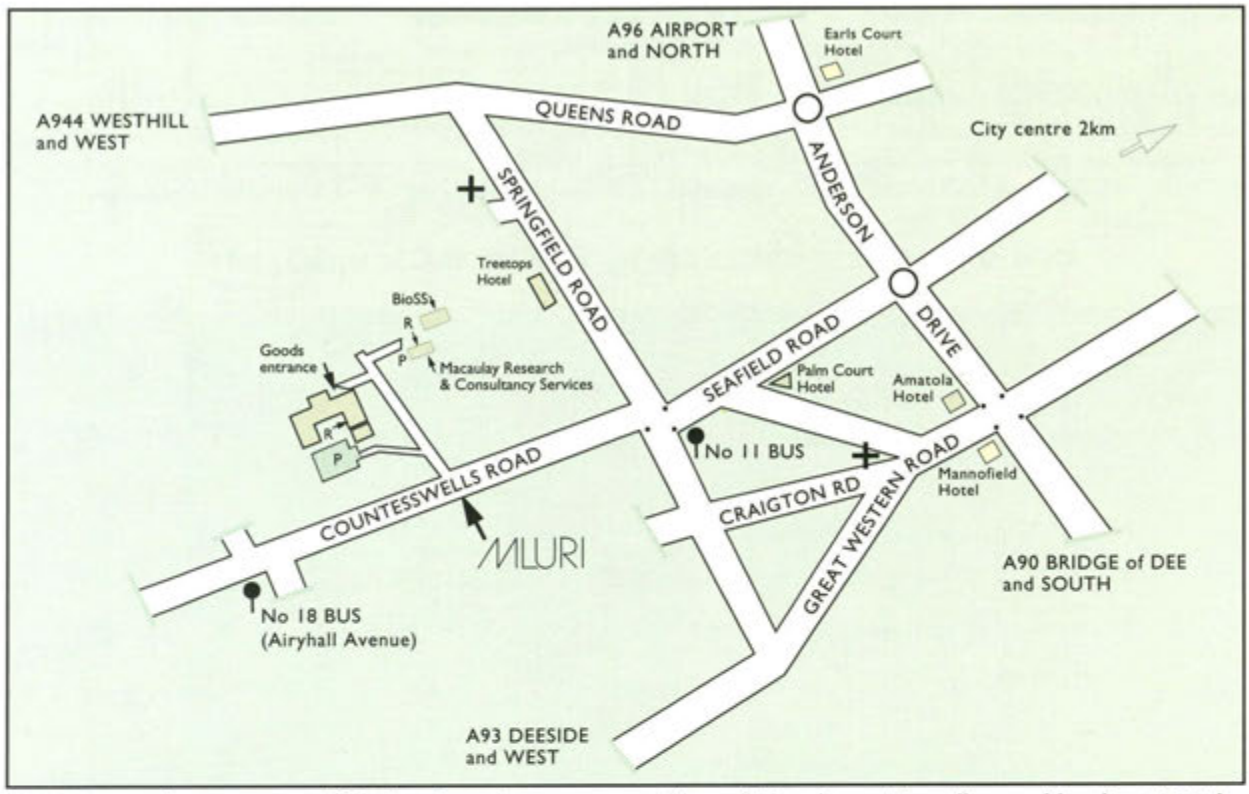


ANNUAL FINANCE STATEMENT for the YEAR ENDING 31 MARCH 1995

Income	£k
Scottish Office Agriculture and Fisheries Department	5,888
SOAFD Flexible Research Funding and other SOAFD contracts	552
European Union research contracts	475
Funding from other Government Departments, Public Bodies and Agencies	250
Private research and consultancy contracts	161
Other income	199
	7,525
Less Equipment purchased from revenue grants	-66
Total income	7,459

Expenditure	£k
Staff costs	5,121
Research expenditure including Research Station costs	1,100
Other operating costs	1,187
	7,408
Surplus (deficit)	51

The capital funds received from SOAEFD totalled £1,199,453 of which £412,731 was for capital works.
During the year the turnover of the MRCS Consultancy Division was £247,021.



MLURI is on the east coast of Scotland on the western outskirts of Aberdeen. It is well served by direct British Rail *Intercity* and *Scotrail* links. By road from the south the A90 runs directly from the motorway network at Perth. From the north follow the A96 from Inverness.