FINAL REPORT

COUNTERMEASURES:

ENVIRONMENTAL AND SOCIO-ECONOMIC RESPONSES - A LONG-TERM EVALUATION

Co-funded by the Nuclear Fission Safety Programme of the European Commission
Contract FI-4P-CT95-0021

The Final Report of the

CESER

Countermeasures**: E**nvironmental and **S**ocio-**E**conomic **R**esponses

Project

Co-funded by the Nuclear Fission Safety Programme of the European Commission
Contract: FI 4P-CT95-0021

Duration: 1 January 1997 -30 June 1999

Authors: C. A. Salt[1], J. Grande[2], N. Hanley[3], H. Solheim Hansen[2], H. Lettner[4], G. Kirchner[5], S. Rekolainen[6], I. Bärlund[6], R. Baumgartner[4], M. Berreck[7], M. Culligan Dunsmore[1], H. Ehlers[5], S. Ehlken[5], M. Gastberger[4], K. Haselwandter[7], V. Hormann[5], F. Hosner[4], T. Peer[4], M. Pintaric[4], S. Tattari[6] and M. Wilson[1].

1) Department of Environmental Science, University of Stirling, UK
2) Nord-Trøndelag College, Steinkjer, Norway
3) University of Edinburgh, UK
4) University of Salzburg, Austria
5) University of Bremen, Germany
6) Finnish Environment Institute, Finland
7) University of Innsbruck, Austria, sub-contractor

Stirling, 31 August 1999

Contents

1. INTRODUCTION

Accidental releases of radioactivity into the environment have the potential to cause widespread and long-term contamination of agricultural land. Although in the most severe case, food production and collection of wild foods may need to cease, more often it is possible through appropriate mitigation to allow farming to continue (Tveten *et al.,* 1998). The difficulty lies in designing countermeasure strategies that will deliver the required reduction in radiation dose in the most efficient, acceptable, cost-effective and technically feasible way. In the past this process of optimisation has typically neglected potential impacts on the environment and agricultural productivity. Equally the acceptability of different remediation options to consumers has received only limited attention and cost-benefit calculations have not been comprehensive. However, long-term use of countermeasures may increase the risk of environmental, social and wider economic impacts. The optimal remediation strategy should therefore seek to balance these impacts against the costs and benefits of dose reduction. This has been addressed in the CESER project.

The central theme of the CESER project is the assessment of long-term environmental and socio-economic impacts (or side-effects) of countermeasures. Hence, other aspects of the countermeasure selection process such as the prediction of contamination levels in different foods, the identification of vulnerable areas and the radiological effectiveness had to be treated in a pragmatic way. They are addressed more fully in parallel projects such as SAVE, RESTORE and TEMAS. CESER has purposefully taken a case study approach rather than attempting to develop countermeasure assessment tools for the whole of Europe. Nevertheless the methodologies presented are suitable for adaptation to circumstances other than those investigated. Only long-term countermeasures and their impacts have been evaluated, focusing on long-lived isotopes of caesium and strontium.

Since environmental and agricultural side-effects of countermeasures have not been intensively studied in the past, it was a key task to identify and characterise these side-effects as comprehensively as possible and subsequently to develop methods for their quantification. Effective management of all aspects of countermeasure implementation can only be undertaken if good knowledge of the nature and extent of any impacts is available. Any physical impacts, whether damaging or beneficial, on environmental resources or agricultural productivity will lead to economic impacts. The application of a full cost-benefit analysis is advocated that would include these factors alongside the direct costs of countermeasure implementation and health benefits to humans. In addition the degree of acceptability of countermeasures to consumers may have economic implications in terms of their willingness to pay for clean versus 'treated' foods. A consumer survey has been used to reveal people's attitudes and behaviour towards radioactively contaminated food and countermeasure, which provides the basis for a set of consumer recommendations to assist in future policy making.

Decision-makers faced with the task of planning countermeasures in agricultural production systems may need to operate at different geographical scales. While farm managers or agricultural advisors need to implement very specific countermeasure strategies for a single farm, it will be equally important that an overall strategy for a parish, region or even country is put in place. Therefore two different types of Decision Support System have been developed in the CESER project, one for farm level evaluation requiring user inputs to determine local suitability and side-effects and a second one for regional evaluation within a Geographic Information System relying on availability of large spatial data sets. Both systems are PC-based and the CeserDSS will be disseminated via the internet (see project web site - http://www.stir.ac.uk/envsci/ceser/ceser.htm).

The sequence of methodological steps taken in the CESER project to assess environmental and socio-economic impacts of countermeasures is shown in Figure 1. More detailed information on the project results can be found in Grande *et al.* (1999), Salt *et al.* (1999a,b,c) and Wilson *et al.* (1999)

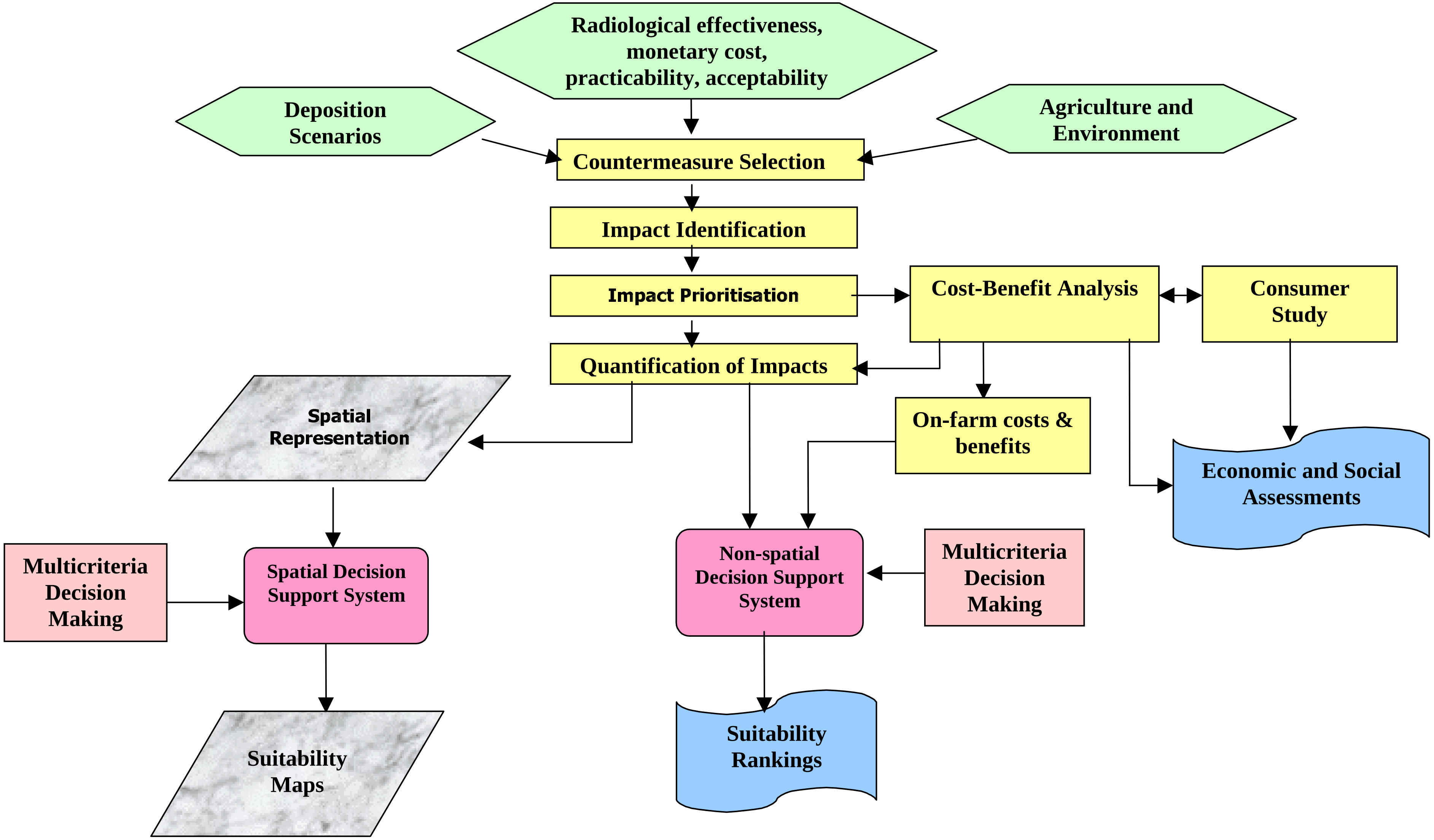


Figure 1. Overview of CESER methodology for environmental and socio-economic assessment of countermeasures

2. OBJECTIVES

The global aim of the CESER project was to develop decision support tools for long-term management of radioactively contaminated agricultural systems that would take into consideration environmental and socio-economic side-effects of countermeasures.

This following specific objectives were set at the beginning of the project:

1. To identify the most significant environmental and agricultural impacts arising from application of countermeasures designed to reduce soil-plant-animal transfer of radionuclides.

2. To quantify through modelling, experiments and expert judgement the degree and duration of these environmental and agricultural impacts.

3. To evaluate the combined impacts of countermeasures including differential responses of radiocaesium and radiostrontium under different food production systems.

4. To predict the spatial patterns of side-effects on a regional and national basis through utilisation of geographical information systems and classify geographical areas according to their suitability for countermeasures.

5. To identify and assess consumer attitudes towards contaminated food products, the use of countermeasures in food production and their willingness to pay to avoid damages.

6. To compare the direct and indirect costs and benefits of countermeasures related to changes in economic output, environmental quality and human health.

7. To provide a decision support package which can be used as a regional and national planning tool in the long-term evaluation of countermeasure suitability of land, incorporating both environmental and socio-economic impacts.

These objectives remained valid throughout the project.

3. RESULTS AND DISCUSSION

3.1. Development of Case Studies

Since environmental and socio-economic side-effects of countermeasures are likely to be highly dependent on the circumstances in which they are applied, a series of case studies were developed. The first task was to characterise the radionuclide deposition. This was limited to environmental contamination caused by atmospheric release and subsequent deposition of radionuclides. Of the many radionuclides that may be emitted in the course of a nuclear accident, only few show high transfer rates to man via food chains or pose a long-term radiation problem due to long half-life. The deposition scenarios therefore focus on ^{137}Cs, ^{90}Sr and alpha-Pu (Table 1). They reflect different sources and variable distances from the point of release. The subsequent process of selecting countermeasures was specific for radiocaesium and –strontium, while alpha-Pu was only considered in the evaluation of external dose.

Table 1. Deposition scenarios

	^{137}Cs	**^{90}Sr**	**alpha-Pu**	**Situation**
	kBq m^{-2}	kBq m^{-2}	kBq m^{-2}	
Scenario 1	100	2	0.02	Chernobyl-like fallout on distant land
Scenario 2	100	100	0.02	Fallout with a higher Sr fraction on distant land
Scenario 3	1000	200	0.2	Fallout on land close to site of release
Scenario 4	5000	500	1	Fallout on land very close to site of release

A wide range of countermeasures for agricultural production systems have been suggested in the literature (e.g. IAEA, 1994a; Roed *et al.*, 1995). These were reviewed in order to select those most likely to be applied under each of the deposition scenarios. The initial criteria of countermeasure applicability used in the selection process (after Nisbet 1995) were:

- radiological effectiveness
- practicability
- direct costs
- acceptability

The outcome of this screening process is separately summarised for soil-plant and for animal-based countermeasures.

3.1.1. Soil-Plant Based Countermeasures

The following categories of soil-based countermeasures were examined:

- Mechanical/physical treatment
- Application of fertilisers
- Application of chemical binders
- Crop and land use changes

An initial screening of the literature showed that different forms of ploughing, potassium fertilisation, liming and, in the case of high deposition, crop and land use changes were the countermeasures most worthy of more detailed examination. The effectiveness of ploughing by diluting or even removing the contamination present in the rooting zone is similar for all soil types treated. Potassium and calcium compete with caesium and strontium for the ion exchange sites on the soil particles and can remobilize sorbed radionuclides. However, when added in high quantities, they lower the Cs/K and Sr/Ca ratios in the soil solution which govern root uptake rates of both radionuclides. The effectiveness of adding Ca and K is highly dependent on the soil type. Therefore, soil types were broadly classified according to their cation exchange capacity (CEC) and organic matter content prior to assigning countermeasure applicability. Five priority countermeasures were identified for the different soil categories as shown in Table 2. This was later refined for the case study areas by determining a more specific set of thresholds based on actual pH and CEC through simulation modelling (see Table 13 & 14, page 35-36).

Table 2. Applicability of priority soil-based countermeasures to different soils (high CEC was defined as > 100 meq/kg of soil and high organic matter was defined as > 10%).

Countermeasure	**Organic soils**	**Mineral soils**	
		low CEC	*high CEC*
K addition	high	high	low
Ca addition	low	high	low
Shallow ploughing Deep ploughing Skim and burial ploughing	low-high	high	high

Land use related countermeasures selected for further evaluation were a) conversion from cereal or root crops to oilseed rape, b) afforestation of agricultural land and c) fallow. These are most appropriate at high levels of deposition and their effectiveness is independent of soil type.

3.1.2. Animal-Based Countermeasures

Countermeasures that reduce the transfer of ^{137}Cs and ^{90}Sr to animal products (e.g. milk, meat and eggs) are based on 2 main principles:

1) Avoiding ingestion of highly contaminated feed. This can be achieved through changes in the feeding regime, the management of animals or the management of the land.
2) Chemical treatment via
   a) intake of a chemical compound, which binds the radionuclide and prevents absorption,
   b) intake of a chemical analogue, which through competition reduces the absorption of the radionuclide.

In addition land use changes were considered for situations where it is not possible to continue animal production. The following countermeasures, considered to be generally applicable, were more closely evaluated with respect to case study areas:

Changing the feeding regime

Part or all of the contaminated feed is replaced with uncontaminated feed, thereby reducing both ^{137}Cs and ^{90}Sr intake. For dairy cows, locally grown roughage can be partly replaced with uncontaminated concentrate, raising the contribution of concentrate to the net energy intake up to 80%. Similarly during the final fattening period uncontaminated roughage and concentrate can be fed to lambs and beef calves. A further option for lambs is early weaning followed by quick fattening on concentrate. For veal production uncontaminated milk replacer can be bought in for calves. The duration of the countermeasure diet will vary according to the level of contamination.

Changing the animal management

It may be advantageous in contaminated areas to change from producing fattened animals to producing lambs or calves. These are weaned early and sold to other farms, with access to uncontaminated feed, for fattening. The age or live weight at which the animals are sold may be varied according to the level of contamination.

Changing land management

For animal production with extensive use of unimproved (semi-natural) land for grazing, it may be beneficial to improve the fertility of selected areas of rough grazing by reseeding, liming and fertilising. Farms with existing improved land may increase the productivity of that land by raising fertiliser application levels and reseeding more frequently. This enables higher stocking densities.

Chemical treatments

Administration of AFCF (ammonium iron-hexacyano ferrate) to animals leads to the binding of ^{137}Cs into a chemical complex that is not absorbed in the gut but excreted in the faeces. AFCF must be present in the digestive tract continuously to bind ^{137}Cs, and therefore should be administered in a manner that provides a daily supply. This can be achieved by direct incorporation into feed or salt licks or as slow-release boli. The compound has been accepted by the CEC as a feed additive to reduce ^{137}Cs accumulation in animal products, and is recognised as one of the most likely countermeasures to be used in a future fallout situation.

Feeding of high doses of calcium reduces the transfer of ^{90}Sr to milk by changing the ratio between Ca and Sr in the digestive tract of the cow. When the essential mineral Ca is transferred to the milk, the transport mechanism discriminates against Sr. Thus by increasing the Ca/Sr ratio, even less Sr is being transferred. Ca supplementation is expected to give up to 50% reduction in transfer of Sr to milk, and is thus not efficient enough in all situations.

Land use changes

If only certain regions of a country are highly contaminated, animal production may be transferred to less contaminated areas. In the most severe deposition scenario where external radiation exposure exceeds the dose limit, termination of animal production is the only option. Afforestation and fallow have been considered in the project.

3.1.3. Agricultural Production Systems in the Case Study Areas

The case study areas were selected to represent a wide range of agricultural production systems and natural conditions, such as climate, soils and topography. For Finland and Scotland a range of river catchments were selected to test the CESER approach to assessing countermeasure suitability and side-effects. For Austria two study areas were selected to represent the special case of pre-alpine and alpine environments. The study areas are shown in Figure 2 (page 7) The types of data used in the project and the data sources are given in Salt *et al.* (1999c).

Finland

Three catchments are located in southern Finland (Lepsämänjoki, Rekijoki, Yläneenjoki) and two in the north (Lestijoki, Taipaleenjoki). The agricultural land use varies from 10 to 50% with the remaining area taken up by forests (Table 3, page 8). The catchments can be divided into very flat northern catchments and less flat southern catchments. The most frequent soil types are: clay loam and silt loam in Yläneenjoki, silty clay and clay loam in Lepsämänjoki, silt loam and sandy loam in Lestijoki and silt loam and silt in Taipaleenjoki. The two southern catchments represent typical arable farming areas concentrating on cereal production with some pork and poultry, whilst the more northern areas represent dairy production areas (Table 4 & 5, page 8-9). Grass production is mostly for silage, usually for 4-5 years, and is then ploughed for cereals. The animal densities are typically below 1.5 animal units/ha. In Yläneenjoki the number of farms under organic production was relatively high (13%), in other areas it varied from 4 to 5%. The farming intensity as indicated by nitrogen surplus (N input - N output in yields) showed relatively low input farming. The median N surplus in all studied field parcels was ca. 20 kg/ha in all areas except in Taipaleenjoki, where it was ca 15 kg/ha.

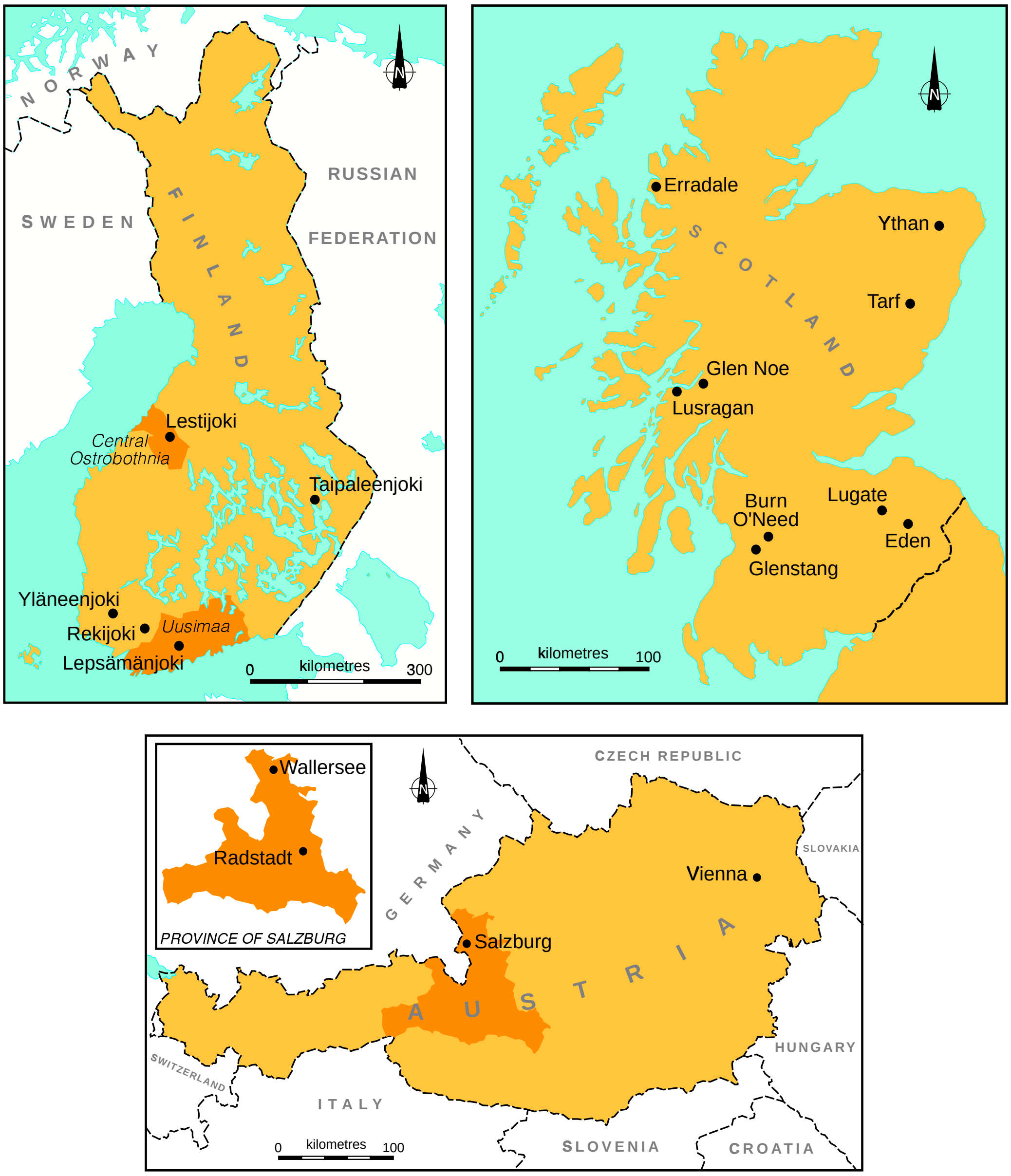


Figure 2. Location of case study sites

Scotland

Nine small catchments were selected in areas dominated by intensive as well as extensive farming (see Table 3-5). In contrast to the Finnish study areas, many Scottish areas have moderate to steep slopes and are dominated by semi-natural vegetation. Forestry cover is very low. Stocking densities vary from 1.5 livestock units in areas with significant dairy farming to 0.04 LU/ha in areas of extensive sheep grazing. The existing range of farming systems had to be simplified focussing on the most common crops and forms of livestock husbandry. Pork and egg production were omitted, partly because they are not common in the catchments selected but also because they only require countermeasures under Deposition Scenario 4. This situation has been assessed for the Finnish catchments. Specific countermeasures were developed for the following farm types:

- Dairy farms producing milk from dairy cows.
- Lowland sheep farms that breed and fatten lambs, and do not receive LFA (‘less-favoured area’) payments.
- Upland/hill sheep farms that breed lambs, and either fatten them or sell as store lambs (for final fattening on other farms), and receive LFA payments.
- Lowland beef farms that breed and fatten beef calves, and do not receive LFA payments.
- Upland/hill beef farms that breed beef calves and either fatten them or sell as store cattle (for final fattening on other farms), and receive LFA payments.
- Arable = Farms growing wheat, barley, oilseed rape, potatoes, swedes or similar crops.
- Management for deer = Land managed for the hunting of wild red deer. The number of red deer in Scotland is estimated at 300 000. Generally hunting takes place on privately owned sporting estates in upland areas. Income is derived from the sale of venison and hunting (mainly stags).

Table 3. Physical characteristics and land use in the case study areas (A=Austria, F=Finland, S=Scotland)

Catchment		Annual rainfall mm (1)	Area km^2	Median Slope degrees	% arable (3)	% improved grassland	% rough grazing
Yläneenjoki	F	712	227	1	27	0	0
Lepsämänjoki	F	718	214	1	23	0	0
Lestijoki	F	632	1373	0	10	0	0
Taipaleenjoki	F	758	35	0	50	0	0
Rekijoki	F	632	26	0	64	6	0
Glenstang Burn	S	1256	9	2	3.5	90	0
Burn O’Need	S	1256	23	3	0	51	41
Eden Water(2)	S	690	22	2	88	7.5	0
Lugate Water	S	858	33	9	1	31	66
Water of Tarf	S	1286	49	9	0	3	97
River Ythan (2)	S	797	14	3	91	8	0
Lusragan Burn	S	1978	7	4	0	10	85
River Noe	S	1978	18	20	0	0	100
River Erradale	S	1839	14	3	0	2	97
Wallersee(4)	A	1186	2.5	5-10	*2*	*86*	*0*
Radstadt(4)	A	1086	2	7-12	*3*	*75*	*4*

1) 10 year average Finland 1981-1990, Scotland 1986-1995, Austria 1971-1981
2) Only a sub-section of these catchments was assessed
3) This includes rotational grass using for cutting or grazing.
4) Estimated value, only average value (23 degrees) for the whole province was available

Table 4. Percentage distribution of crops in areas with arable land use.

	Spring cereals	Winter cereals	Spring OSR(2)	Winter OSR92)	Sugar beet	Potato	Swedes	Mowing grass	Grazing grass
Yläneenjoki(1)	67	6	4	0	1	1	0	9	0
Lepsämänjoki(1)	65	3	5	0	0.2	0	0	13	0
Lestijoki(1)	31	0	0	0	0	5	0	63	0
Taipaleenjoki(1)	39	0	0	0	0	0.1	0	51	0
Glenstang Burn	0	3	0	0	0	1	0	33	63
Eden Water	29.8	42.3	0	6.1	0	1.4	1.5	10.7	8.1
River Ythan	44.7	9.3	1.7	6.8	0	3.8	3.9	14.9	14.9
Wallersee	1	2	0	0	0	0	0	63	34
Radstadt	1	3	0	0	0	0.1	0	50	40

1) values do not add to 100% since some crops and set-aside are not included.
2) OSR = oilseed rape

Table 5. Number and type of animals in the case study areas

Catchment	Dairy cattle	Beef cattle	Poultry	Pigs	Sheep	Red Deer [(1)]
Yläneenjoki	872	495	233190	7859	115	0
Lepsämänjoki	512	357	0	690	42	0
Lestijoki	2072	800	0	377	151	0
Taipaleenjoki	395	832	0	0	0	0
Glenstang Burn	866	946	0	0	1356	0
Burn O'Need	969	1023	0	0	5588	0
Eden Water	0	1185	0	0	4400	0
Lugate Water	0	1314	0	0	12510	0
Water of Tarf	0	14	0	0	900	200
River Ythan	0	787	0	8521	1810	0
Lusragan Burn	0	40	0	0	800	20
River Noe	0	0	0	0	1872	200
River Erradale	0	0	0	0	850	100
Wallersee(2)	86	3	84	2	0	0
Radstadt(3)	91	46	30	6	105	0

1) Estimates of red deer numbers only available where game management is practised
2) Only a subsection of 52 ha was assessed
3) Only a subsection of 75 ha was assessed

Austria

The two study sites, Wallersee and Radstadt (see Tables 3-5), are located in the province of Salzburg. The agro-economic structure is dominated by small scale production and supplementary income farming. Sixty-one percent of the farms are classified as mountain farming with a share of 34.8% of the overall land, non-farmable land included. Approximately two thirds of the farms are smaller than 20 ha. Organic farming is an increasing source of income in recent years resulting in a shift towards less intensive land use. Wallersee lies in the more productive northern pre-alpine part of the province of Salzburg while Radstadt lies in a valley floor in the southern alpine part. The latter is more extensively used with insignificant arable production. In both areas mowing and grazing grass account for up to 96 % of the agricultural land. In the pre-alpine area grass can be mowed three times per year with subsequent use for grazing, while in the alpine area mowing can be done only twice. This equates to a productivity of 1.7 cattle units (500 kg live weight) in the pre-alpine region and 1.3-1.5 in the alpine region.

The prevailing soil types in the Wallersee area are calcareous and – due to management practices - decalcified cambisols, formed on Quarternary sediments, while in the Radtstadt area the soils are more diverse, with lime-free cambisols on the slopes and fluvisols developed on the alluvium on the valley floors (Österreichische Bodenkartierung, 1978, 1986).

The main food products for which countermeasure strategies were developed in the study areas are summarised in Table 6.

Table 6. Food products considered in the study sites.

	arable	cow's milk	beef	veal	lamb	pork	chicken	eggs	venison*
Austria		x		x	x				
Finland	x	x	x			x	x	x	
Scotland	x	x	x		x				x

* meat of wild deer

3.1.4. Countermeasure Selection for Case Study Areas

Once a set of realistic countermeasures has been defined, those food products had to be identified that would most likely exceed Community Food Intervention Levels (CFIL's; CEC, 1989) under a particular deposition scenario, thereby identifying the production systems requiring application of countermeasures. By applying detailed knowledge of each farming system it is then possible to carefully select countermeasures that can be optimally integrated into existing management systems. This selection of countermeasures is based on the following steps:

1. For each deposition scenario and food product, contamination levels were predicted using 95% confidence intervals of transfer factors from IAEA (1994b). Where CFIL's are likely to be exceeded countermeasures are necessary. The calculations for the study areas agreed well with the post-Chernobyl experience regarding which production systems required countermeasures.
2. Only those countermeasures were selected which are generally feasible under the environmental conditions and farming practices in the case study areas.
3. Some countermeasures were found to be too expensive or drastic under certain deposition scenarios and are therefore not always recommended (e.g. afforestation).
4. The additional dose to farmers executing countermeasures was calculated for each deposition scenario, based on average working times given in Roed *et al.* (1995). Where these seemed inappropriate, they were modified by case study area specific information. Dose conversion factors were taken from BMU (1989) for external, and from EU (1996) for internal irradiation. In Deposition Scenario 4 the external dose to the population will exceed 1 mSv/year and the only option is evacuation of the population and termination of agriculture. The area may be converted to forestry or left fallow.

The countermeasure selection process is implemented more specifically within the Decision Support Systems developed for Scotland (see Section 3.6.).

In each case study area countermeasures against Cs and Sr as well as some countermeasure combinations were allocated to each farm type following the 4-step procedure outlined above. Step 2, i.e. the selection of countermeasures suitable for regional environmental conditions and farming practices, took into account a range of potential limitations that might preclude the use of certain measures. This approach is illustrated for the Austrian study sites in the following section.

The Austrian sites present particular restrictions in the countermeasure implementation. In alpine areas, e.g. Radstadt, only extensive agriculture is possible and countermeasures at the soil/plant level are less suitable due to poor accessibility, terrain conditions and increased workload. Animal-based countermeasures are more appropriate, such as administration of AFCF and Ca. As a consequence of the limited suitability of countermeasures and the much higher transfer factors in alpine regions compared to valley and pre-alpine areas (Lettner, 1990), these areas have to be excluded from agricultural production at lower contamination levels. In the pre-alpine Wallersee test site the majority of soils are shallow; deeper soils are only found in flatter areas. Deep ploughing is restricted to less than 1% of arable land. Most soils have been formed on very variable, fine to coarse glacial material and moraines with limited hydraulic conductivity and poor drainage status. The combination of geology and high precipitation, favours the formation of gley soils that are less suitable for arable production and ploughing. In addition the mountainous topography is a limiting factor for ploughing countermeasures as more than 80% of the surface is steeper than 10°. The common slope limits for ploughing are set at 12-15° to avoid erosion and for safety reasons. Deep and skim and burial ploughing were not regarded as appropriate and only shallow ploughing was assessed for side-effects. Ploughing and reseeding for continued grass production can be applied when the contamination is not too high (Deposition Scenario 1 and 2). Ploughing and converting the land to cereal production is recommended when the contamination is higher and the reduction of transfer factors achieved through reseeding is not sufficiently effective to comply with CFIL or dose limits.

Tables 7-10 give examples of the many tables compiled for the 3 countries, to illustrate the approach taken. Each combination of countermeasure and deposition scenario is given a code, as follows:

R = recommended
NE = no effect on the radionuclide
NR = not required since CFIL's are not likely to be exceeded
NSE = not sufficiently effective to comply with CFIL's or dose limits
TE = too expensive or less drastic countermeasures are available
CFIL = Community Food Intervention Limit (CEC, 1989)

Table 7. Countermeasures allocated to Austrian dairy production.

Dairy production - Austria	**Scen 1**	**Scen 2**	**Scen 3**	**Scen 4**
Reduction factor required to meet CFIL *Cs* *Sr*	*1* *0*	*1* *3*	*2* *4*	
Administer AFCF with the feed	R NE	R NE	R NE	NSE NE
Supply Ca in the diet	NE NR	NE R	NE R	NE NSE
Feed clean roughage	TE NR	R R	R R	NSE NSE
Feed more concentrate (all imported)	TE NR	R R	R R	NSE NSE
Pasture intensification (Shallow ploughing and reseeding; depending on site suitability)	NR/R NR	R R	R/NSE R/NSE	NSE NSE
Feed more home-grown concentrate (shallow plough grassland and introduce cereal production once or in crop rotation)	TE TE	TE/R TE/R	R R	NSE NSE
Lime the soil	NE NR	NE R	NE R	NSE NSE
Apply K fertiliser	TE/R NE	R NE	NSE NE	NSE NSE
Exclude dairy production	TE NR	TE TE	TE/R TE/R	R R
Afforestation	TE NR	TE TE	TE TE	R R

Table 8. Countermeasures allocated to Finnish beef production.

Beef production - Finland	**Scen 1**	**Scen 2**	**Scen 3**	**Scen 4**
Reduction factor required to meet CFIL *Cs* *Sr*	*0* *0*	*0* *0*	*2* *1*	
AFCF administration during fattening period. AFCF given direct on the feed	NR NE	NR NE	R NE	NSE NE
Sell beef cattle for slaughter from the farm. Feed clean concentrate and/or roughage during the last part of the fattening period .	NR NR	NR NR	R R	NSE NSE
Beef cattle sold for final fattening at other farms	NR NR	NR NR	R R	NSE NSE
Exclude animal production	NR NR	NR NR	TE TE	R R
Afforestation	NR NR	NR NR	TE TE	R R

Table 9. Countermeasures allocated to Scottish sheep production on hill/upland farms (1).

Sheep production on upland/hill farm - Scotland	**Scen 1**	**Scen2**	**Scen 3**	**Scen 4**
Reduction factor required to meet CFIL *Cs* *Sr*	*3* *0*	*3* *1.5*	*32* *4*	
Administer AFCF as boli or in feed blocks to lambs.	R NE	R NE	R NE	NSE NE
Improve land (plough, fertilise, lime & sow grass/clover on rough grazing land)	TE NR	R R	R R	NSE NSE
Intensify the use of existing improved land (fertilise, lime, reseed). Effectiveness uncertain	TE NR	R R	R R	NSE NSE
Lime the soil (apply 2 t/ha lime every 2 years)	NE NR	NE R	NE R	NE NSE
Apply K fertiliser (apply 100 kg/ha of potassium annually)	+Cs NE	R NE	R NE	NSE NE
Sell early for fattening (Wean lambs early and sell for finishing outside the contaminated area.).	TE NR	R R	R R	NSE NSE
Sell for fattening (Sell lambs after 1 grazing season for finishing outside the contaminated area. Apply slaughter restrictions)	R NR	R R	R R	NSE NSE
Fatten lambs on clean roughage	R NR	R R	R R	NSE NSE
Fatten on clean concentrate (wean lambs early and fatten indoors)	TE NR	R R	R R	NSE NSE
Excluding animal production	TE NR	TE TE	TE TE	R R
Afforestation	TE NR	TE TE	TE TE	R R
Administer AFCF and fatten on clean roughage	R	R	R	NSE
Administer AFCF and sell for fattening	R	R	R	NSE
Administer AFCF and intensify use of improved land	R	R	R	NSE
Administer AFCF and apply K fertiliser	R	R	R	NSE
Administer AFCF and improve land			R	NSE

1) The transfer of Sr to lamb on organic soils remains uncertain, and therefore also the required level of effectiveness of the countermeasures. For Cs an aggregated transfer factor (Hove *et al.* 1994) was used to estimate the need for countermeasures.

Table 10. Countermeasures allocated to arable production - Scotland(1)

Arable production- Scotland	**Scen 1**	**Scen2**	**Scen 3**	**Scen 4**
Deep ploughing	TE NR	TE TE	R R	NSE NSE
Skim and bury ploughing	TE NR	TE TE	R R	NSE NSE
Shallow plough and apply K	R NE	R NE	NSE NE	NSE NSE
Shallow plough and apply lime	NE NR	NE R	NE NSE	NE NSE
Shallow plough and apply lime and K	 NR	R R	NSE NSE	NSE NSE
Change to oilseed rape	TE NR	TE TE	R R	NSE NSE
Exclude arable production	TE NR	TE TE	TE TE	R R
Afforestation	TE NR	TE TE	TE TE	R R

1) Countermeasures were recommended if the contamination in grain for human consumption was likely to exceed CFILs, and contamination in grass was likely to cause animal products to exceed CFILs.

3.2. Identification and Quantification of Side-Effects

The most significant environmental and agricultural side-effects (in terms of likelihood, magnitude and duration) following the application of the selected countermeasures were identified via literature review and discussions with experts from within and outside the project. A list of clearly defined criteria was developed to formalise the subsequent process of impact quantification. These are listed below with examples of possible side-effects (for a more detailed explanation see Salt *et al.* (1999a)):

- Soil Erosion and Sedimentation
  Erosion is the loss of soil through water and wind induced transport. Sedimentation is the deposition of eroded soil in surface water bodies where detrimental effects, e.g. on drinking water quality or biological habitats may occur. Any countermeasures involving a change in the ploughing regime or in land use may affect this criterion.
- Soil Organic Matter
  The humus content of topsoil can diminish through countermeasures that increase mineralisation such as liming or ploughing. Conversely afforestation or fallow on arable land can lead to a long-term increase in humus levels.
- Soil Nutrient Transport to Water
  Soil nutrients are transported in dissolved or particulate form through surface runoff and percolate into surface or ground water where they may cause eutrophication. Countermeasures can interfere with these processes through changes in erosion or nutrient inputs to the soil. Ploughing countermeasures, changes in land use or changes in the feeding and management of livestock can be implicated.
- Soil Pollutant Transport to Water
  Soil pollutants such as heavy metals are transported in dissolved or particulate form in runoff and percolate and may enter surface or ground water, causing water pollution. Pollutants can be mobilised when countermeasures lead to increased mineralisation of soil organic matter (see above). Decreased or increased use of biocides due to changes in the intensity of farming will also affect the quantities of these pollutants reaching water courses.
- Animal Welfare
  This is defined as the maintening of animals in good health through humane handling, care and treatment. Any countermeasures involving more intensive livestock feeding regimes and longer periods of housing could be perceived as negative in terms of animal welfare.
- Product Quality
  The quality of agricultural products in terms of their saleability could be affected, e.g. some of the proposed animal feeding regimes would lower or raise the fat content of milk or meat.
- Product Quantity
  The amount of food produced for sale could change, e.g. deep ploughing is likely to reduce crop yields while under some feeding regimes the slaughter weight of animals would increase.
- Ammonia Emissions
  Emissions of ammonia are due to volatilisation from nitrogen contained in animal faeces, urine or manure, or in mineral fertilisers. Emissions from livestock occur during periods of housing and outdoor grazing, as well as during storage and land spreading of manure. Countermeasures that alter the normal feeding and management of livestock are likely to change ammonia emissions.
- Biodiversity
  Biodiversity is defined as ‘the variability among living organisms and the ecological complexes of which they are part’ (UNEP, 1993). In the CESER project biodiversity was defined as: the ecological richness on a particular farm type including higher plant and animal diversity as well as rarity and distinctiveness of species and diversity of habitats/ecosystems. These can be affected by many countermeasures, in particular when changes in land use or farming intensity occur.

- Landscape Quality
  This is defined as the value of a landscape based on known and predicted preferences of people. Preference depends on cultural background, knowledge and educational level. Factors that may play a role are the perceived 'naturalness', diversity and fragility of an area and it's economic/recreational value. Countermeasures involving land use change, e.g afforestation and pasture improvement have the most visible impacts.

It was a key objective of the CESER project to research methods suitable for quantifying these impacts to form a common basis for comparing diverse countermeasures with respect to side-effects. Table 11 summarises the methods of quantification applied. Often more than one method had to be used to quantify the impacts on a particular criterion, for example, the selected model was not suited for simulating erosion and nutrient losses after afforestation. In all quantification exercises a period of 10 years was assessed.

Table 11. Impact criteria and methods of quantification with relevant sections of the report.

Criteria	Methods	Section
Soil Erosion and Sedimentation	Modelling, expert judgement	3.2.1
Soil Organic Matter	Expert judgement	3.2.8.
Soil Nutrient Transport to Water	Modelling, experimentation, expert judgement	3.2.1.
Soil Pollutant Transport to Water	Experimentation, expert judgement	3.2.5, 3.2.6
Animal Welfare	Expert judgement	3.2.8.
Agricultural Product Quality	Expert judgement	3.2.8.
Agricultural Product Quantity	Calculations, expert judgement	3.4.2
Air Quality - Cyanide release from AFCF	Experimentation	3.2.4.
Air Quality - Ammonia Emissions	Spreadsheet calculations	3.2.2 3.3.1.
Biodiversity	Landscape structure analysis, expert judgement	3.3.2 3.2.8.
Landscape Quality	Contingent valuation, expert judgement	3.4.4

3.2.1. Modelling Erosion and Losses of Phosphorus and Nitrogen

The potential for countermeasures to cause long-term changes in soil erosion and losses of essential plant nutrients in runoff was assessed through mathematical simulation modelling. The selected model, ICECREAM (Tattari *et al.*, In prep), is a field-scale mathematical simulation model predicting water, soil, phosphorus (P) and nitrogen (N) losses at the edge of fields and out of the root zone (Figure 3, page 15). It is an extension of the CREAMS/GLEAMS models (Knisel 1980, 1993), originally developed in the U.S. to assess and compare the impact of different management practices on soil and nutrient losses. The hydrology, crop growth, and partly also the erosion calculations have been further developed by Rekolainen and Posch (1993).

The submodels for P and N are mainly taken from the GLEAMS model with a few adaptations to achieve a better fit to local conditions. The P cycle in the soil is described by three inorganic and two organic pools, and flows between these and the biomass. The most active inorganic pool is the plant available P, which has been defined as anion exchange extractable P (Sharpley *et al.*, 1984). Chemical fertilizer P is added to plant available P at the day of fertilisation, and crops are assumed to take up P from this pool only. The loss of soluble P with surface runoff also originates only from this pool, whilst the loss of particulate P (attached to soil particles) takes place from all soil P pools.

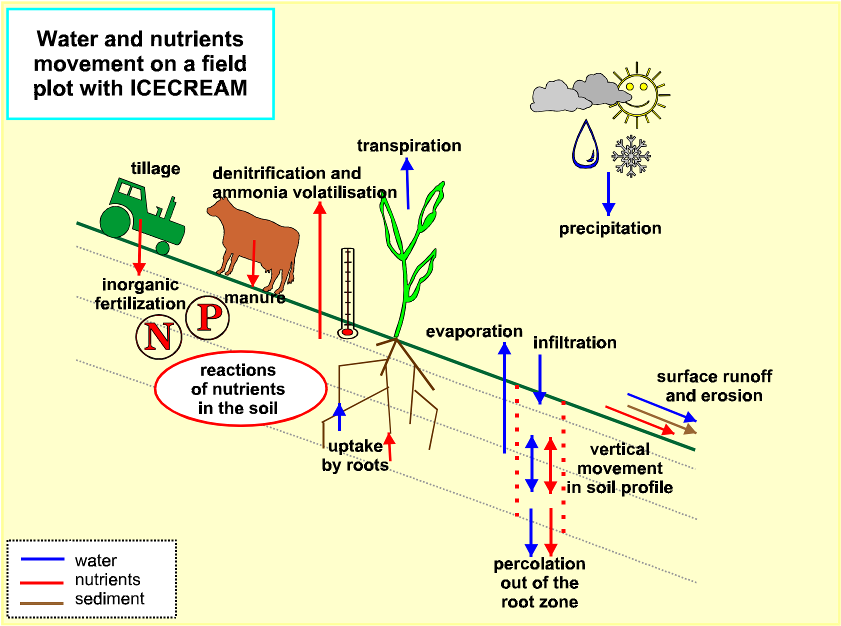


Figure 3. The main processes simulated in the ICECREAM model

The soil nitrogen cycle is described using two inorganic (nitrate and ammonia) and three organic pools differing in their stability against microbial degradation. Processes between the pools and the atmosphere include mineralisation, assimilation, nitrification, denitrification, volatilisation and nitogen fixation. Soluble N losses take place from the nitrate and ammonia pools, and particulate N losses from all organic pools.

The output parameters examined for the CESER Countermeasure Scenarios (see below) are:

a) soil loss (erosion), kg/ha
b) dissolved phosphorus in surface runoff (DP_r), kg/ha
c) particulate phosphorus in surface runoff (PP), kg/ha
d) dissolved P in deep percolate (DP_p), kg/ha

In addition, a series of nitrogen simulations for Finnish sites was undertaken for particulate N in soil loss (PN), dissolved nitrate and ammonia in surface runoff ($D(NO+NH)_r$), nitrate in percolation ($D(NO)_p$), denitrified N (denN) and ammonia volatilisation (volNH). However, the results of these as well the results for DP_p are not sufficiently reliable to be presented in detail and it was deemed more appropriate to apply expert judgement.

Model Simulations of Countermeasure Implementation

The six Countermeasure Scenarios simulated with the ICECREAM model are:

CM Scenario 1: deep ploughing (F, S)
CM Scenario 2: skim and burial ploughing (F, S)
CM Scenario 3: changes in the feeding of animals (F, S, A)
CM Scenario 4: cessation of production (F, S)
CM Scenario 5: pasture intensification (A)
CM Scenario 6: shallow ploughing of permanent grassland (A)

As explained in Salt *et al.* (1999b), the application of models widely used to simulate soil loss and nutrient transport processes is restricted to mineral soils. For Scotland, 5 of the 9 catchments have a large proportion of organic soils and modelling had to be restricted to the Ythan, Eden, Glenstang and Burn O'Need catchments. All simulations were performed over a 10 year period to mimic long-term impacts.

Countermeasure Scenario 1 and 2

To simulate the changes resulting from deep as well as skim and burial ploughing three separate soil databases were created: an original database describing the *status quo* and two databases describing the change in soil properties due to the ploughing. For deep ploughing the top 50 cm layer of the soil was inverted, leading to significant changes in a wide range of soil properties in the surface layer. The soil database for skim and burial ploughing showed only a minor change in the order of the layers, since only the top 5 cm are removed and placed at a depth of 50 cm (Roed *et al.*, 1996).

Countermeasure Scenario 3

This scenario involves a significant change in the diet of dairy cows to achieve a reduction in the daily intake of contaminated feed. The proportion of imported concentrate or home-grown barley in the diet is raised to 80% of the net energy intake from a typical level of 40% in Finland, 28% in Scotland and 15% in Austria. This increases the amount of N and P excreted by the cows in faeces.

For Finland, the impact on soil and nutrient losses was simulated, assuming that in each catchment 50% of the grass fields are converted to barley fields “as random as possible”. Simultaneously the P-fertilization on barley fields is increased by 20% and the N-fertilization by 25% compared to grass fields.

In the Austrian study sites monoculture over a longer time period is almost impossible (Quade, 1993) because of the climatic conditions, soil structure and current management practices. Thus three different crop rotations were simulated, involving conversion of permanent grassland to cereal production:

a) grass, grass, winter wheat (ww), winter rye (wr) or barley (b), spring oats (so), grass, grass, ww, wr or b, so (Pirklhuber & Gründlinger, 1993; Aubert, 1981).
b) as a) but with a trefoil mixture between winter and spring cereals
c) winter wheat or rye once in 10 years

For Scotland, changes in the diet of dairy cows, beef calves and lambs were studied for the Glenstang and Burn O’Need catchments. Scenario 3A assumes that all concentrate feed is imported. The area of mowing and grazing grass is reduced and a corresponding area of green fallow created. Scenario 3B assumes that all concentrate is provided through increased on-farm production of barley. Most grassland is converted to barley leaving only a small area fallow. The amount of N and P spread onto mowing grass via manure is increased by 27% and 20%, respectively. Beef calves receive a diet of uncontaminated roughage and concentrate during the last part of the fattening period in the same proportions as normal. To prevent lambs from grazing pasture on organic soils where radiocaesium transfer would be high, most lambs are moved from Burn O'Need to Glenstang for fattening. The resulting changes in the relative areas of grass and crops and the introduction of fallow areas were implemented in the GIS to enable net effects at the catchment level to be quantified.

Countermeasure Scenario 4

For Finland the effects of abandonment were studied, assuming cessation of dairy production and conversion to green fallow in Lestijoki. Milk production was transferred to Lepsämänjoki where the P- and N-fertilization was increased in accordance with the increase in animals, by +13 kg/ha/year for P and +34 kg/ha/year for N (as NH_4-N). Additionally all barley fields were converted to grass fields. For Scotland cessation of crop and animal production was assumed to occur in all 4 test catchments, replacing crops and improved grassland with green fallow.

Countermeasure Scenario 5

For the Austrian sites pasture intensification was simulated by applying mineral fertiliser, raising the annual P application from 20 (Radstadt) or 30 (Wallersee) kg/ha P to 50 kg/ha. Under normal management grasslands are assumed to receive only organic fertiliser (farm yard manure and slurry).

Countermeasure Scenario 6

For the Austrian study areas, shallow ploughing of normally uncultivated grassland to a depth of 25 cm was modelled by introducing tillage (ploughing, disking, harrowing, sowing), either 1,2,3 times over 10 years.

Finnish Results

The results are illustrated for the Yläneenjoki catchment; similar results were obtained for the other study areas. The soil type abbreviations are given in Table 12. If not mentioned separately, the results are presented for the most common soil types, silt loam (HHt) and clay loam (HtS), for the most common crop, barley, for a field slope of 1 % and an initial soil P-status of 10 mg/l. For each output variable only relative values are presented by setting the highest value in each graph to 100 % and the others in relation to this maximum.

Table 12: Finnish soil types based on an approximate conversion of the Finnish soil textural classes into the USDA classification.

Finnish	American	Finnish	American
Lj	organic silt (6-20 % organic matter)	KHs	silt
AS	heavy clay	He	silt loam
HsS	silty clay	HHt	silt loam
HeS	clay loam	KHt	sandy loam
HtS	clay loam	HHk	sand
HHs	silt loam	HtMr	sandy moraine

To illustrate the effect of soil type, results for all soils in Yläneenjoki are shown in Figures 4-6 (page 18). The two most frequent soils, HtS and HHt, have relatively low soil loss and consequently low PP loss (particulate P in surface runoff). Deep ploughing increases soil loss but can either decrease or increase PP loss. This depends on the degree of change in erosion relative to the initial P status of the subsoil brought to the surface. The marked increase in soil loss for HHt following deep ploughing is due to the low organic matter content of the subsoil (1%) compared to the original topsoil (12%). Deep ploughing decreases DP_r loss (dissolved P in surface runoff). In comparison to deep ploughing, skim and bury has only minor effects.

Crop type has a marked effect on all output variables (Figures 7-9, page 19). Mowing grass and green fallow have the lowest soil and PP losses due to their dense biomass. Grass has the highest DP_r loss due to the surface application of fertilizer. The effects of deep ploughing are similar for spring barley, winter wheat and sugarbeet. Bare fallow shows the highest PP losses and ploughing countermeasures have a negligible impact. DP_r increases after deep ploughing of grass as a result of soil and crop properties. The distinct difference between the PP and DP_r losses for spring barley and grass explains some of the effects seen in Scenario 3 where land use changes occur as a result of changes in animal feeding.

Soil loss and consequently PP loss increase with field slope (Figure 10, page 20). The coarser soil (HHt) shows higher losses of soil, PP and DP_r than the clayey HtS. Deep ploughing has no effect on soil loss for these two soils, however, the poor subsoil coming to the surface causes a drop in PP and DP_r losses. The difference in the original PP output between the soil types, caused by differences in erosivity, is diminished by deep ploughing. DP_r decreases slightly with increasing slope, most likely due to decreasing P content in the surface layer caused by the increased P loss via erosion.

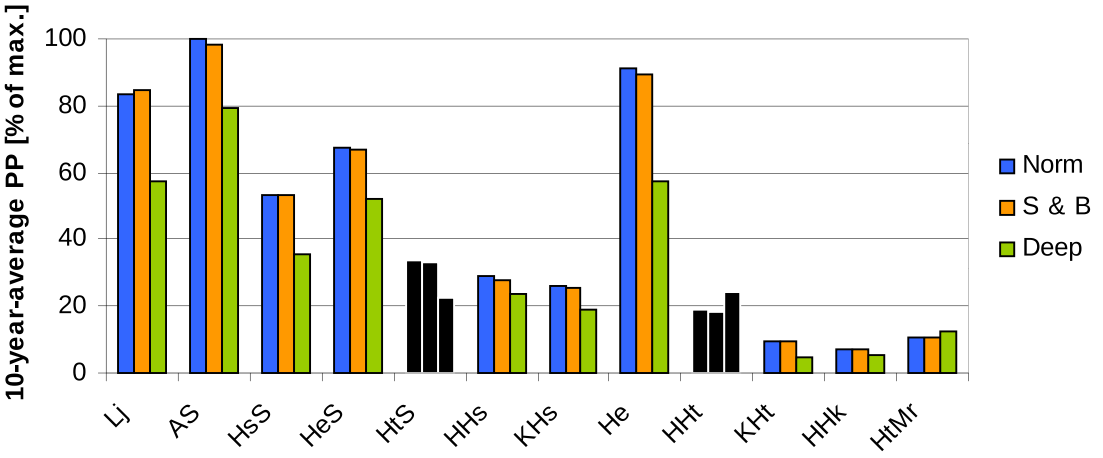


Figure 4. The effect of soil type on PP loss for normal practice (Norm), deep (Deep) and skim and burial ploughing (S&B). The most frequent soil types are marked in black.

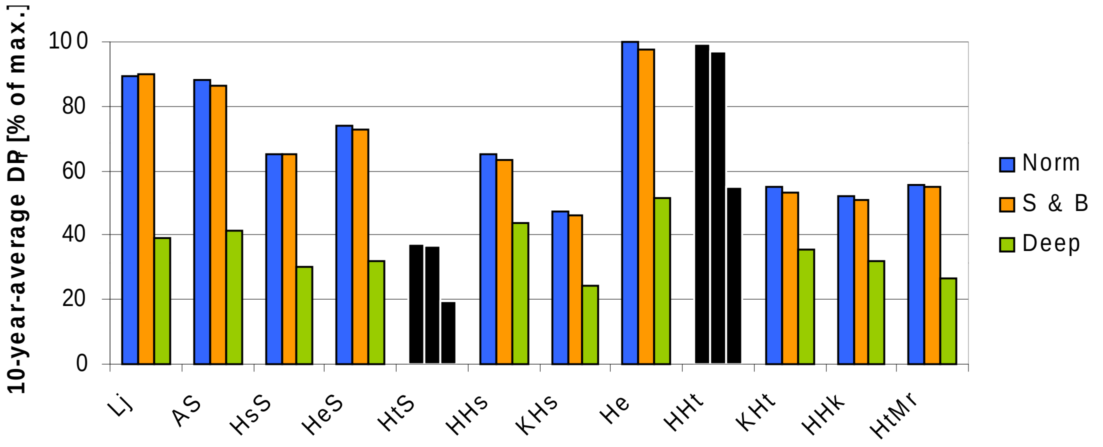


Figure 5. The effect of soil type on DP_r for normal practice (Norm), deep (Deep), and skim and burial ploughing (S&B). The most frequent soil types are marked in black.

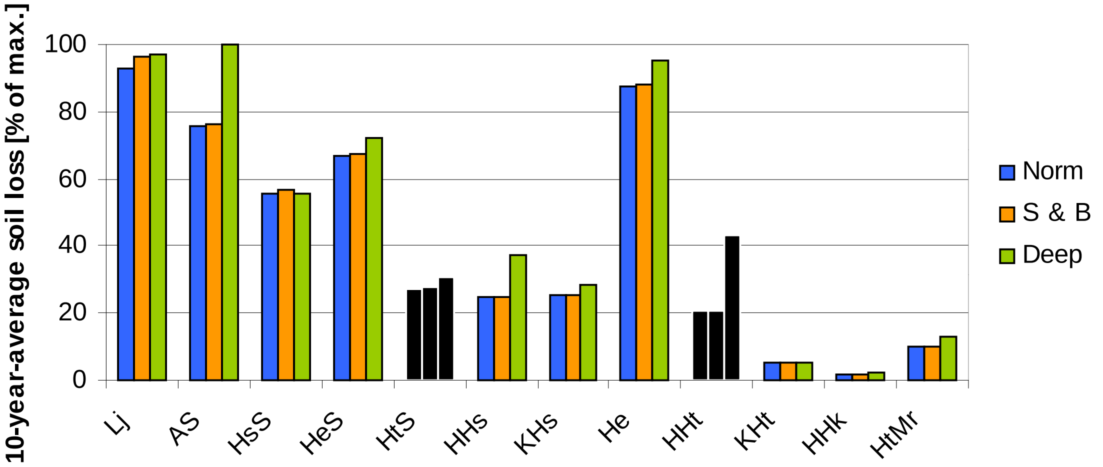


Figure 6. The effect of soil type on soil loss for normal practice (Norm), deep (Deep) and skim and burial ploughing (S&B). The most frequent soil types are marked in black.

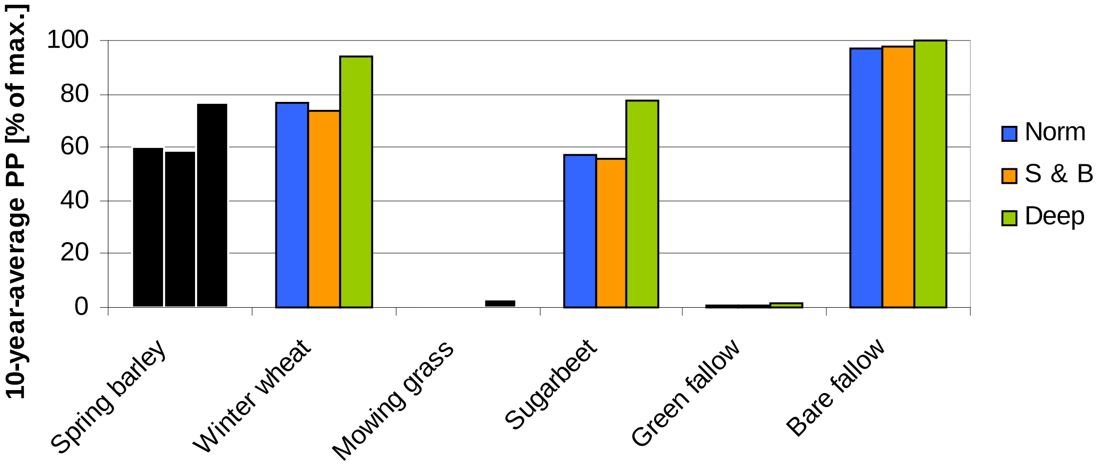


Figure 7. The effect of crop type on PP for normal practice (Norm), deep (Deep) and skim and burial ploughing(S&B). Typical crops are marked in black.

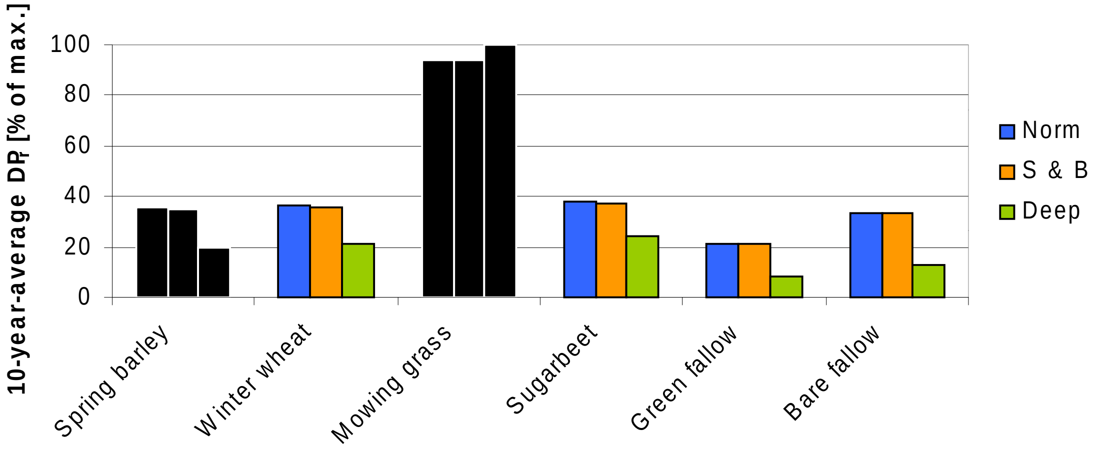


Figure 8. The effect of crop type on DP_r for normal practice (Norm), deep (Deep) and skim and burial ploughing (S & B). Typical crops are marked in black.

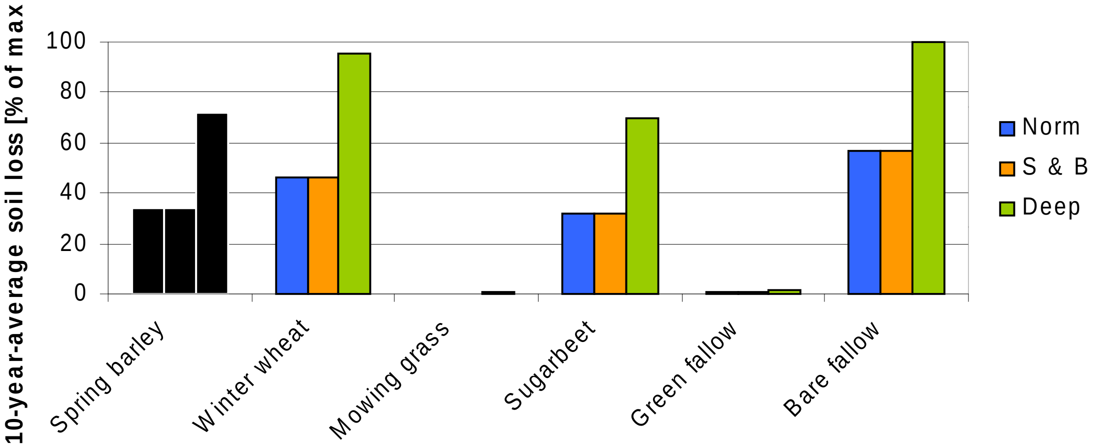


Figure 9. The effect of crop type on soil loss for normal practice (Norm), deep (Deep) and skim and burial ploughing (S&B). Typical crops are marked in black.

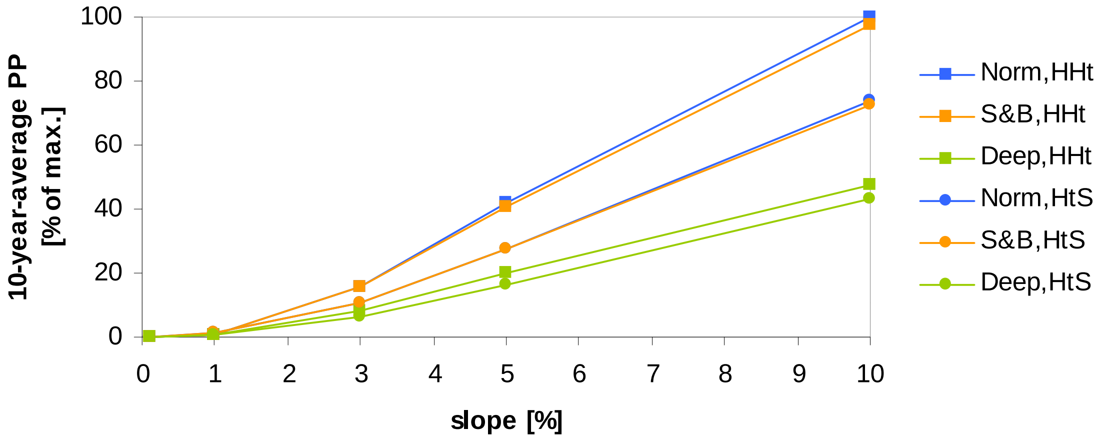


Figure 10 The effect of field slope on particulate phosphorus in surface runoff for normal practice (Norm), deep (Deep) and skim and burial ploughing (S & B).

Scottish Results

ICECREAM simulations were performed for the Ythan, Eden, Glenstang and Burn O'Need catchments to estimate the impacts of Countermeasure Scenarios 1-4 on erosion and phosphorus losses. Selected results are presented for a uniform slope of 6% equivalent to 3.4 degrees and expressed as relative values compared to the highest value in each graph.

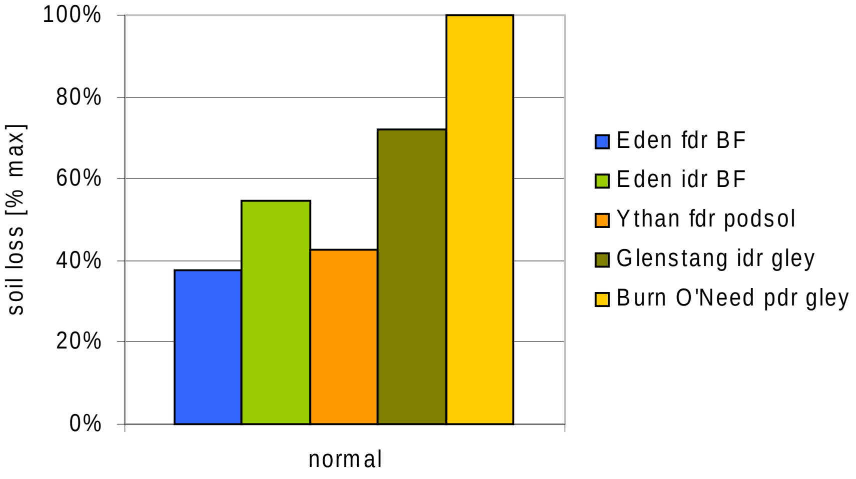


Figure 11. Soil loss on mowing grass at 6% slope on the dominant soil types of each catchment (fdr, idr, pdr = freely/imperfectly/poorly draining; BF = brown forest soil).

Differences in climate and soils lead to different rates of erosion across the catchments, as shown in Figure 11. The lowest rates are predicted for freely draining soils while imperfectly and poorly draining soils show higher rates of soil loss. The effects of crop type on soil loss are illustrated for the Ythan catchment in Figure12a (page 21) for the dominant soil type. The consistent difference between winter and summer sown crops is due to the exposure of partially bare soil to winter rainfall and snow melt. When crops are sown in autumn they grow insufficiently to cover the soil during winter. This applies in particular to winter wheat. The fine tilth produced before sowing erodes much more readily than a ploughed field or stubble (Evans & Cook, 1987; Speirs & Frost, 1985).

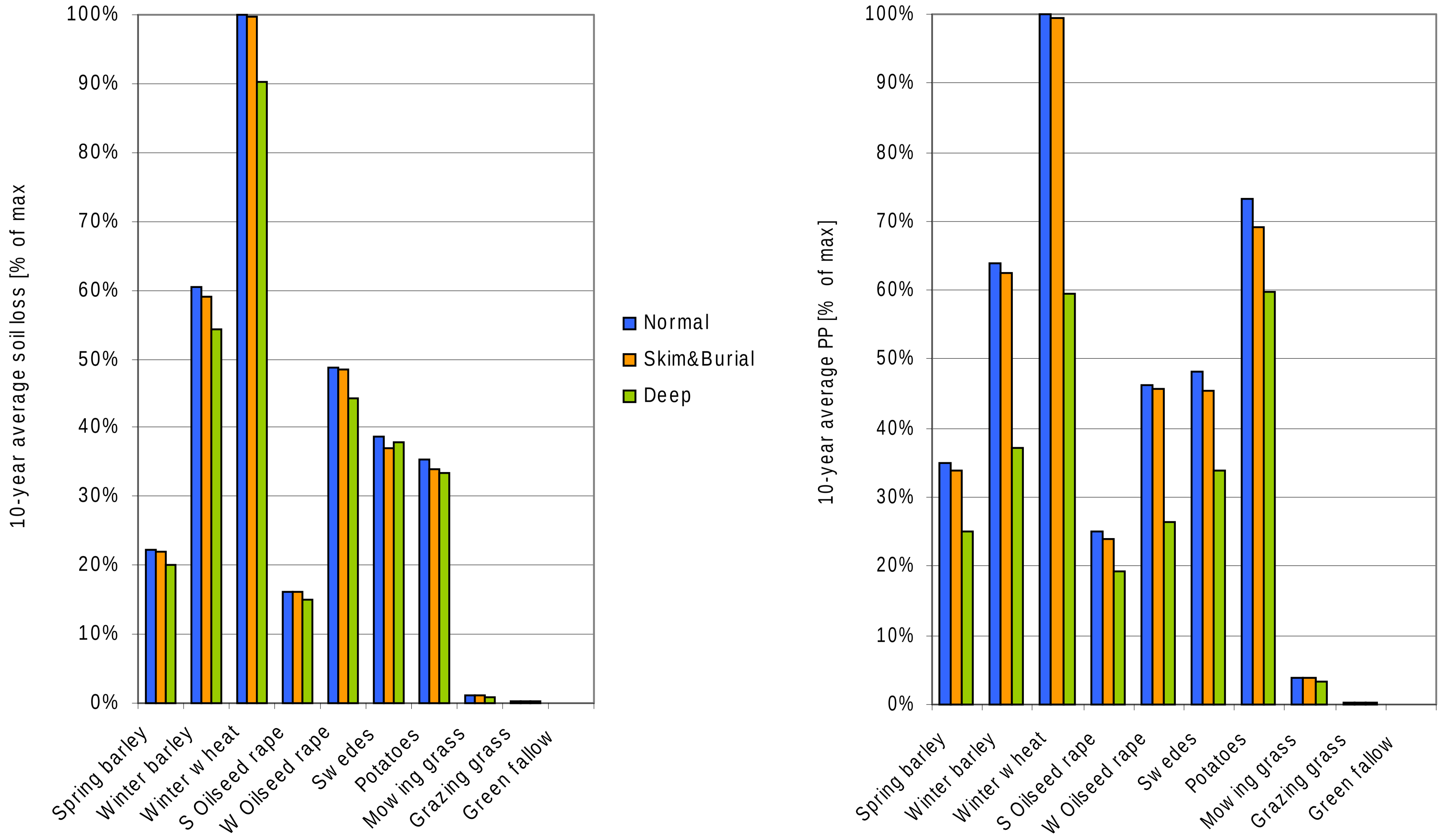


Figure 12. The effect of crop type on soil loss (a) and PP loss (b) for normal practice and after deep and skim and burial ploughing (6% slope; freely draining iron podsol) in the Ythan catchment.

Losses of PP are highest on winter wheat in line with soil loss (Figure 12b). Potatoes show comparatively high losses of PP since they receive the highest rates of P fertilization (150-200 kg/ha of P_2O_5). For the same reason losses of DP_r (not shown) are almost twice as high for potatoes compared to other arable crops. As shown in the Finnish results, soil loss and PP are very sensitive to slope, while DP_r varies little in response to slope.

In agreement with the Finnish results, deep ploughing of Scottish soils leads to much greater changes compared to skim and bury ploughing. In the Ythan catchment deep ploughing reduces the soil loss potential since subsoil with a higher sand and lower clay content is brought to the surface (Figure 12a). PP (Figure12b). and DP_r (not shown) are also reduced since the subsoil has a lower P status. Figure 13 shows how deep ploughing differentially affects the soils in the Eden catchment due to differences in the erodibility of the subsoil. Soil type also affects PP and DP_r losses due to differences in the depth distribution of labile and total phosphorus (not shown).

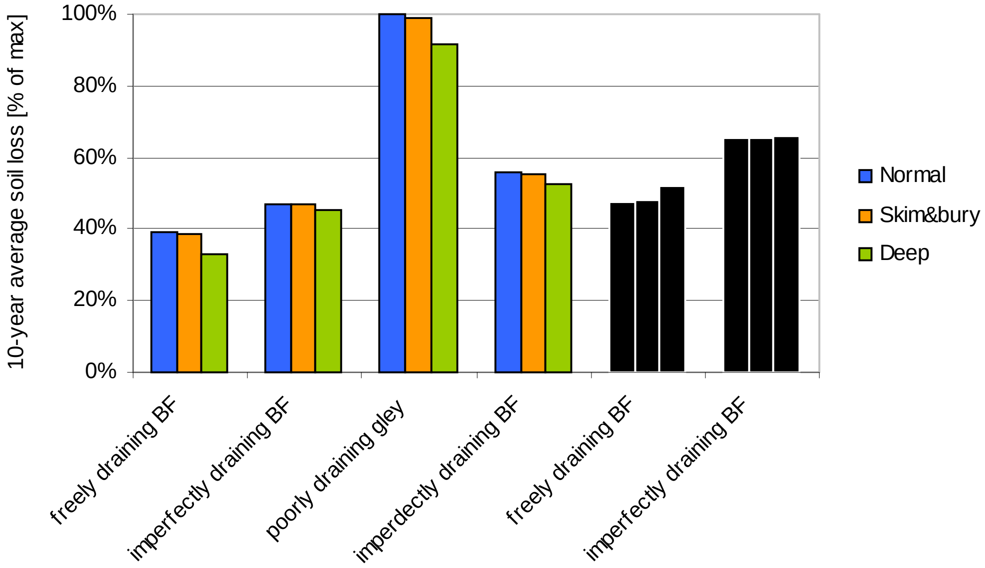


Figure 13. The effect of soil type on soil loss in the Eden catchment at 6% slope before and after ploughing countermeasures. Values are for all arable land using a weighted average of crop types including grass. The soils vary in texture from sandy loam to clay loam. The most frequent soil types are marked in black.

In the grass-dominated Glenstang catchment deep ploughing of the dominant soils increases soil loss on grazing grass, while on mowing grass soil loss only increases up to a slope of 4-5%. PP significantly decreases for mowing grass, while grazing grass shows a variable response depending on slope. Skim and bury ploughing causes very little change in soil loss. Results for PP and DP_r confirm this trend with the exception of grazing grass, which shows a 9 and 14% increase, respectively. Scientifically this is difficult to explain since the properties of the surface layer do not change. Tests carried out with the ICECREAM model suggest up to 10% error on the predictions for changes in soil and P losses after deep and skim and burial ploughing. This relates to the unexpected sensitivity of the model to changes in the depth distribution of soil layers in the input files which were necessary to simulate the soil profile changes after ploughing.

Only 13% of the grass-dominated Burn O'Need catchment has soils suitable for deep and for skim and burial ploughing. Although the same soil type is modelled as for Glenstang, some differences in the results occur. These appear to be due to different P inputs via faeces and manure as a result of differences in livestock densities. After deep ploughing PP and DP_r on grazing grass decreases. Changes following skim and bury are variable but small.

In Countermeasure Scenario 3 the feeding regime implemented for dairy cows and fattening cattle leads to an increase in phosphorus loadings via increased manure applications and faeces inputs to mowing grass and via extra faeces only to grazing grass. This is a combined effect of increased volume of manure due to higher concentrate feeding and fewer grass fields being available for manure disposal and grazing. Figure 14 illustrates the increases in DP_r and PP on the main soils in each catchment. At the field scale DP_r is increased by 75-84% on mowing grass and 34-64% on grazed grass. The effect on PP is slightly less with increases of 57-60% and 17-45%, respectively.

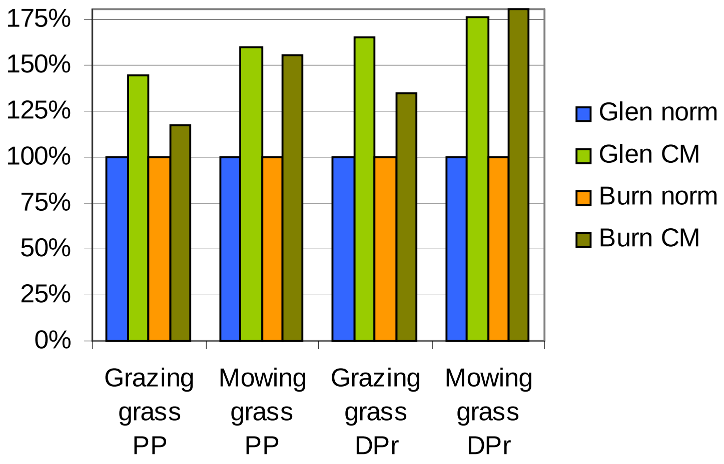


Figure 14. Changes in PP and DPr in the Glenstang and Burn O'Need catchments on the dominant soils for normal practice and after changes in the feeding of dairy cows and fattening cattle (norm=normal, CM=countermeasure). 'Normal values' are set to 100%.

Green fallow simulations for Countermeasure Scenario 4 showed low rates of soil loss, typically below those of grazed grass but slightly higher than on rough grazing land (Figure 12). Since no fertilisers are applied, DP_r and PP are also low.

Austrian Results

Model simulations for Countermeasure Scenarios 3, 5 and 6 were performed for the two study sites, Wallersee and Radstadt. In Scenario 3, the conversion of permanent grassland to rotational cereal production increased erosion rates 80 to 260 fold compared to grassland, depending on soil type and crop rotation. Crop rotation can be applied up to slopes of 2-4% without causing erosion rates that would result in permanent depletion of the soils (Auerswald & Schmid, 1986). Increased erosion and dissolved phosphorus in the runoff (DP_r) are the predominant side-effects. Significant reduction of erosion rates can be achieved, if a seed mixture of trefoil is used as a cover crop in autumn (Figure 15, page 24). The sowing of winter wheat or rye once in 10 years increases soil erosion 10 to 25 fold compared to grassland but this countermeasure is less effective in reducing radionuclide transfer.

Pasture intensification (Scenario 5) had no apparent effect on erosion, but influenced the nutrient cycle of the soils thereby potentially reducing water quality and biodiversity (Czerwinka, 1951; Meisel, 1977). These side-effects are more pronounced in the alpine test site of Radstadt, because of the extensive agricultural management (Figure 16, page 24).

Shallow ploughing (Scenario 6) was considered to be the most effective countermeasure even in alpine regions although suitable areas are limited due to shallow soils. This increases rates of erosion significantly (Figure 17, page 25) compared to permanent grassland which is the most sustainable form of agricultural use. If grass is planted immediately after shallow ploughing to minimise erosion, this method can be applied for steeper slopes up to 12° with restrictions. Depending on the frequency of ploughing, it is possible not to exceed the 5000 kg/ha*y erosion threshold which can be tolerated on arable land (Auerswald & Schmid, 1986; Schwertmann, 1981).

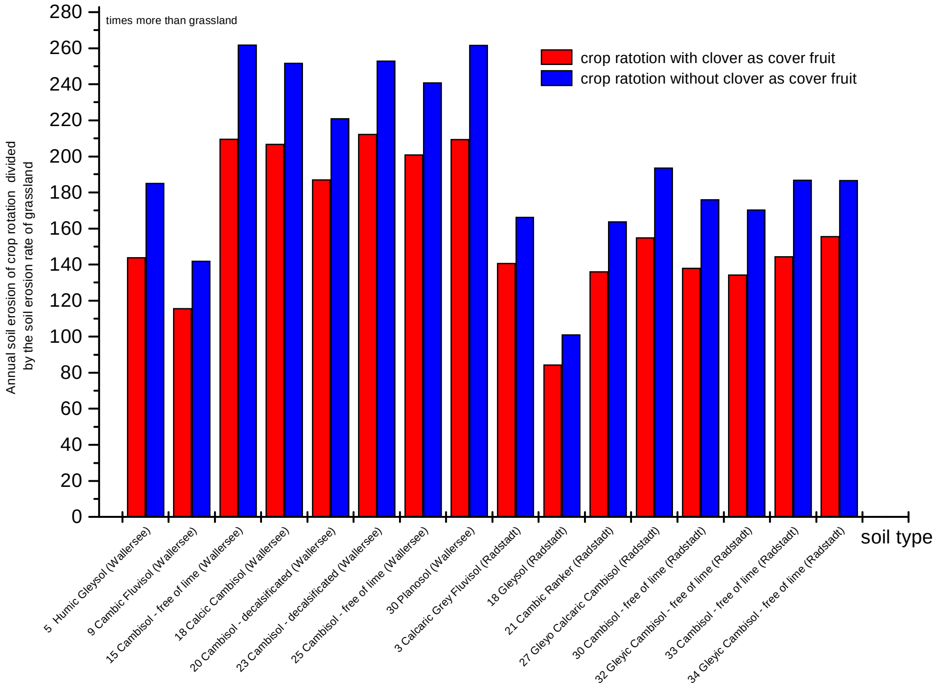


Figure 15. Change in soil loss after introduction of crop rotation on permanent grassland. Reference point: Normal use as grassland. Parameter: 3% slope.

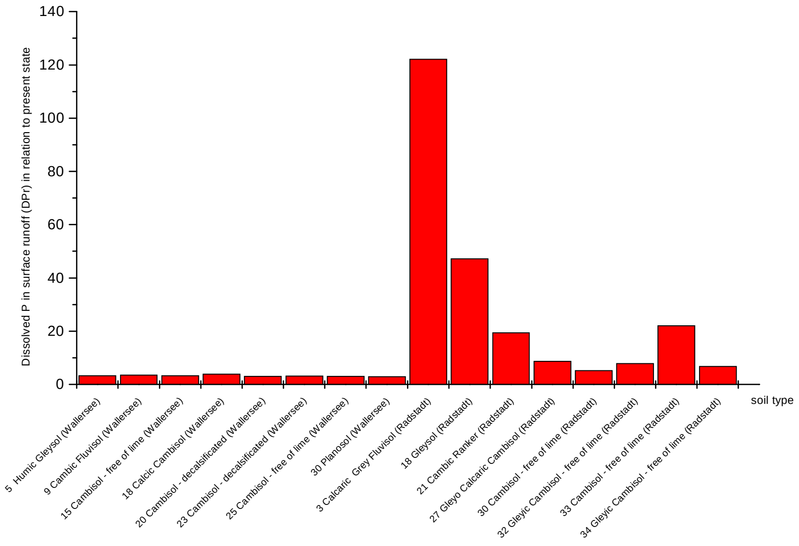


Figure 16. Effect of pasture intensification (raising the P application from 20 (Radstadt) or 30 (Wallersee) kg/ha*y P to 50 kg/ha.y) on dissolved P in surface runoff. Reference point: Normal use as grassland. Parameter: 5 % slope inclination.

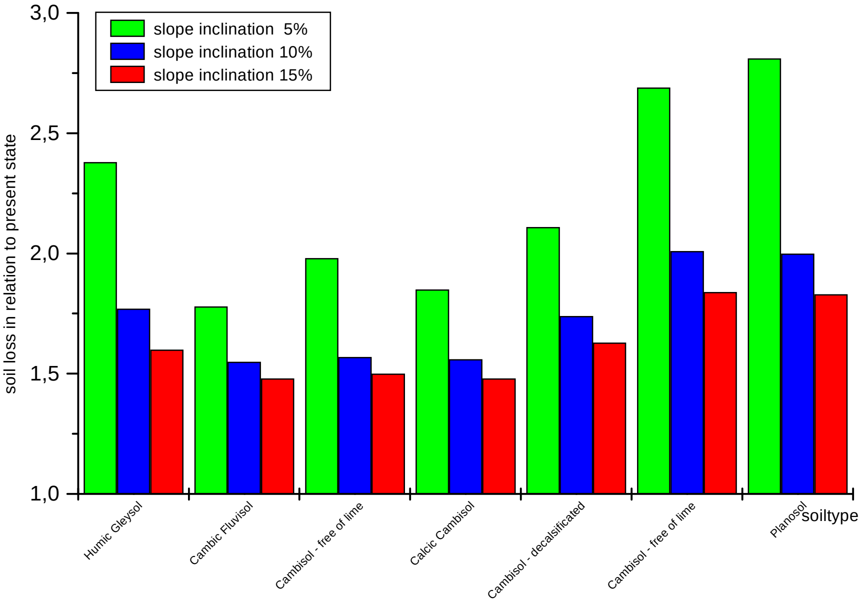


Figure 17. Effect of shallow ploughing (end of June) once in ten years on relative soil loss on grassland at the study site Wallersee.

<u>Summary of ICECREAM Modelling Results</u>

Deep ploughing has positive effects on water quality as it generally reduces nutrients inputs, but from a soil fertility perspective greater fertiliser inputs may be required to achieve good yields. Soil erosion may increase or decrease depending on the erosivity of the subsoil. Skim and bury ploughing, if feasible, has distinct advantages over deep ploughing as effects on soil and nutrient losses are small. An increased risk of erosion immediately after any ploughing countermeasure can be minimised by rapid establishment of vegetation cover. Losses of soil and nutrients in runoff can be mitigated by avoiding countermeasures on steeper slopes or introducing soil conservation tillage. When arable production is abandoned bare fallow should be strictly avoided.

More intensive use of pastures increases the risk of nutrients reaching water courses. Soil erosion may also increase where grassland is ploughed more frequently or land is overstocked. Increased feeding of concentrate to dairy cows locally increases the risk of phosphorus loss from grassland. The conversion of grassland to cereal production will increase soil erosion. When more than on management or land use change occurs at the same time the overall impact has to be studied at the catchment level (see Section 3.3.4.). Ceasing crop and animal production has many environmental benefits, as long as a good vegetation cover is maintained. However, if production is moved to other areas, these will experience negative side-effects due to agricultural intensification.

On the basis of ICECREAM simulation results, impact scores in the CESER Decision Support Systems for the criteria 'soil erosion and sedimentation' and 'nutrient transport to water' have been set (see Section 3.6.).

3.2.2. Calculating Ammonia Emissions

The degree of change in ammonia emissions was estimated for Countermeasure Scenarios 3 and 4 (see page 16) for Scotland and Finland using calculation methods developed for the respective countries (Pain *et al.*, 1997; Grönroos *et al.*,1998). The feeding of high levels of concentrate to dairy cows increases the total nitrogen excretion per animal by 25-27% (Wilkerson *et al.*, 1997). The emission rate of ammonia relative to the nitrogen content of manure was approx. 57% (Paul *et al.*, 1998). The results have been aggregated at the catchment and regional level (see Section 3.3.1.).

3.2.3. Modelling Nutrient and Trace Element Availability in Soils

The application of lime or potassium to soils as a countermeasure leads to significant changes in soil solution composition. This is mostly due to cation exchange reactions taking place on the soil particle surfaces (and subsequent precipitation/dissolution reactions). The type and extent of these changes depend on the initial solution composition, its pH value and the cation exchange capacity (CEC). The computer code PHREEQC (Parkhurst, 1982) has been used as a geochemical model to calculate speciation, ion exchange and reactions in the soil solution after application of chemical countermeasures. Evaluation of these data was based on the widely accepted assumption that root uptake by plants is directly related to changes in the ionic composition of the soil solution.

The calculations were performed with four different initial soil solution compositions taken from the literature (Kölling, 1992), corresponding to specific soil types and conditions (cambisol, podsol, aerated peat, waterlogged peat). For each soil type, the CEC and pH value were varied over a range typical for the Scottish study areas. The modelled substances were lime ($CaCO_3$, 2 t per ha), muriate of potash (KCl equivalent to 100 kg of K per ha) and a combination of both, assumed to be uniformly distributed in the soil, corresponding to a ploughing depth of 0.25 m and 0.50 m, respectively. This resulted in a set of 384 simulations from which the effects of these countermeasures were assessed. Each PHREEQC simulation was carried out in four steps:

1. speciation of the soil solution
2. equilibration with the soil exchanger
3. equilibration of the soil solution with $CaCO_3$ and/or KCl
4. equilibration with the exchanger from step 2

For the calculations, several assumptions were made, aimed at simulating the conditions a few weeks after application of the countermeasure:

- the soil is entirely saturated with water
- no transport or leaching processes are considered
- all sorptive processes are described by ion exchange
- CO_2 pressure is set to a minimum value ($pCO_2 = -2.0$, open system) which is allowed to rise when lime is dissolved under acid conditions
- except for the anoxic case, the soil is well aerated (high pe value)
- dissolution of soil minerals is not taken into account
- certain minerals (mostly alkaline earth carbonates and amorphous hydroxides) are allowed to precipitate thus limiting the solubility of cations

In this study, attention was focused on Mg as a nutrient and Cd as a toxic trace metal. Plant availability is governed by the concentration ratio Mg^{2+}/Ca^{2+} and by the concentration of free Cd^{2+} in the soil solution. The relative change in these ratios after the application of countermeasures was assessed. In addition the relative change of Sr^{2+}/Ca^{2+} and Cs^{+}/K^{+} was recorded as an indicator of the effectiveness of the countermeasures.

The cation concentrations generally increased after liming or KCl application due to competitive effects on the exchanger surface. This effect was greater at a ploughing depth of 0.25 m (which is assumed in the following discussion) and at higher CEC. After liming, the relative change in Cd^{2+} decreased with the initial concentration of Ca^{2+} (Fig. 18, page 27) and rose with the initial pH value. At low initial Ca^{2+} concentrations, few Ca^{2+} ions are bound to the soil particles and relative concentration changes of other ions, e.g. Cd^{2+} are high. At low pH values, the initial Cd^{2+} concentration on the exchanger surface is low and the concentration change in solution tends to rise with pH. In anoxic peat, the initial Ca^{2+} concentration is so high that less $CaCO_3$ is dissolved at high pH; therefore, the relative change in Cd^{2+} is comparatively low. In the cambisol the pH may rise above 7, precipitating otavite ($CdCO_3$) and thus reducing the relative change in Cd^{2+}. The change in $Mg^{2+}/$ Ca^{2+} in solution is less pronounced with a minimum of approx. 0.6 at low pH values. This is almost equal to the change of Sr^{2+}/ Ca^{2+} which reflects the effectiveness of liming.

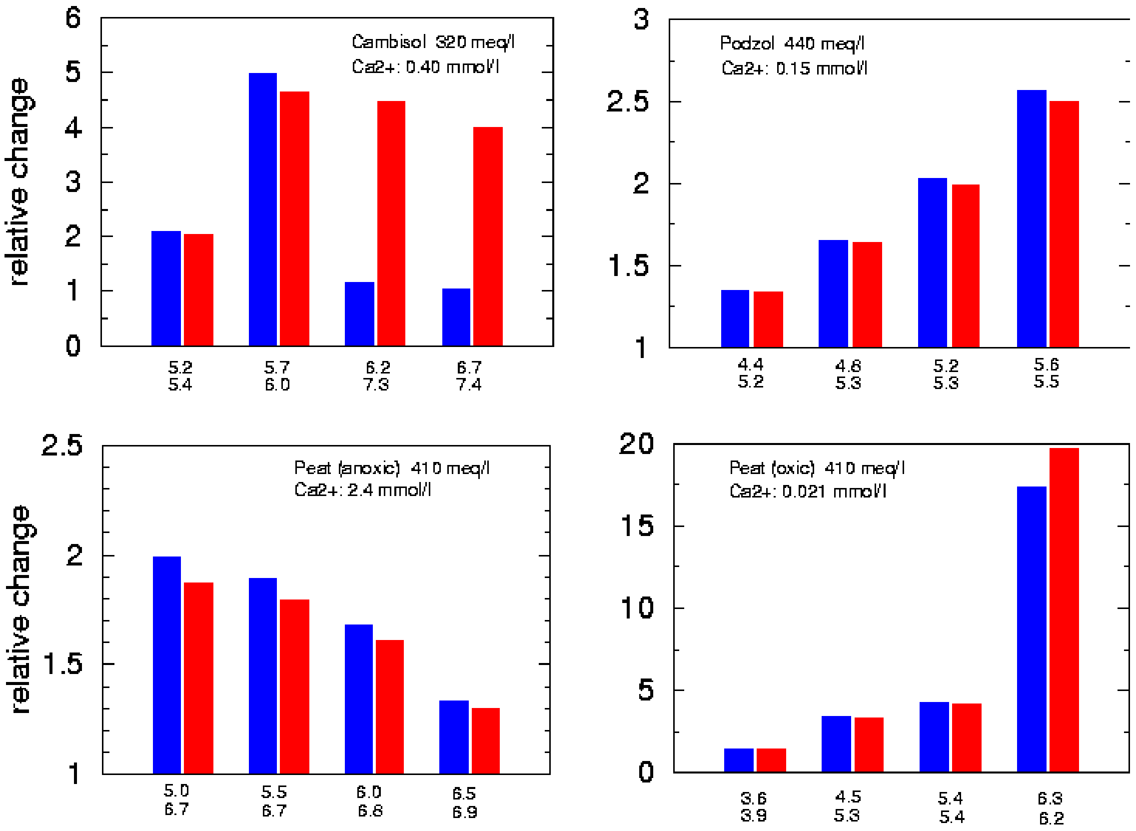


Figure 18. Relative change in total Cd (blue) and Mg^{2+}(red) in solution after liming; the numbers on the abscissa denote the pH before (upper values) and after liming (lower values).

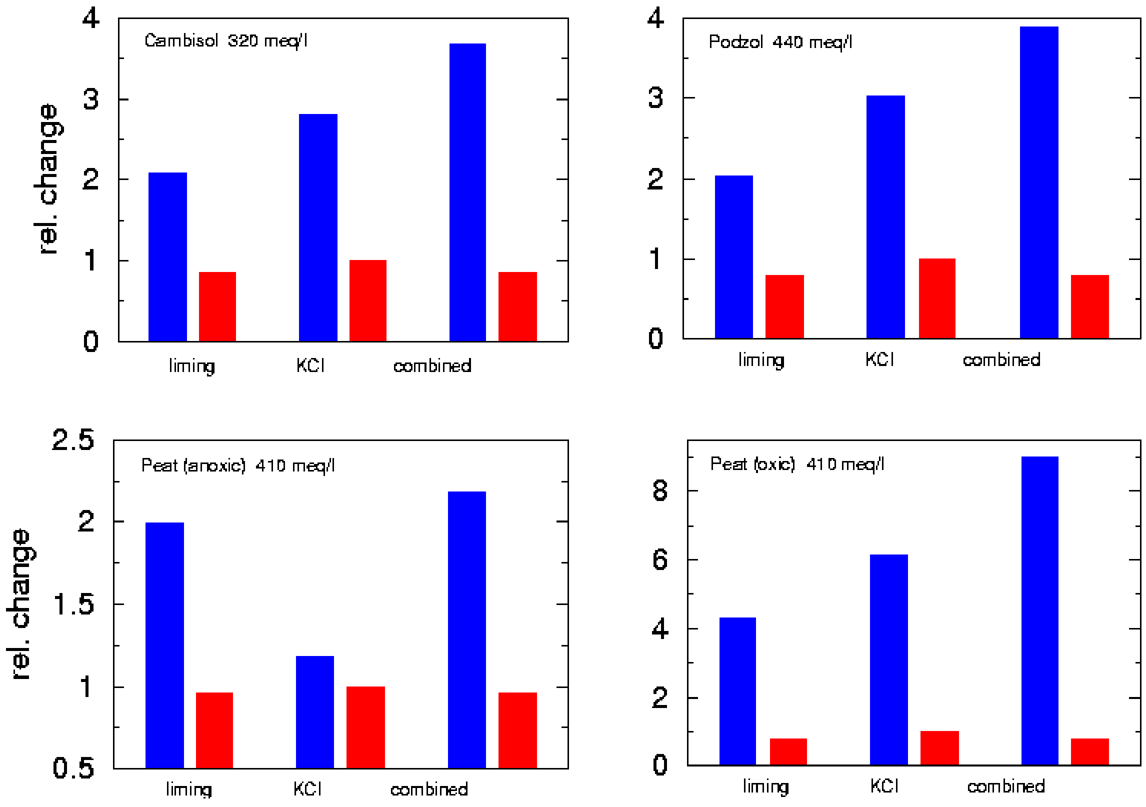


Figure 19. Comparison of the relative change of total Cd (blue) and Mg^{2+}/Ca^{2+}(red) after liming (left), KCl application (middle) and combined application (right).

As with liming, KCl application increases concentrations of cations in soil solution due to exchange reactions. It tends to acidify the soil and about 10% of the Cd in solution is complexed as $[CdCl]^+$ due to the addition of chloride anions. The Mg^{2+}/Ca^{2+} ratio is almost unaffected, but higher effectiveness (lower Cs^+/K^+ ratio) is coupled with an increase in Cd^{2+} available for plant root uptake. Figure 19 (page 27) shows a comparison of liming, KCl and of the combined application of both countermeasures, the latter having the most pronounced effect on the cadmium concentration.

In summary, two major side effects of liming and K application have been identified through PHREEQC simulations. Firstly, the concentration of Cd^{2+} in solution increases. The magnitude of this effect depends on initial soil solution composition, pH and CEC and it may be smaller if the soil contains substances which effectively immobilize the Cd ions. Secondly, liming decreases the Mg^{2+}/Ca^{2+} ratio in the soil solution, thus leading to a lower magnesium supply to plants. PHREEQC results were used in the CESER Decision Support Systems (see Section 3.6.) to set soil suitability thresholds for lime and K application and assign impact scores for the criteria 'soil pollutant transport to water' and 'soil nutrient transport to water'.

3.2.4. AFCF Degradation Experiments

The risk of cyanide release during the degradation of AFCF was investigated to assess the potential occupational exposure of humans. AFCF may degrade to NH_4^+, $Fe(CN)_6^{4-}$, and Fe^{3+} . The $Fe(CN)_6^{4-}$ anion can undergo further degradation to Fe^{2+} and CN^-, which can form hydrocyanide (HCN), a very poisonous gas (boiling point: 26.7°C), readily absorbed when inhaled and lethal in very small doses (Rumack & Lovejoy, 1991). Maximum permissible levels at the workplace are regulated under national and EU-regulations. (Austrian regulation: 10 ppm at the workplace; MAK 1994).

For the experiments a metal container (Volume: 25 l, diameter 26 cm) with a UV transparent quartz-glass window in it's lid was used to allow light penetration without UV loss (Figure 20). The light source was a lamp **(**metal-halogen bulb, 125 Watt**)** with a spectral distribution similar to normal daylight. Openings were made into the container to mount temperature, relative humidity and HCN sensors. HCN production was measured with a factory calibrated sensor (Compur Statox-S/501, sensitivity: 0 – 100ppm). AFCF (Riedel de Haen, 30-35 weight % NH_4Cl impurity) was finely ground and either homogeneously distributed on a paper surface (0.36, 0.61 and 0.96g) or mixed with liquid manure. The AFCF-manure mixture was subjected to normal and elevated humidity (rH=80%). The temperature in the chamber was at least 4 °C above the boiling point of 26.7°C for HCN.

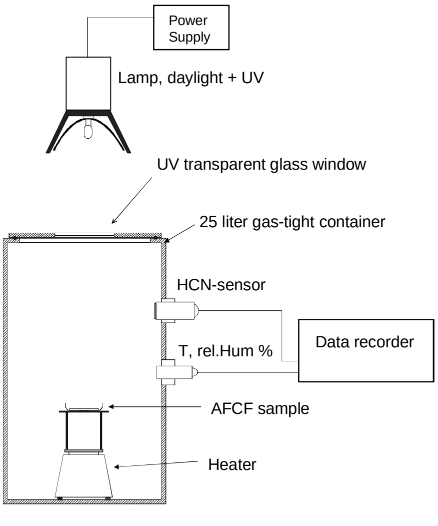


Figure 20. Experimental set-up for AFCF degradation experiments

Due to the light sensitivity and opaqueness of AFCF, the release of HCN is likely to be related to the area exposed to light. Figure 21 shows that the dependency on mass was small. When AFCF was mixed with manure and dried the HCN release was greater than for the pure substance. However, the wet mixture had a lower release of HCN compared to the pure substance. The release followed an exponential function, reaching saturation after 3-10 hours (Figure 21). Through curve fitting the following saturation concentrations in the container were derived: 11-17 $\mathrm{ppm_{HCN}/g_{AFCF}}$, for the pure substance, and 15-42 $\mathrm{ppm_{HCN}/g_{AFCF}}$ for the mixture AFCF + liquid manure, depending on the amount of AFCF used. High humidity lowered the release of HCN significantly. Under dark conditions no HCN release was detectable but additional tests at an elevated temperature of 47°C showed thermal degradation of AFCF and release of HCN in the absence of light.

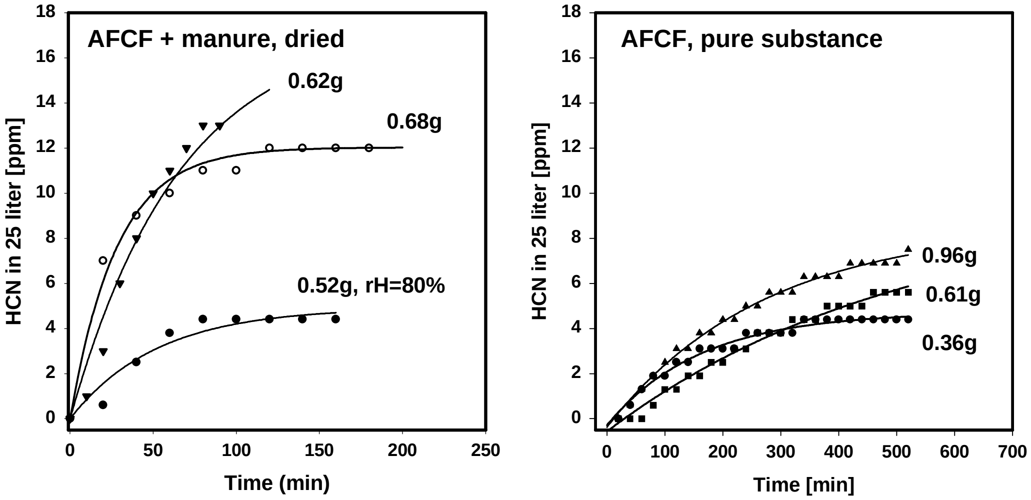


Figure 21. HCN gas production as a function of time for different experimental conditions in a 25 l vessel.

It is very unlikely that under natural conditions the maximum permissible levels of HCN in the atmosphere would be exceeded during spreading of manure with AFCF on the land. This is due to the dilution of HCN in the open atmosphere. However, the experiments have proved that HCN release from AFCF occurs and should be considered when using AFCF as a countermeasure.

3.2.5. Experiments on the Mobility of FCF-bound ^{134}Cs in Soil

Laboratory experiments to assess the mobility of CsFCF complexes have been carried out on three soil types typical for alpine regions of Austria. Specifically designed columns were constructed and filled with three types of soil: peaty, loamy and sandy soil. The columns were treated with manure and either AFCF bound ^{134}Cs or ^{134}CsCl. Then they were exposed to different light conditions in order to simulate different levels of UV irradiation and to investigate the influence of light on the degradation and mobility of CsFCF. The soil columns were watered over a period of 4 to 6 months with an amount of water equivalent to approx. half of the annual precipitation in Austrian alpine regions. Following the watering period the depth distribution of radiocaesium was determined in all soil columns.

For all soil types and all treatments the downward migration of ^{134}Cs was very slow, with 90% and 95% of the ^{134}Cs on the peaty soil and on sandy and loamy soils respectively remaining in the top 1.5 cm. Figure 22 (page 30) shows the depth distribution in the loamy and sandy soils, with very similar curves for both soil types and little difference between ^{134}CsCl and ^{134}CsFCF (not shown). However, for the peaty soils the difference in the depth distributions of ^{134}CsCl and ^{134}CsFCF treated columns was pronounced. The migration rate for CsCl was significantly lower than for CsFCF. In all soil columns the depth distribution can be described by an exponential decrease of the activity concentration in the upper layers ($d(\log_{act})/dz$ = constant) with a breakpoint between 2 and 5 cm followed by another exponential but more gradual decrease depending on the soil type. In the peaty soil the second exponential is almost flat and the activity concentration tends to reach a constant value (Figure 22). The smaller decrease in the deeper layers in the loamy and sandy soil and the plateau in the peaty soil indicate increased mobility of only a small fraction of the radiocaesium. No apparent variations could be observed between columns exposed to light, to light plus UV and to darkness.

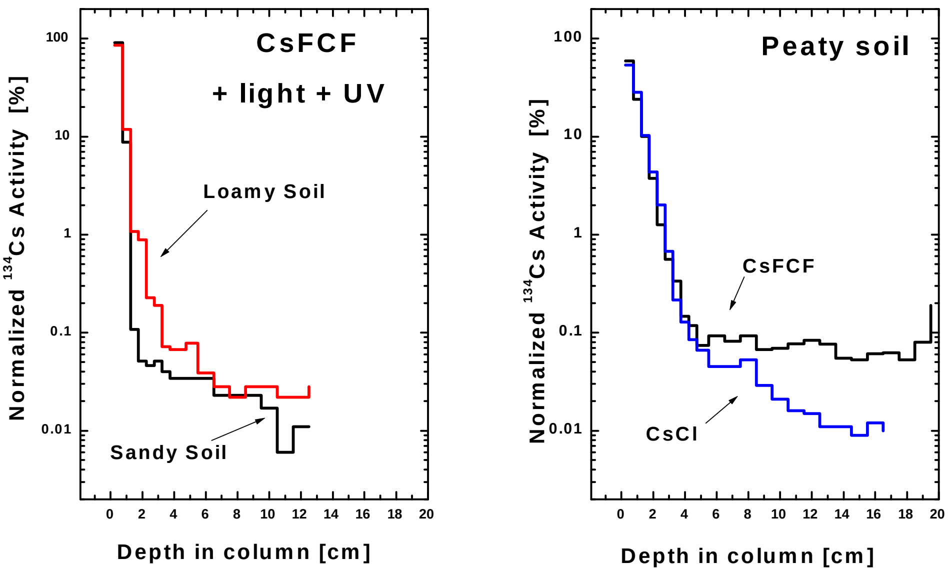


Figure 22. Selected examples of the depth distribution for ^{134}Cs activity measured in soil column experiments.

The results indicate a potential risk of enhanced mobility of FCF-bound radiocaesium in peaty soils after soil application of manure from AFCF-treated livestock. This has been incorporated into the CESER Decision Support System.

3.2.6. Fulvic Acid Transport Experiments

Countermeasures involving ploughing, liming and fertilisation are likely to increase the mineralisation of soil organic matter. As a consequence, nutrients and toxic trace substances may be mobilized, since soluble organic matter (preferentially the fulvic acid fraction) may increase the concentration of metals in soil solution far above concentrations of the ionic species due to its potential to form water soluble metal organic complexes. This effect may be especially important for sandy soils abundant in Northern Central Europe and Southern Scandinavia, because their organic matter plays an important role in sorbing and mobilizing nutrients as well as contaminants. Since knowledge on the transport of fulvic acids in soils is still very limited, it was decided to perform laboratory experiments, studying both diffusive and convective transport for a podsol soil.

Fulvic acids were isolated from a commercial sodium humate (Aldrich Chemical Company) using a standard procedure recommended by the International Humic Substances Society and were labeled with ^{241}Am. For the diffusion experiments, a through-diffusion technique was used (Kirchner *et al.*, 1993). The labelled fulvic acids diffused from a reservoir cell through the soil pellet into a measurement cell. Dimensions of the soil pellet were 2.5 cm^2 x 0.5 cm. A second set of experiments was performed using a recently developed diffusion-convection technique (Brünjes et. al, in press). During the experiments the level of the solution in the reservoir cell was held higher than in the measurement cell, thus causing a convective flow through the soil pellet. The fulvic acid complexes in the reservoir were substituted by distilled water after 17 days. Prior to the experiments with fulvic acid complexes, the homogeneity of the soil pellets (1 cm length) was controlled by recording the break-through curve of HTO. Evaluation of the experimental data was performed using methodologies described elsewhere (Kirchner *et al.,* 1993; Brünjes *et al.,* in press).

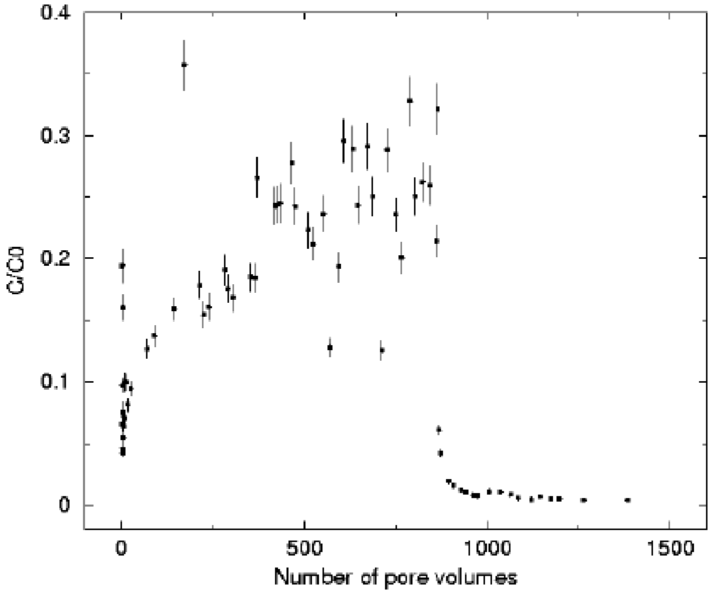


Figure 23. Concentrations c(t) of fulvic acid molecules in the effluent normalized to its concentration C0 in the reservoir. Data are given as function of the number of pore volumes of fluid passed through the soil pellet.

The diffusion experiment with tracered fulvic acids was stopped after 17 days, since no ^{241}Am could be detected in the measurement cell. From the detection limits of the gamma-spectrometric ^{241}Am measurements, an effective diffusion coefficient of fulvic acids in the podsol soil of $< 1.07\ 10^{-8}$ cm^2 s^{-1} was calculated corresponding to a mean displacement of the fulvic acid molecules by diffusion of < 8.3 mm per year. This illustrates that the transport potential of organic degradation products by diffusion in soil moisture is low in the podsol studied.

Activity concentrations of ^{241}Am passed through the podsol during the convection experiment with ^{241}Am-labeled fulvic acids are given in Figure 23. as a function of the solution volume passed through the soil pellet. Four phases can be identified from these data: *Phase1* - an initial sharp increase of ^{241}Am in the measurement cell which shows that a fulvic acid fraction of ca. 10 % moves through the soil pellet with almost no retardation. *Phase 2* - during which the concentration of fulvic acids in the effluent slowly increases until an equilibrium concentration is reached. This time dependency indicates that some 10-15 % of the fulvic acids are retarded by their passage through the soil. From Figure 23 a retardation factor of ca. 200 can be estimated. *Phase 3* -, fulvic acid concentrations in the effluent are quite constant with time - although some scattering is apparent from the experimental data. At equilibrium, about 25 % of the fulvic acid complexes have passed through the soil, whereas 75 % become immobilized within the soil. *Phase 4* - characterized by a fast decrease of fulvic acid concentrations in the effluent after flushing of the soil with pure water was started. This confirms that the fulvic acids retained in the soil are not readily remobilized.

These results demonstrate the influence of the flow regime in soils on the transport potential of these macromulecules as carriers for nutrient and toxic trace substances. The transport potential of the fulvic acids is very low as long as movement of solutes is dominated by diffusion within the soil solution, but it becomes high if solute transport in soils is mainly by convection. The fulvic acid recovery of 25 % which was observed in our experiments shows that in sandy soils trace substances complexed with fulvic acids may be much more mobile than the ionic species. The results have implications for remediation of soils where convective flow is likely to occur, e.g. sandy and some peaty soils. Countermeasures such as ploughing or liming which have the potential to enhance mineralisation of organic matter could thereby mobilize nutrients and pollutants bound to fulvic acids, making them vulnerable to leaching.

3.2.7. Mycorrhiza Experiments

Mycorrhiza represents a mutualistic symbiosis (non-pathogenic association) between soil-borne fungi and roots of higher plants. The most widely distributed type of mycorrhiza is the vesicular-arbuscular mycorrhiza (VAM), a form of endomycorrhiza. Despite the notion that mycorrhizal infection affects the mineral nutrition of plants, remarkably little research has been carried out on the effect of VAM infection on plant uptake of radionuclides; only a very limited number of species of both mycorrhizal fungi and host plants has been investigated in this respect. So far, the results of these investigations are controversial; some mycorrhizal species may enhance the uptake of radiocesium, whereas other species appear to decrease the radiocesium content in plants.

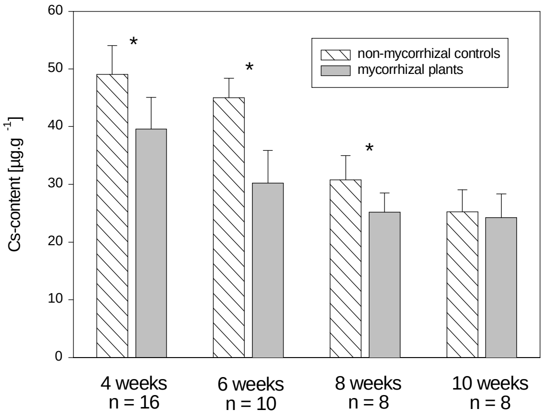
Basic knowledge of the uptake mechanisms is a pre-requisite for the design of specific countermeasures. In the present study pot experiments were carried out with a common grass species to determine the species specific uptake of (radio)caesium by mycorrhizal and non-mycorrhizal plants and possible side -effects of K application on VAM infection development, and uptake of caesium and nutrients.

VAM infection by the fungus *Glomus mosseae* led to a decrease in stable caesium content of *Agrostis tenuis* from the first to the third harvest. The difference in caesium content of mycorrhizal and non-mycorrhizal plants is highly significant (Figure 24, page 33). The results of this experiment agree with an earlier study with radioactive ^{137}Cs (Haselwandter & Berreck, 1994). The experiments with stable and with radioactive caesium demonstrated that VAM-infection can decrease caesium uptake under moderate nutrient levels. One explanation is that Cs may be sequestered by the hyphae (fungal biomass) and is not transferred to the plant to the same extent as in non-colonized roots. So far nothing is known about a caesium filter mechanism and results of investigations are not always consistent when different plant and fungal species are compared. Rogers and Williams (1986) found a marked increase in ^{137}Cs uptake in VAM-infected *Melilotus officinalis* , but no additional ^{60}Co accumulation, whereas in the grass *Sorgum sudanense* the contrary was true.

In the experiment with stable Cs- and K application, additional potassium led to a significant decrease in caesium uptake of both mycorrhizal and non-mycorrhizal plants (*Agrostis tenuis*) over a growth period of 10 weeks (Fig.24 & Fig.25, page 33). Potassium fertilised non-mycorrhizal plants contained 56 to 78% of the Cs-concentration of the non-fertilised plants, whereas in the case of mycorrhizal plants potassium fertilisation was less efficient in reducing the caesium uptake by *Agrostis tenuis*. Fertilised mycorrhizal plants contained 61 to 78% of the Cs concentration of the non-fertilised mycorrhizal plants.

In general, the potassium application resulted in a higher potassium content of the plants. Negative side-effects of potassium fertilisation as a countermeasure for Cs-uptake could not be observed with regard to VAM infection of the host plants. VAM infection intensity with *Glomus mosseae* was only slightly, but not significantly depressed by the potassium treatment.

An antagonism in ion uptake is known to exist between K^+, Na^+, Ca^{2+}, Mg^{+2} and NH_4^+ (Ehrenberg, cf Amberger, 1983). This also seems to be applicable to Cs^+ (Fig. 24 & 25). In our experiment the K application had strong effects on the Ca uptake but only slight effects on Na uptake. Potassium fertilised plants contained 55 to 26% of the Ca concentration of the non-fertilised plants.



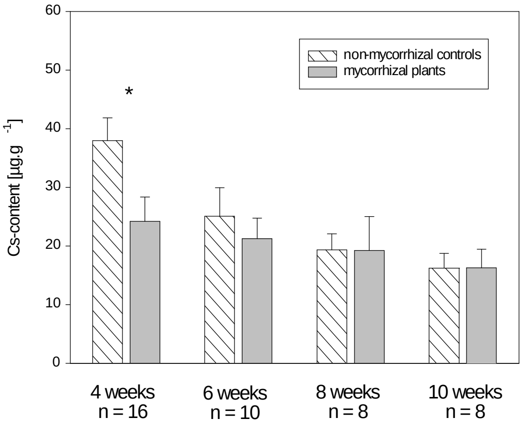


Figure 24. Cs content of the shoot system of mycorrhizal and non-mycorrhizal *Agrostis tenuis* after 4, 6, 8 and 10 weeks. * indicates that mycorrhizal and control means are significantly different at the 5% level.

Figure 25. Cs content of the shoot system of mycorrhizal and non-mycorrhizal *Agrostis tenuis* 4, 6, 8 and 10 weeks after application of potassium (196,3 µg g^{-1}; =100 kg potassium/ha).

3.2.8. Expert Judgement

Expert judgement was applied where it was not possible to quantify side-effects through modelling, experimental work or other techniques. The main constraints on full impact quantification were:

a) difficulties in expressing many impacts, e.g. biodiversity, product quality, landscape quality or animal welfare, on a numerical scale
b) lack of suitable models to predict changes, e.g. for organic matter and product quantity
c) limited understanding of the extent of some impacts, e.g. effects on greenhouse gases
d) time scale of the project.

Despite these limitations it was possible to predict the direction and relative magnitude of change using the impact scale shown in Figure 26. To assess the performance of all selected countermeasures within a Decision Support System (see Section 3.6.) it was necessary to score all countermeasures on the same impact scale. This was done for the Scottish agricultural production systems in an exercise involving all group members as well as through consultation with experts outside the group. The process went through several iterations to optimise the relative scale of impact within countermeasures across impact categories and within impact categories across countermeasures. Salt *et al.* (1999a) gives descriptions of the side-effects of each of the countermeasures assessed.

Greatly Decrease	**Moderately Decrease**	**Slightly Decrease**	**No Change**	**Slightly Increase**	**Moderately Increase**	**Greatly Increase**
- 1	**- 2/3**	**- 1/3**	**0**	**+ 1/3**	**+ 2/3**	**+ 1**

Figure 26. Relative impact scores.

3.3. Upscaling Side-Effects to Catchment, Regional and National Level

The results obtained in quantifying countermeasure side-effects have demonstrated that some impacts will vary greatly in relation to environmental and management parameters, e.g. the extent of soil erosion following deep ploughing is influenced by slope, soil and crop type as well as agricultural management. To map the spatially variable risk, e.g. of soil erosion following deep ploughing, the ICECREAM modelling results for each catchment have to be combined with the topography, soil and land use data to create impact maps using GIS techniques.

However, the mapping of impacts has to be preceded by the identification of areas suitable for each countermeasure. Therefore the limits of countermeasure application were defined in terms of environmental and agricultural conditions as illustrated for Scotland in Tables 13 & 14. In the GIS these limits are used to 'mask out' cells within each catchment that are unsuitable for a particular remediation technique. Examples of suitability maps are shown in Section 3.6.3. For the suitable areas, impact maps can then be created for each combination of countermeasure and assessment criterion. These maps form the basis of the countermeasure evaluation process in the Spatial Decision Support System (Section 3.6.3.).

In order to derive the net impact of a countermeasure over a whole catchment and to enable between catchment comparisons, the changes in soil and phosphorus losses for each grid cell in a catchment were summed over all cells treated with the countermeasure. This provides catchment inventories of change and also enables average rates of soil and nutrient loss across the treated areas of each catchment to be calculated. For ammonia emissions a mixture of maps and inventories are presented covering the catchment, regional and national scales.

Table 13. Limitations to countermeasures involving ploughing and land use change in Scotland.

Parameter	**Shallow ploughing**	**Deep ploughing**	**Skim & Bury**	**Improve pasture**	**Convert grass to barley**	**Afforestation ***
Slope	15 degrees	15 degrees	15 degrees	15 degrees	11 degrees	25 degrees
Soil depth	> 30 cm	> 60 cm	> 60 cm	> 30 cm	> 30 cm	> 30 cm
Stoniness to plough depth	< 35% by volume (moderately stony)					--
Depth of peaty surface layer	--	--	--	< 20 cm	--	--
Soil wetness class	class I, II, III suitable (soil profile should lack gley features or an impermeable horizon within 40 cm depth) class IV, V, VI not suitable					--
Soil drainage status	Excessive, free, imperfect – suitable; Poor, very poor – not suitable					
Altitude	--	--	--	--	220 m	--
Land Capability Class	--	--	--	--	4.1 or better	--

*It was outside the scope of the project to include an assessment of windthrow hazard. Special software is being developed for this purpose by the Forestry Commission (Quine & White, 1993).

Table 14. Limitations to potassium and lime application in Scotland.*

Soil Type	Potassium application	Lime application	K and lime application
Sandy (non-podsolic) & loamy soils	$pH < 6.2$, $CEC < 15$	Not suitable	Not suitable
Clay soils	Not suitable	Not suitable	Not suitable
Podsolic soils	$pH < 4.4$, $CEC < 30$ $pH < 5.2$, $CEC < 15$	$pH < 4.4$, $CEC < 20$	$pH < 4.4$, $CEC < 20$
Organic soils, not waterlogged	$pH < 4.5$, $CEC < 130$	$pH < 4.5$, $CEC < 100$ $pH < 5.4$, $CEC < 70$	$pH < 4.5$, $CEC < 100$
Organic soils, waterlogged	Not suitable	Not suitable	Not suitable
Slope	15 degrees	15 degrees	15 degrees

*pH measured in $CaCl_2$, CEC= cation exchange capacity (in meq= milliequivalents/100g soil)

3.3.1. Ammonia Emissions

Changes in ammonia emissions were assessed for Countermeasure Scenarios 3 and 4 (see page 16). In the Finnish Countermeasure Scenario 3 it was assumed that increased amounts of imported concentrate would be fed to all dairy cows in the whole country. The average use of concentrate would be raised from 40% of net energy intake to 80%, leading to an estimated 25% increase of nitrogen in manure (Wilkerson *et al.,* 1997). This will increase ammonia (NH_3) emissions during storage and spreading. In addition more manure may have to be stored in field heaps or spread at unsuitable times since the storage capacity may be exceeded. These changes were taken into account by increasing the emission coefficients for cattle by 10%. As a result of the increased N excretion, a 25% increase in NH_3 emissions from cattle was estimated. This would increase total livestock NH_3 emissions in Finland by 13%. Taking into account the possible increase in emission coefficients due to storage problems, the corresponding increases for the whole country are likely to be approx. 37% for NH_3 emissions from cows and bulls and 21 % for total agricultural emissions.

For Scenario 4, it was assumed that radioactive deposition takes place in central Ostrobothnia and that all cattle are moved to the southern province, Uusimaa (Fig. 2, page 7). Increasing the cattle production in an area previously dominated by cereal production, such as Uusimaa, would most likely require increased use of concentrates. However, the possible impacts of the change in feeding systems were not considered in this context. If cattle production is increased in a region lacking infrastructure for livestock farming (manure storage facilities, application machinery), this would probably increase the emissions. It is difficult to quantify this in absolute terms, but an additional 10% increase was assumed. Figure 27 illustrates the regional changes in municipal ammonia emissions with a noticeable decrease in Central Ostrobothnia and an increase in Uusimaa after countermeasure implementation.

For Scotland the impact of Countermeasure Scenarios 3 and 4 on ammonia emissions was assessed at the catchment scale. Estimates of baseline emissions are given in Salt *et al.* (1999c). The impact of increased concentrate feeding to dairy cows was calculated assuming a 27% increase in nitrogen excretion (Wilkerson *et al.,* 1997). Additional emissions due to lack of storage capacity for manure were not considered. Changes in the dairy diet lead to a predicted rise in NH_3 emissions of about 15% in the 2 catchments with significant milk production (Table 15, page 36). Feeding countermeasures for meat producing animals will have smaller effects since shorter feeding periods are required and the diet composition is altered less drastically. The most drastic changes in ammonia emissions occur under Countermeasure Scenario 4, where animal production ceases. The greatest reductions occur in catchments with significant numbers of cattle. In contrast, cessation of arable production has only a small effect.

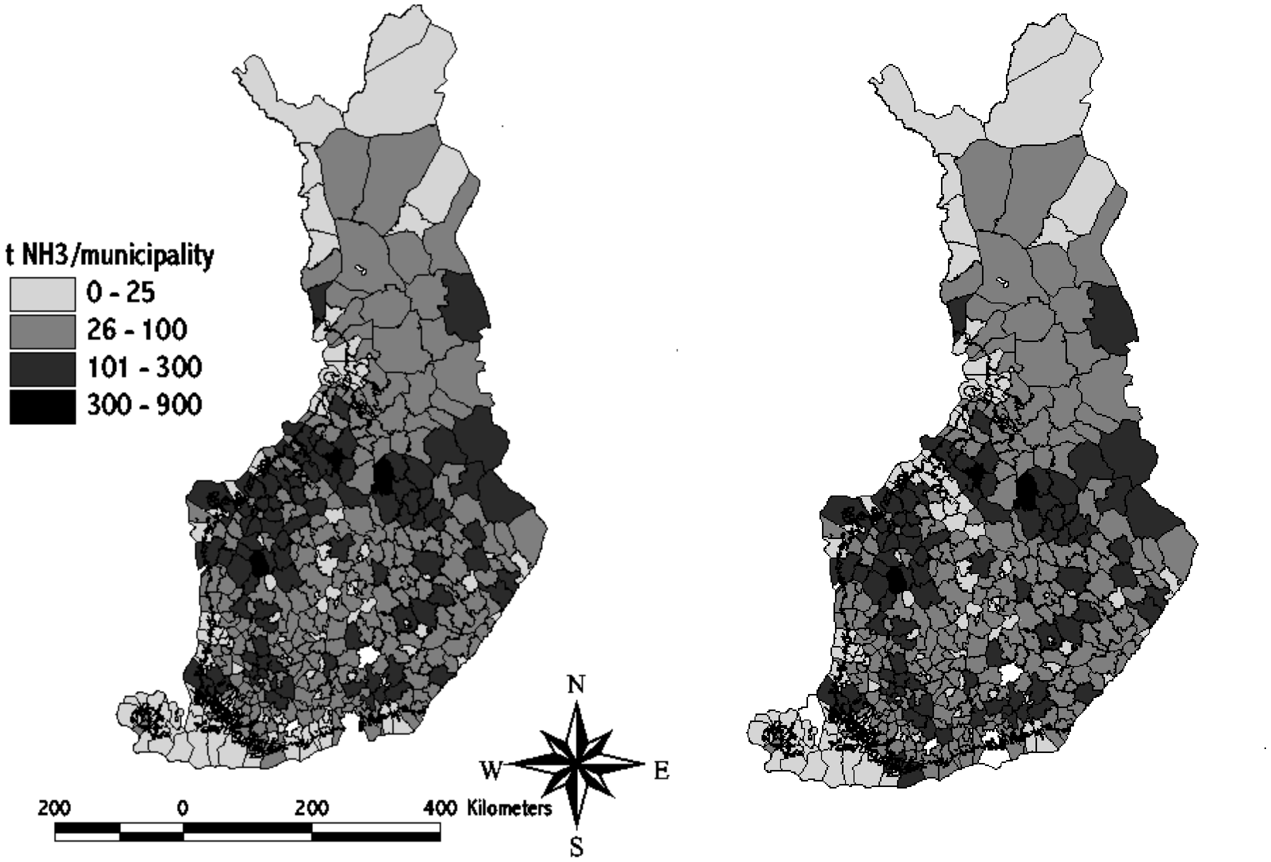


Figure 27. Ammonia emissions (t per year) for the municipalities in Finland in 1995 (a) and for Countermeasure Scenario 4 (b).

Table 15. Changes in Scottish ammonia emissions resulting from countermeasures (kg NH_3-N per year)

	Change dairy cow diet		**Cease animal production**		**Cease arable production**		**Afforestation**	
	Emission increase		Emission reduction		Emission reduction		Emission reduction	
	kg/year	%	kg/year	%	kg/year	%	kg/year	%
Glenstang Burn	3849	15.4	24960	99.86	34	0.14	24994	100
Burn O’Need	4090	15.5	26459	100	0	0	26459	100
Eden Water	0	0	9385	82	1990	18	11375	100
Lugate Water	0	0	9522	100	0	0	9522	100
Water of Tarf	0	0	276	100	0	0	276	100
River Ythan	0	0	43219	98.7	562	1.3	43781	100
Lusragan Burn	0	0	559	100	0	0	559	100
River Noe	0	0	255	100	0	0	255	100
River Erradale	0	0	120	100	0	0	120	100

For both Finland and Scotland, it is concluded that the predicted changes in ammonia emissions will have only a small effect at the national level. However, locally important impacts may arise if livestock production is intensified or transferred to a different region. The severity of environmental impacts such as acidification and eutrophication of soils and surface waters, will depend on the sensitivity of local ecosystems. The results were incorporated into the CESER Decision Support Systems.

3.3.2. Landscape Structure Analysis for Biodiversity Changes

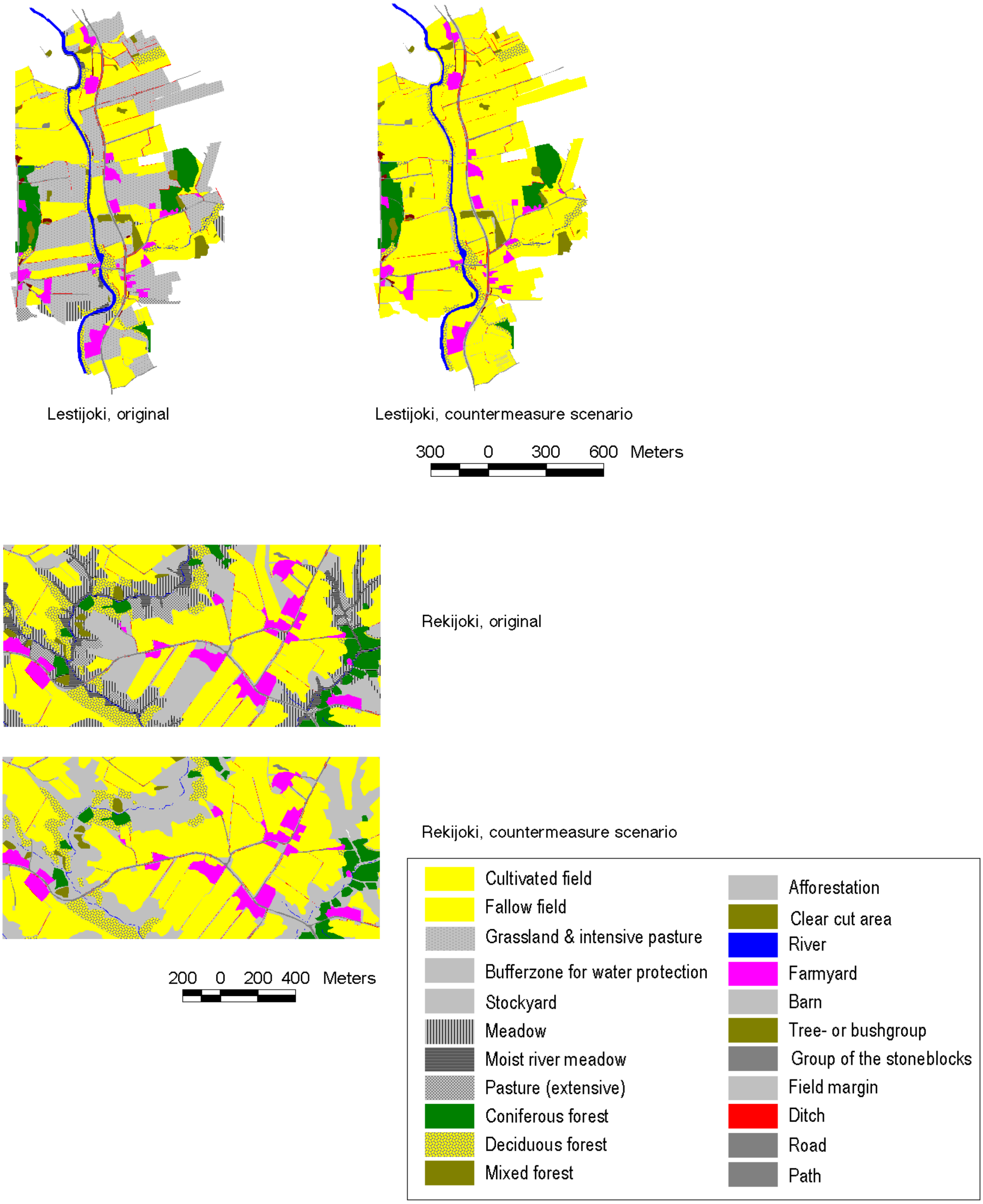
Some countermeasures involve alterations in land use that may impact on landscape structure and subsequently lead to changes in habitat and species diversity of the agricultural landscape. Under Countermeasure Scenario 3 (changes in the diet of livestock) grassland may be converted to barley production to replace grass in the diet of dairy cows with less contaminated barley concentrate. Under Countermeasure Scenario 4 afforestation is a suitable alternative land use when animal and crop production have to cease due to the high level of radioactive deposition. The resulting changes in landscape structure were studied in two Finnish areas, Lestijoki and Rekijoki (Luoto *et al.*, submitted). Lestijoki is characterisized by a high proportion of dairy production with large areas of intensively managed mowing grass in rotation. Rekijoki is a typical cereal production area in south-western Finland, but with exceptionally large areas of semi-natural pastures and meadows. The changes in landscape structure caused by countermeasure implementation were studied using a spatial pattern analysis programme (Fragstats Raster Version 2.0, McGarical & Marks, 1994) in combination with GIS-software (ArcInfo). The results show considerable changes in landscape structure and habitat diversity. Figure 28 (p.38) illustrates the changes caused by converting extensively used pasture in Leistijoki to arable land use, while in Rekijoki extensive pasture was afforested and intensively used pasture was cultivated.

The countermeasure scenarios examined, created a more monotonous habitat structure compared to the present management, indicated by increased mean habitat patch size, reduced total habitat edge length and reduced Shannon diversity index. The degree of change was dependent on the present agricultural production structure and land use. In Lestijoki, the landscape changes were mostly due to conversion of intensive pastures and mowing grass to cereal production. In Rekijoki, the greatest impacts resulted from afforestation of pastures. Countermeasures can also increase biodiversity by creating a more varied mosaic of habitats if land use changes are restricted to smaller areas.

3.3.3. Impact Maps for Soil Erosion and Phosphorus Losses

The changes in soil and phosphorus losses predicted for Countermeasure Scenarios 1-4 (see section 3.2.1.) were mapped for Scottish and Finnish catchments. Selected Scottish impact maps, based on 10*10 m grid cell size, are presented. Areas marked as 'not modelled' are either a) soil types for which no data exist, b) organic soils, c) non-agricultural land, or d) areas unsuitable for the countermeasure. Figure 29 (p.39) shows the predicted change in soil erosion following deep ploughing of arable and rotational grassland in the Ythan sub-catchment. Since 90% of the area is dominated by one soil type, the spatial differences in soil loss are mainly driven by the slope angle, which ranges from 0-21°. For all land below 13° slope the modelling results are mapped as a weighted average of arable crops and grassland. Land between 13° and 15° slope is mapped as mowing grass and steeper land as grazing grass.

Changes in particulate phosphorus losses in surface runoff (PP) are illustrated for the Eden sub-catchment (Figure 30, p.39). The map highlights the differential effect of the two most common soil types. In the eastern part of the area PP loss decreases after deep ploughing, while in the western part it increases. The dominant freely draining brown forest soil in the western half of the sub-catchment has an unusually high labile P status in the subsoil which causes this effect. The impact of converting large areas of grassland to winter barley cultivation (Scenario 3b) is illustrated for the Glenstang Burn catchment (Figure 31, p.40), showing increased losses of particulate P in runoff. As only one soil types dominates, losses mainly reflect differences in slope angle. The feeding of increased amounts of imported concentrate to dairy cows (Scenario 3a) and the associated increased need for manure application to mowing grass explains the increased loss of dissolved phosphorus (DP_r) in runoff illustrated for the Burn O'Need catchment (Figure 32, p. 40). The large areas not modelled in this map represent mainly built up areas and woodland in the south-west and areas of rough grazing on peat in the north-east.


Lestijoki, original

Lestijoki, countermeasure scenario

Rekijoki, original

Rekijoki, countermeasure scenario

Figure 28. Changes in landscape structure and habitat diversity in 2 Finnish catchments as a result of land use changes.

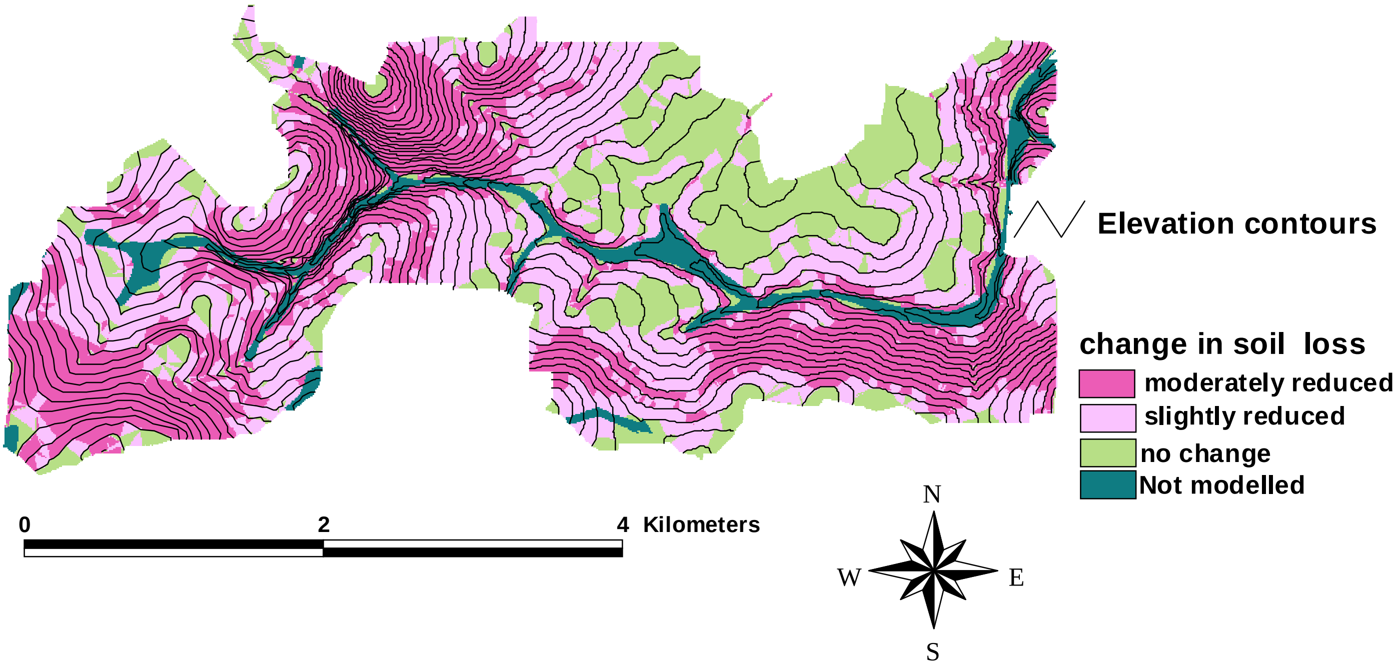


Figure 29. Soil erosion risk in the upper Ythan catchment (north-east Scotland) following deep ploughing.

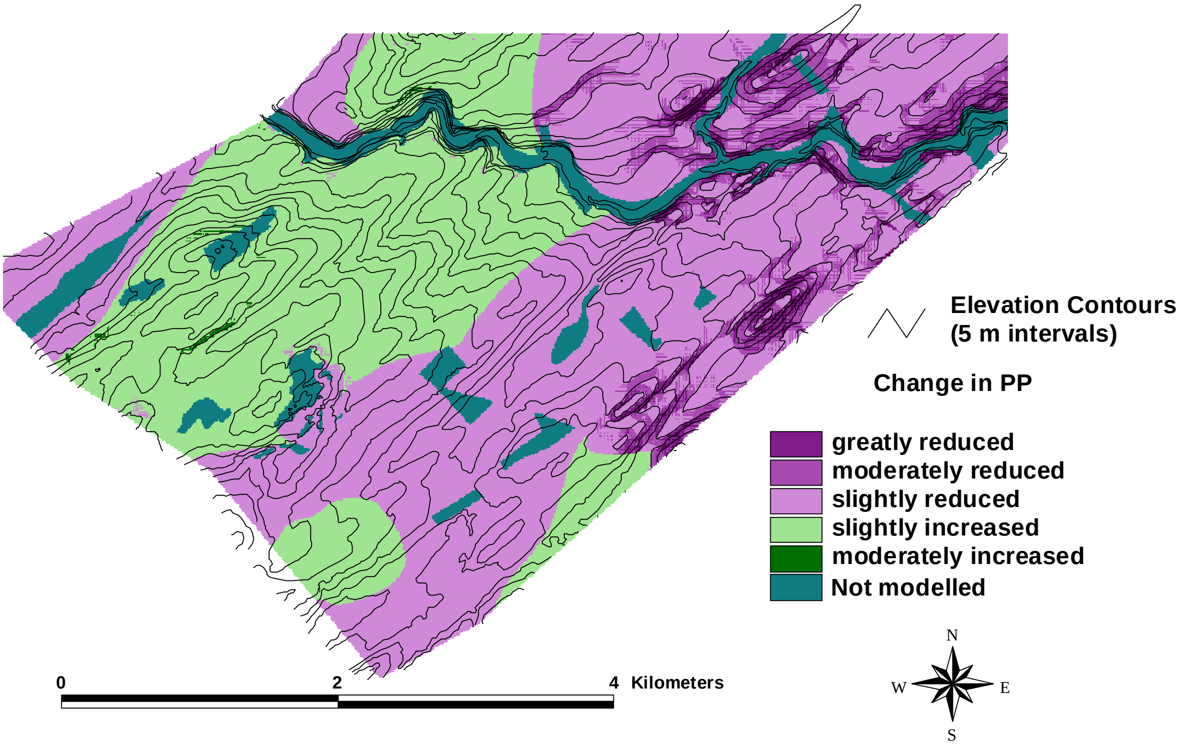


Figure 30. Risk of particulate phosphorus loss in the Eden Water sub-catchment (south-east Scotland) following deep ploughing.

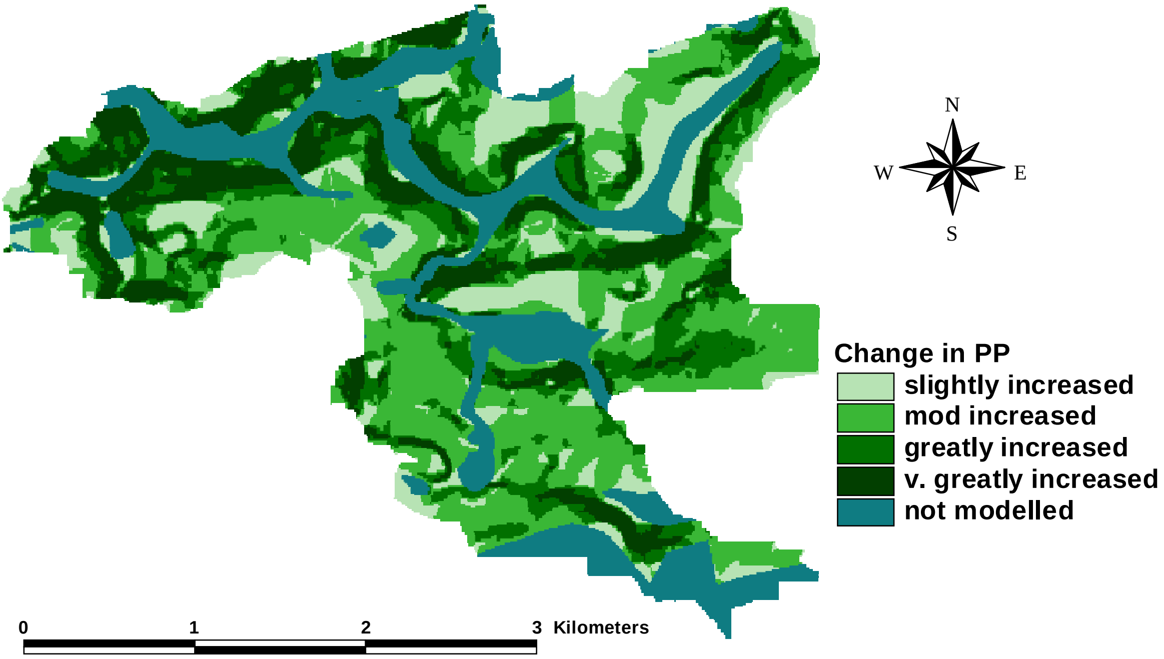


Figure 31. Risk of particulate phosphorus loss in the Glenstang Burn catchment (south-west Scotland) under Countermeasure Scenario 3b.

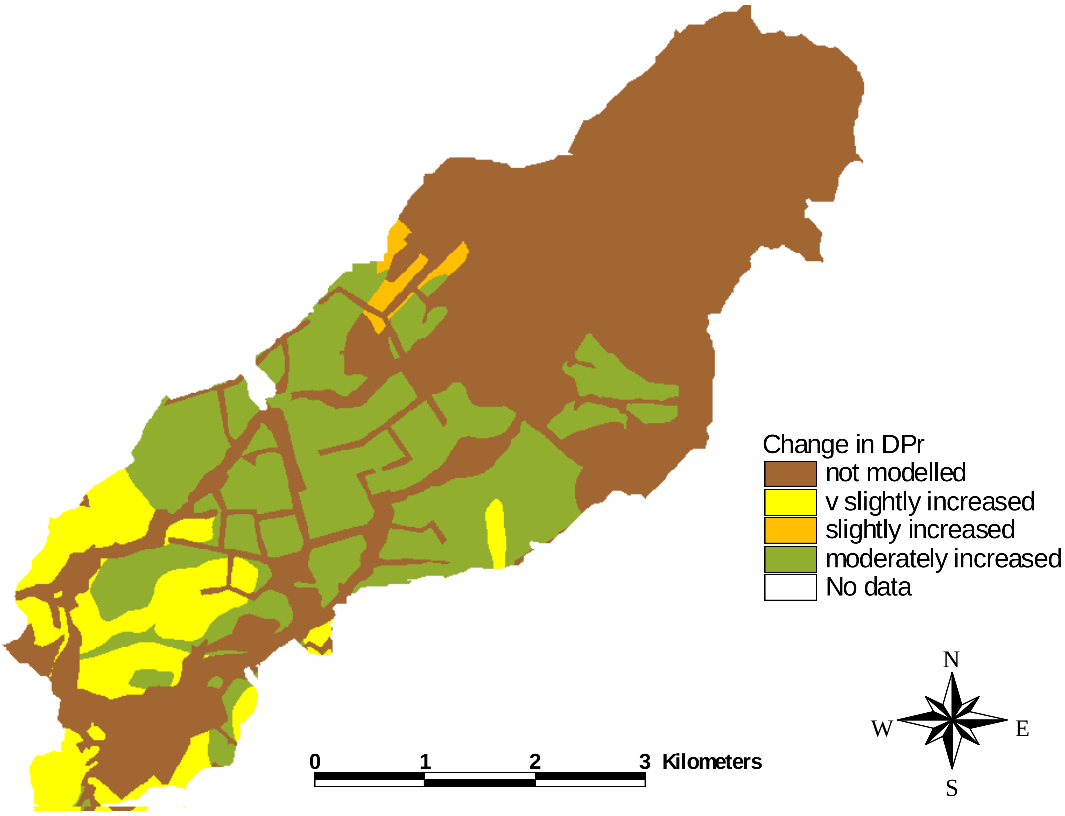


Figure 32. Risk of dissolved phosphorus loss in the Burn O'Need catchment (south-west Scotland) under Countermeasure Scenario 3a

3.3.4. Catchment Inventories for Soil Erosion and Phosphorus Losses

The impacts of Countermeasure Scenarios 1 (deep ploughing), 2 (skim and bury ploughing), 3 (changes in the feeding of animals) and 4 (cessation of production) (see page 16) were calculated as the difference between the simulation results for normal practice and following the countermeasure on a catchment scale using GIS techniques.

Finland

The aggregated effects of Countermeasure Scenarios 1, 3 and 4 (see page 16) at the catchment scale are discussed for the particulate P fraction (PP) and dissolved P fraction in surface runoff (DP_r). The results are 10-year-average values (1981-1990) based on field-scale model simulations (see Section 3.2.1.), scaled up to the catchment. The catchments are abbreviated: Yläneenjoki (YLA), Lepsämänjoki (LEP), Lestijoki (LES), Taipaleenjoki (TAI) and the results are expressed as percentage values relative to the catchment with the highest value.

The original values for PP and DP_r show differences between the catchments (Figure 29). The highest value for PP, in the Lepsämänjoki catchment, is explained by the steeper slopes and the more erodible soil types. The low values for Lestijoki and Taipaleenjoki are, in addition to slope, linked to the dominance of grasslands, which are less prone to erosion compared to arable land. The high DP_r values for Lestijoki and Taipaleenjoki catchments are also related to the fact that grassland receives surface applied fertilizer in Finland, while for cereals and root crops fertiliser is injected into the soil.

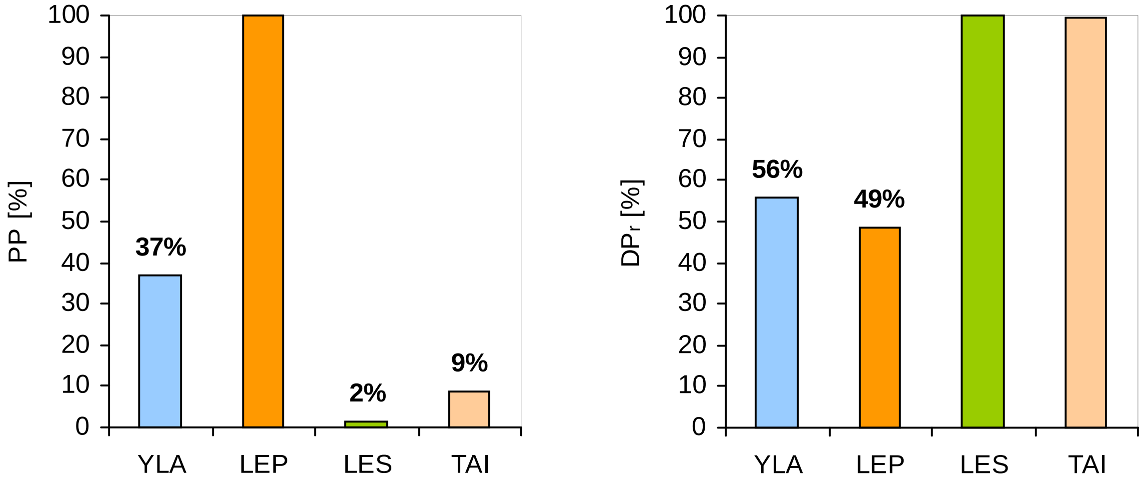


Figure 29. Aggregated 10-year-average losses of PP and DP_r under normal practice.

Deep ploughing reduces the total PP losses in every catchment (Figure 30, page 42), because poor subsoil with low phosphorus content comes to the surface following the reversal of the soil layers. For DP_r the results are not as simple because deep ploughing reduces DP_r for the southern catchments, but increases it slightly for the northern catchments. This is related to the soil types and the dominance of mowing grass in the northern catchments. Skim and burial ploughing changes the PP and DP_r output only slightly, the maximum change being less than 3 % of the original value.

In Countermeasure Scenario 3, 50% of the grass fields are converted to barley and P-fertilization is also increased. This results in increased PP values, with the largest impact occurring in the catchments with the originally highest proportion of mowing grass and the largest grass fields (Figure 35). Spring barley is more susceptible to soil loss than mowing grass and it receives injected fertilization instead of surface application. This explains why the PP values rise whereas DP_r values decrease, again in direct relation to the number and size of the grass fields prior to implementing the countermeasure.

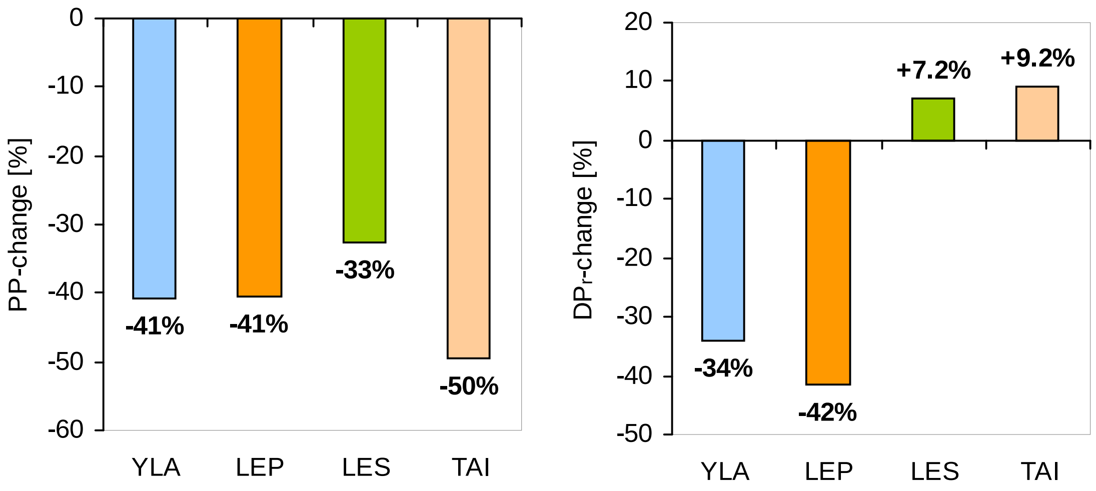


Figure 30. Relative changes in 10-year-average aggregated losses in PP and DP_r after deep ploughing compared to normal practice.

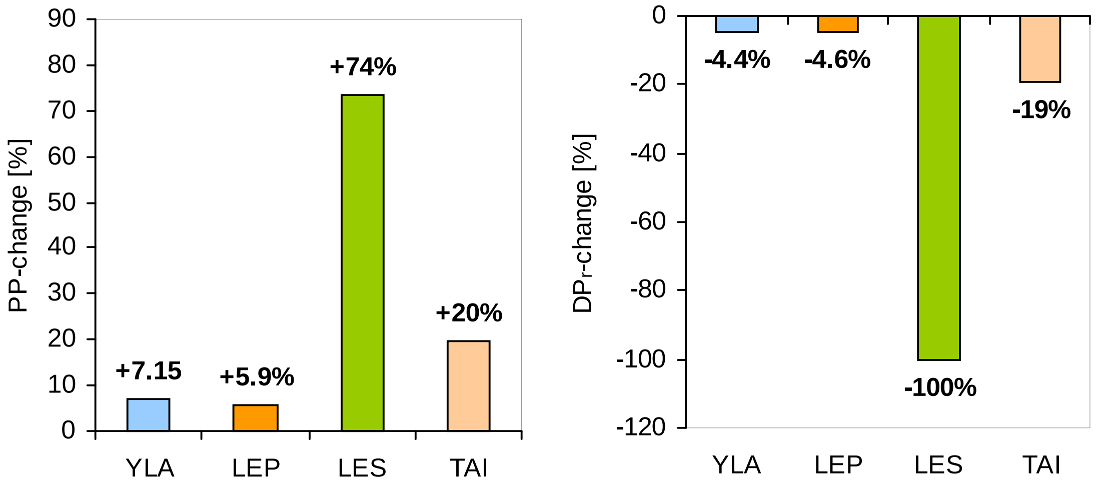


Figure 31. Relative changes in 10-year-average aggregated losses of PP and DP_r following changes in dairy livestock feeding compared to normal practice.

In Countermeasure Scenario 4 the introduction of green fallow after cessation of dairy production in the Lestijoki catchment greatly reduces both PP (-90%) and DP_r (-65%). The change from barley to grass in Lepsämänjoki to feed to increased number of dairy cows decreases PP output (-49%) but increases DP_r output (+75%) mainly for the reasons mentioned above. The effect of higher P-fertilization is not as marked as the effect of changes from cereals to grass.

Scotland

The aggregated effects of Countermeasures Scenarios 1, 3 and 4 (see page 16) at the catchment scale are presented for the particulate P fraction (PP) and dissolved P fraction in surface runoff (DP_r). The results are 10-year-average values (1986-1995) based on field-scale model simulations (see Section 3.2.1.), scaled up to the catchment level. The catchments are abbreviated: Eden (EDE), Ythan (YTH), Glenstang (GLE), Burn O'Need (BUR). In the Glenstang and Burn O'Need catchments 22% and 87%, respectively, of the land, were classed as unsuitable for ploughing countermeasures and calculations of inventory changes are restricted to the suitable areas. Catchment inventory changes are illustrated in Figures 36 and 37.

The most significant change associated with deep ploughing in all catchments is a reduction of 24-34% in PP (Fig 36). This can be explained by the generally lower total P status of the subsoil in all major soil groups. DP_r shows very variable behaviour across different catchments (Fig. 36). In Ythan DP_r is 14% lower after deep ploughing since the subsoil of the dominant soil type has a lower labile inorganic pool of P. In contrast, in the Eden sub-catchment there is little overall change in DP_r. This hides marked opposite trends in the 2 main soil types.

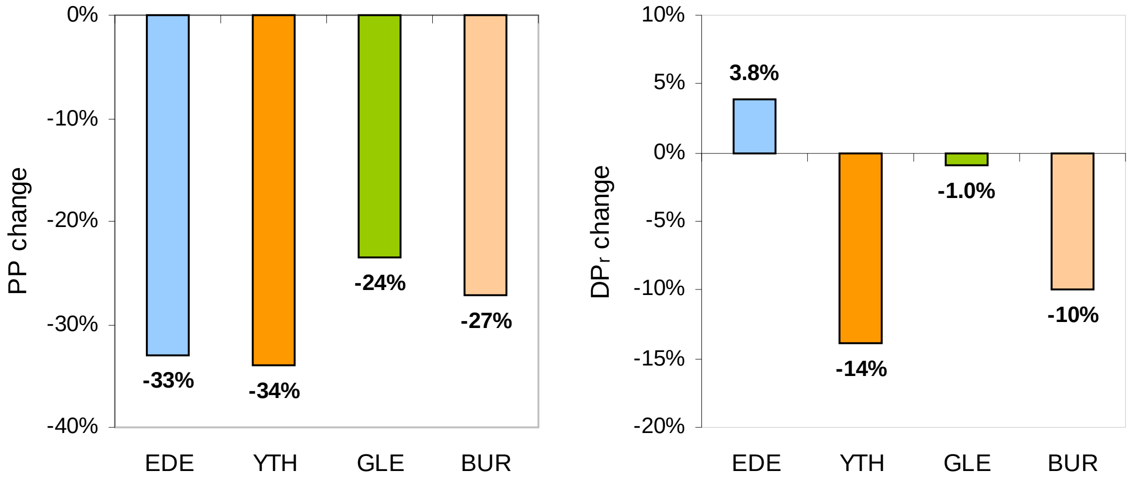


Figure 32. Relative changes in 10-year-average aggregated losses in PP and DP_r after deep ploughing compared to normal practice.

Deep ploughing in the Glenstang area has no net impact on DP_r at the catchment level, since small changes for individual crops are compensating each other. The only soil suitable for ploughing countermeasures is an imperfectly draining gley with a low labile P status and an even distribution of P_{lab} down the profile. The same soil type was also modelled for the Burn O'Need area, but here there is a more noticeable change of -10% in DP_r. in response to deep ploughing. It appears that due to the low labile P status of the soil, external applications of P have a disproportionate effect. Small differences in the P application via animal faeces may partly explain the catchment differences, while the greater proportion of grazing grass in Burn O'Need also plays a role.

The complex changes in land use envisaged under Countermeasure Scenarios 3a and 3b (see page 16) have very different impacts on the two catchments modelled. Under Scenario 3a the introduction of areas of green fallow leads to a significant decrease in PP (Figure 33, page 44). The difference between the catchments is explained by the fact that more green fallow would be created in Glenstang. Both catchments show a small increase in $DP_{r,}$ most likely in response to the additional manure applications to mowing grass. Under Scenario 3b the increased production of barley leads to a large rise in PP and DP_r in Glenstang while Burn O'Need shows no change compared to the original losses. This results from the suitability of the Glenstang area for winter barley cultivation, while in Burn O'Need spring barley is a more suitable crop. Rates of erosion and hence PP losses, are much higher on winter compared to spring barley. The same applies to DP_r but to a lesser extent.

The cessation of both animal and crop production in all Scottish catchments leads to drastic reductions in soil and phosphorus losses, ranging from 84-99%, as arable and improved pasture land are converted to green fallow.

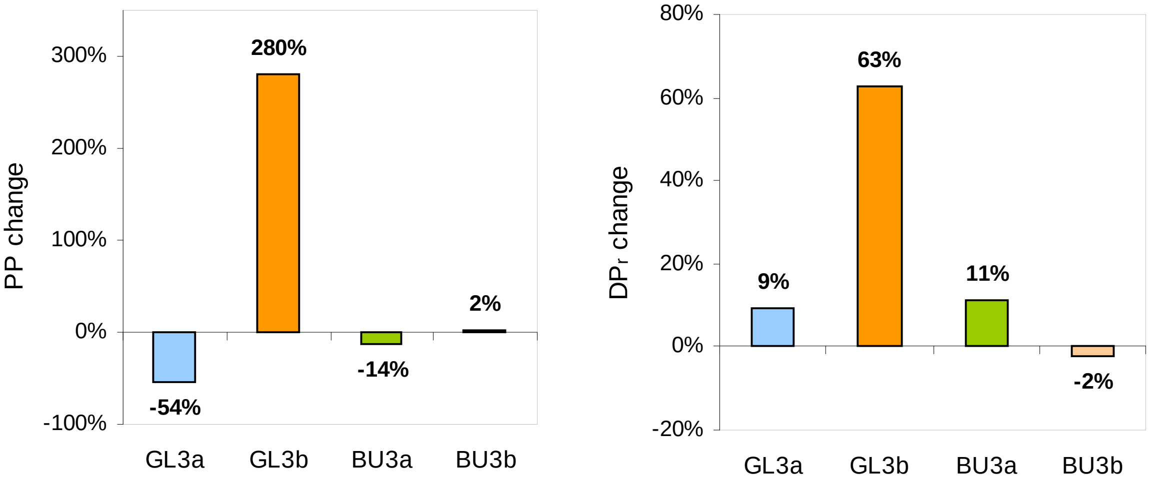


Figure 33. Relative changes in 10-year-average aggregated losses of PP and DP$_r$ following changes in livestock feeding (Scenarios 3a and 3b)

3.4. Economic Assessment of Countermeasures

The economic assessment of countermeasures in the CESER project had four main objectives:

- To estimate the private costs of countermeasures;
- To estimate the environmental costs of countermeasures;
- To estimate the benefits of these measures;
- To use the Cost-Benefit Analysis (CBA) methodological framework to enable costs and benefits to be compared for a range of countermeasures.

In addition, data on costs and benefits was generated in a form that would facilitate inclusion within the non-spatial Decision Support System (CeserDSS) (see Section 3.6.2.). The economic assessment of countermeasures is closely linked to the study of consumers' attitudes to treated products within the CESER project, since this provides information on the likely magnitude of benefits (see Section 3.5.) These links are outlined below. The main types of benefits and costs associated with countermeasures are outlined as well as the methods used to estimate these impacts. This has involved two approaches: a benefit/cost transfer based on a literature search and a contingent valuation study.

3.4.1. Main Types of Benefits and Costs

Within the Cost-Benefit Analysis (CBA) framework, the correct accounting procedure is to include all economic impacts of an action on the relevant population (Hanley & Spash, 1994). This is a more inclusive approach, than for example financial appraisal. The relevant population is taken to be all members of society. Thus, any economic impacts which remediation of radioactive contamination has on any member of society should be included. Economic impacts conventionally refer to changes in the utility levels of consumers and the profit levels of producers. Adding the monetary value of these together gives an estimate of the net social benefits of an action (which may be negative).

In the case of countermeasures against radioactive contamination, the main costs will be:

- private costs to the farmer of undertaking the countermeasure
- the potential environmental costs of the countermeasure, evaluated in monetary terms

Farmers clearly incur costs in undertaking certain countermeasures. Some of these costs may be direct, financial costs (eg the costs of feeding calcium supplements to dairy cows, or the costs of deep ploughing); others may be opportunity costs, for example the gross margin forgone if arable crops must be replaced with forestry. Farmers may also incur costs in terms of the value of foregone future output or increased future input requirements, e.g. if on-site soil erosion occurs as a result of the remediation technique used. Added together, the costs to the farmer of any countermeasure comprise the *private costs* of that countermeasure. However, society may incur costs greater than this. If the measure causes environmental damage which impacts on the utility of consumers (for example, if water quality falls due to soil erosion or eutrophication) or on the costs/profits of other producers, then the economic value of these *external costs* must be added to private costs to give a figure for the *social costs* of the countermeasure (strictly speaking, environmental costs should be evaluated as net of any improvements in environmental quality due to countermeasures) :

Social cost = private costs to farmer + environmental costs

The benefits of countermeasures can be expressed in two ways:

- The monetary value of avoided health risk to consumers; or
- The value of the avoided loss in product output, valued using consumers' Willingness to Pay for this treated product.

The first approach either requires WTP estimates for avoided health risk, which were not available, or the use of health detriment costs, which is controversial (Wilson *et al.*, 1999). The CESER project has therefore focussed on the second approach. Consumers may require a price reduction in order for them to be willing to purchase treated, but safe, products rather than un-treated, safe products from outside the affected area. Related work within the CESER project has estimated what this price reduction is for two important food products (milk and meat).

Costs and benefits of a countermeasure may occur over long time periods following the initial action. In this case, future costs and benefits are discounted at a chosen discount rate to allow them to be aggregated into a *present value* (PV). This PV can then be expressed in annual terms to allow comparison with those costs/benefits which are annual in nature, such as supplement feeding.

3.4.2. Estimating Private Costs

The private costs of remediating radioactive contamination in agricultural systems are those accruing to the farmer as a result of his actions. The countermeasures studied are explained in detail in Wilson *et al.* (1999). In each case, the method taken was to use farm management information contained in the Scottish Agricultural College Farm Management Handbook (SAC 1998), supplemented with other data, to calculate a budgetary cost for the particular countermeasure (Table 16, page 46). This avoided the requirement to produce our own cost estimates from original farm models.

Costs will vary across farm types and according to changes in output (eg livestock weight or crop yield) and input (eg labour) prices. Widespread implementation of countermeasures might change input and output prices, although it was beyond our remit to predict these kinds of impacts. The cost estimates produced are broadly representative of average costs on "typical" Scottish farms across farm types, given current prices as input to the non-spatial Decision Support System (see Section 3.6.2.).

Table 16. Farm level costs: examples of variables and data sources

Countermeasure	Cost element	Variables and Data Sources
Supply calcium daily to dairy cows	Cost of calcium	Number of cows – input by user Calcium fed per day – 500 g Calcium fed per day (normal) – input by user Price of calcium - £25/tonne (pers. comm. Franzefoss Bruk A/S)
Improve pasture	Additional labour	Area of improvement (ha) – input by user Labour rate - £6.1/hr (SAC, 1998 p307) Ploughing rate – 0.9 ha/hr (SAC, 1998 p301) Fertilising rate – 3 ha/hr (SAC, 1998 p301) Sowing rate – 1.3 ha/hr (SAC, 1998 p301)
	Seeding material	Cost of materials - £96/ha (SAC, 1998 p 111)
Afforestation (on livestock farms)	Loss of existing margin	Number of animals – input by user Margin per animal – varies by farm type (SAC, 1998)
	Animal disposal	Number of animals – input by user Average weight of animals – input by user Disposal to landfill - £25/t (Connell, pers comm.)

3.4.3. Estimating Environmental Costs: Value Transfers from the Literature

The possible environmental impacts of the range of countermeasures studied in the CESER project are many and varied. With regard to the CBA, the following environmental impacts were identified as potentially relevant:

- Erosion and sedimentation
- Soil organic matter
- Soil nutrient transport to water
- Soil pollutant transport to water
- Ammonia emissions
- Biodiversity
- Landscape quality

Per unit estimates of the monetary value of changes in each of these impacts were sought from the literature. The monetary values are typically based on either:

- the value of avoided damages to producers (eg soil erosion)
- or consumer Willingness to Pay (WTP) to avoid damages (eg decline in landscape quality)

Values could only be found for a sub-set of these impacts, whilst others were judged too complex to be valued in monetary terms for this project. No useable estimates could be found for soil organic matter, soil pollutant (eg heavy metal) transport to water, or ammonia emissions. Biodiversity impacts were assessed as too complex to value in monetary terms. Landscape impacts were deemed to be highly localised, thus original estimates were required for case study areas: the procedure for estimating landscape values is outlined in the next section. However, useable estimates were found for soil erosion and soil nutrient transport, drawing on work by Evans (1981), Frost *et al.* (1990), Ribaudo (1986) and Gren *et al.* (1995) amongst others (see Table 17).

Table 17. Environmental cost estimates.

Impact criterion	Costs
Erosion and Sedimentation	crop yield - 0.007 % / t of crop up to a max of 2.5 % off site - £4.72 / t of soil
Soil Nutrient Transport to Water	£4.70/kg of N £15.20/kg of P

These environmental cost estimates can be combined with physical predictions of soil loss and nutrient transport from other parts of the CESER programme to produce environmental costs for a range of countermeasures and deposition scenarios.

3.4.4. Environmental Costs: A Contingent Valuation Study of Landscape Change

The implementation of some countermeasures would result in a change in landscape quality in the affected areas, an obvious example being afforestation of farmland, but changes in grazing/cultivation intensity could also produce landscape impacts. The landscape is a difficult "good" to value in economic terms, partly because it is so heterogeneous in its composition. Therefore valuation studies of particular landscape changes at case study sites were undertaken. The transferability of the resulting estimates to other sites with similar landscape characteristics has not been tested.

In this study, *contingent valuation (CV)* was used. CV is a standard environmental valuation technique, with many thousands of applications world-wide (Hanley *et al.*, 1997). The CV method is a stated preference technique, which consists of getting respondents to express their Willingness to Pay (or Willingness to Accept Compensation) to prevent or acquire specified changes in environmental quality. This can yield estimates of welfare change which are fully consistent and compatible with CBA. In this study, likely landscape changes to two landscape types in Scotland were considered:

- heather moorland; and
- rough grassland

In each case, visual representations of possible landscape change associated with either afforestation or pasture improvement were presented to random samples of the general public. This was undertaken via a questionnaire survey of 639 Scottish people in face-to-face interviews. Respondents were asked to express a preference for landscapes before and after countermeasure implementation, and then to state their maximum WTP to prevent a change away from their preferred alternative. The payment would be made to a conservation trust which would safeguard the area. Examples of the types of landscape change used in the survey are shown in Figure 38 (page 48).

By finding a statistical relationship between how far respondents lived from the case study areas and their WTP to protect, for instance, heather moorland from afforestation, we were able to identify the relevant population over which to aggregate, and the implied values per hectare of current landscape types. The results are summarised in Table 18. Values for a given landscape type depend on what change the countermeasure would produce. These results have been used in the non spatial Decision Support System (CeserDSS) to provide environmental impact scores for landscape changes (see Section 3.6.2.).

Table 18. Aggregated WTP per hectare to protect heather moorland and rough grassland from changes in landscape to either productive grassland or forestry.

	Change to Productive grassland	Change to Forestry
Heather moorland		
Trimmed mean (£/household)	8.1	1.1
Relevant population	48,000	48,000
Area (ha)	800 – 1600	800 – 1600
Implied landscape value £/ha	243 – 486	33 – 66
Rough grassland		
Trimmed mean (£/household)	-5.9	8.4
Relevant population	17,000	17,000
Area (ha)	600 – 1200	600 – 1200
Implied landscape value £/ha	-(84 – 168)	119 – 238

Picture 1A. Rough grassland

This land will only support low levels of grazing by sheep and cattle. No fertilisers have been applied and no drainage improvements have been carried out.

Picture 1B. Change from rough to more productive grassland

This land has been drained and is ploughed, fertilised and seeded on a regular basis to provide better grass. This supports a higher number of sheep or cattle.

Figure 34. Example of the images used in the Contingent Valuation Information Pack.

3.4.5. Conclusions

The economic evaluation of countermeasures via cost-benefit analysis allows alternative countermeasures to be compared in terms of their net social benefit as well as individual measures to be judged in terms of economic efficiency. Calculations of on-farm costs and benefits were made for a wide range of countermeasures in a form suitable for incorporation in the Decision Support System. Environmental costs of countermeasures have for the first time been quantified, partly through original contingent valuation, partly through value transfers from the literature. However, a full CBA was not possible since cost estimates for many environmental impacts are still lacking. With additional resources it would be possible to fill these gaps in the future.

3.5. Assessment of Consumer Attitudes and Behaviour

The main objectives of the consumer study were to assess attitudes and behaviour related to countermeasures and the Chernobyl accident, to determine preferences for information sources in a radioactive emergency situation and to determine WTP for «clean» food from non-affected areas.

Little work has been done on consumer attitudes towards food treated with countermeasures prior to this study. Therefore, a thorough study of literature on related food safety issues was performed before undertaking the consumer survey. Consumer behavioural theory (Fishbein, 1980) together with findings in the literature served as a background for developing a consumer model (Figure 34) and a survey design (Grande *et. al.*, 1999). In addition, trends in food consumption patterns pre and post Chernobyl have been analysed (Grande, 1998 unpublished).

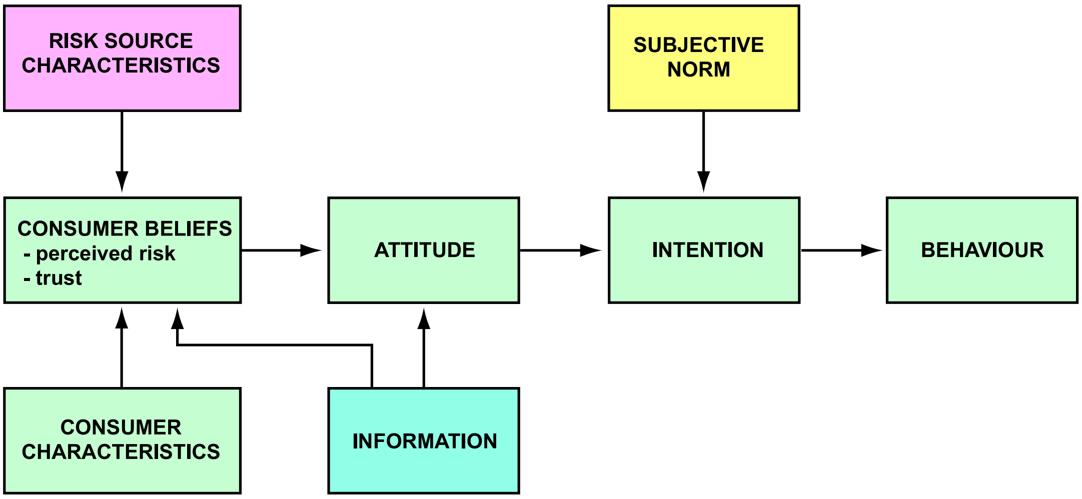


Figure 34. Consumer Model: factors influencing consumer attitude and behaviour in food safety issues.

The consumer model illustrates the relationship between consumer characteristics, risk source characteristics, risk perception and attitude, intention and final behaviour. The survey was designed to detect major effects on consumer demand, the consumers' perceived risk related to food affected by radioactive contamination, their information needs in emergency situations and WTP extra for «clean» food products from non-affected areas. The Norwegian version of the questionnaire was a mail survey sent out to 2000 persons randomly selected from the National Registry. In total 1003 of these responded giving a 50.6 % response rate. In Scotland the same survey was performed by interviewing a random sample of 200 persons.

To identify factors influencing risk perception and behaviour, single measures for both risk perception and risk behaviour were needed. Two methods were used to condense several variables on risk perception down to one variable: 1) computation of an additive index, and 2) data reduction through factor analysis. The relationship between risk perception, behaviour and consumer characteristics were investigated through correlation and analysis of variance.

3.5.1. Food Risk and Radioactive Risk Perceptions

The survey indicates that there is a greater fear of health hazards caused by radioactive contamination of food, than from irradiation, genetic engineering (Scotland) and pesticide residues in food. On the other hand, chemical additives, BSE (Scotland), use of growth hormones, infectious bacteria and genetic engineering (Norway) seem to be perceived as more risky than radioactivity in food. Table 19 shows how consumers rate risk from radioactive contamination of food compared to other risk sources in food.

Table 19: Risk perception measured[1] by the response to questions on the likeliness of suffering ill health as a result of the various risk sources in food. Norway and Scotland.

Source of food risk	mean response		unlikely (1 and 2) % of responses		likely (4 and 5) % of responses	
	Norway	Scotland	Norway	Scotland	Norway	Scotland
Chemical additives	2.91	2.68	37.2	50.0	27.4	26.5
Use of growth hormones	2.74	2.52	45.5	56.6	25.5	23.7
Infectious bacteria	2.73	2.82	44.1	44.5	22.4	28.0
Genetic engineering	2.62	2.53	50.3	57.7	23.3	21.7
Radioactive contamination	2.54	2.47	52.6	56.3	18.4	22.6
Irradiation of food	2.52	2.48	51.6	57.5	14.7	19.7
Pesticide residues in food & vegetables	2.51	2.57	53.6	50.5	17.5	20.0
BSE	Na	2.75	Na	43.6	Na	27.5

[1] Response measurement: Likert scale from 1 to 5. Endpoints labelled: (1) = very unlikely, (5) = very likely. Na = question not asked

The risk perception pattern for radioactive contamination of food in Scotland seems to be fairly similar to the risk perception pattern for genetic engineering, growth hormones and irradiation of food. In Norway the consumers' radioactive risk perception pattern seems most similar to the risk pattern of pesticide residues in fruit and vegetables. This indicates that results from risk research on these issues might be applicable to radioactive food risk. However, radioactive fallout is accidental with no control by food producers, whereas the other risk sources occur due to the producers' free use of technology to increase production and profits.

From a consumers' point of view these risks are associated with lack of control, difficulty of understanding, unfamiliarity and potentially severe damage to health. Earlier studies (Sparks & Shepherd 1994; Slovic 1987) have demonstrated that people often rate their risk perception attached to risk sources described by these characteristics much higher than the experts' calculated real risk.

Analysis of risk perception towards specific food products shows that Norwegians associate highest risk with reindeer meat, wild mushrooms and game (moose), whereas the Scots seem to perceive wild mushrooms and wild berries as most risky. In general, the proportion of the population perceiving these products as risky, is twice as large in Norway as in Scotland. In both countries the respondents perceived risk attached to lamb meat as slightly lower compared to the mentioned food products. This may be related to the level of consumer knowledge of the countermeasures implemented after Chernobyl to reduce the contamination in lamb meat.

3.5.2. Changes in Food Consumption Levels

The impact of the Chernobyl accident on consumption levels was investigated by asking the respondents to indicate whether or not they had made any changes in the intake of selected food products in connection with the accident. Table 20 shows that radioactive risk caused by the accident has had and still has a negative impact on the consumption of meat from sheep, reindeer (Norway) and game (venison/moose) as well as mushrooms. In the months following the accident, more Norwegian respondents reduced their consumption of lamb and reindeer meat compared to Scottish people.

Table 20. Short term and long term changes in consumption due to the Chernobyl accident. Percentage of respondents answering reduced consumption[1].

	Short term reductions		**Long term reductions**	
Food Product	**Norway**	**Scotland**	**Norway**	**Scotland**
Lamb	43.9	32.7	20.8	17.0
Beef	16.5	28.1	8.8	15.0
Reindeer	47.4	Na	27.0	Na
Wild mushrooms	40.4	19.0	24.4	10.0
Game (moose/venison)	37.2	17.0	21.2	11.0
Milk	7.8	19.6	4.1	7.0
Wild berries	Na	20.3	Na	9.5
Honey	Na	16.3	Na	8.5

[1] Response measurement: Likert scale from 1 to 5, where 1 = strongly reduced consumption, 3 = no change in consumption and 5 = strongly increased consumption. Na = question not asked.

In Norway, consumption of reindeer meat was most frequently reduced. Only a small number of the Norwegian respondents gave reduced consumption of milk and beef. The share of respondents claiming to have reduced their long-term consumption of various foods due to Chernobyl was generally less in Scotland.

3.5.3. Factors Influencing Risk Perception and Behaviour

Analysis of the relationship between risk perception, behaviour and consumer characteristics indicates that Norwegian consumers with a higher risk perception and taking actions to reduce risk compared to others are identified by:

- low household income
- small household size
- older people
- women
- widow(er)s
- those having experienced food poisoning
- those who prefer to buy organic food

The results further show that Norwegian consumers having lower risk perception and doing less to reduce risk than the average are identified by:

- high household income
- large household size
- younger people
- men
- households having many rather than few children
- University or college educated

Analysis of the Scottish data indicates that larger households, households with many rather than few children, people having experienced food poisoning and people whose education was focused on the natural sciences, had taken more actions to reduce risk due to radioactive contamination of food compared to others.

3.5.4. Willingness to Pay for Untreated Food

The respondents were asked how much they would be willing to pay extra for food products that are guaranteed never to have been affected by radioactivity, as compared to the current supply of products that may or may not have been affected, and treated with countermeasures if necessary. As shown in Table 21 the survey detected a significant Willingness to Pay (WTP) extra for «clean» food from uncontaminated areas in a fallout situation (Grande *et. al.*, 1999). In Scotland, the respondents were on average willing to pay a premium of 62 % and 31 % above the «normal» price for milk and lamb, respectively. Norwegian consumers were willing to pay 46 % more for «clean» unaffected lamb meat compared to treated meat.

Table 21. Willingness to Pay extra for respondents preferring «clean» untreated lamb meat and milk in Norway[1] and Scotland. Percentage above given price. Includes zero bids.

	Lamb		Milk
	Scotland	**Norway**	**Scotland**
n	108	466	152
Given price	£2.50 per pound	NOK 50 per kg	£0.40 per pint
Mean	31.3	46.6	62.3
Median	20	30	50
5 % trimmed mean	26.1	33.0	350
Maximum	200	200	56.9
95 % confidence interval of mean	13.1 - 39.6	33.7 - 39.5	52.6 - 72.1
Standard error	4.16	1.48	4.94

[1] In Norway only WTP extra for lamb

The resulting WTP-measure can be interpreted in two ways: 1) the welfare loss in terms of risk experienced by consumers from not knowing whether the food is affected by radioactivity or not and 2) the potential extra market value of food products (here milk and lamb) that are guaranteed not to have been exposed to radioactivity.

3.5.5. Risk Communication

Consumers' prior knowledge and information on risks received in an emergency situation will be crucial in the consumers' risk assessment process. Other important issues are the consumers' trust in of information sources, content and design of the message, information medium and labelling of food products. Related studies on information and the Chernobyl accident were undertaken by Weisæth (1990; 1991) and Tønnesen *et. al.* (1995). Earlier findings of food risk research suggest that beliefs might have a greater influence on risk perception than information (Grobe & Douhitt, 1995). The consumers' own knowledge will, however, be the platform for processing new information about the topic. Figure 35 (page 53) illustrates that more Scottish than Norwegian people find information about radioactivity difficult to understand.

The survey data for Norway indicate that University educated people have a lower risk perception than the rest of the population. This indicates that in the case of radioactive contamination of food, increased general knowledge might reduce risk perception. The Scottish data show that those having focused on natural sciences in their education tend to perceive a higher risk connected to radioactive contamination than the rest of the population. A higher risk perception among those not having University or college education, indicates that information might have been too complicated for «ordinary» people. It might also be that academics trust experts and scientists more because they are «one of them».

The reduction in consumption of the various food products by the Norwegian respondents corresponded very well with those products most affected after the Chernobyl accident, indicating fairly good knowledge about the situation. In Scotland it appears that consumers were less well informed.

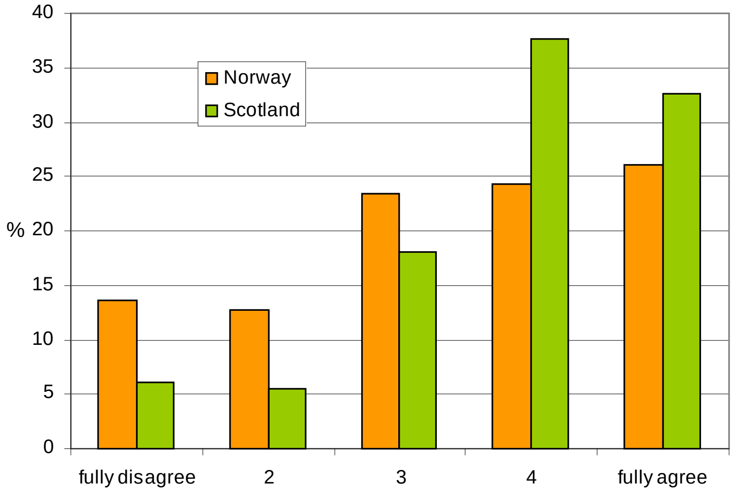


Figure 35. Level of agreement to the statement «Information about radioactivity is hard for ordinary people to understand»

The interpretation of the risk information depends on whether the consumers judge the source of the information credible or not. Trust takes a lot of time and effort to create, but can be lost instantly with a single incident (Slovic 1993, ref. in Henson 1995). As shown in Figure 36 a substantial share of the respondents in both countries doubt the safety of food treated with countermeasures.

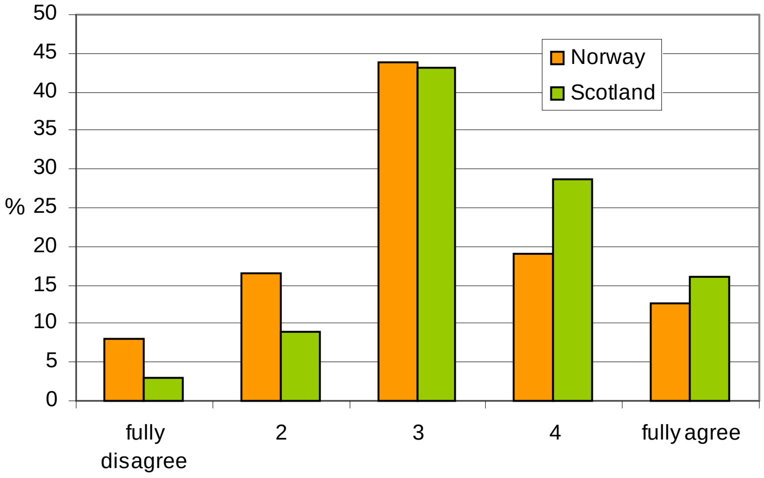


Figure 36. Level of agreement to the statement «Preventive measures against radioactivity in food do not make the food as safe for consumption as the experts claim»

Survey results indicate a high level of distrust in politicians and journalists, which means that these sources should be avoided in risk information. The information should be delivered by governmental authorities or experts as directly as possible. These findings are supported by results in Weisæth (1990, 1991). However, there is no definite preference in terms of trust of experts in Scotland.

The most preferred information sources in both countries were labels on food packaging and television. In Norway, radio and newspapers are also preferred by at least 50 % of the respondents, whereas the same share of the Scottish sample also prefers mail from the authorities. Newspapers are less trusted by Scottish people than Norwegians. However, even if one information medium is less preferred than others, it might be an important medium for vulnerable groups and those having high risk perception.

The respondents were in favour of food labelling in shops to inform about possible treatments to reduce radioactive contamination. This will make more people aware of the situation, and it is uncertain how they would act in a buying situation if they had the choice between a «clean» product from non-affected areas and a food product from affected areas treated with countermeasures. It might increase risk perception for consumer groups that have not been fully aware of the situation earlier. The consumers' reactions to these options will also depend on the price difference between «clean» food from non-affected areas and treated food products. Furthermore, the type of information on labels will be important. It will be necessary to conduct further studies before labelling is put into practice.

3.5.6. Conclusions and Recommendations for Consumer Strategies

The survey shows that radioactive risk caused by the Chernobyl accident has had and still has a significant negative impact on consumption levels of sheep, reindeer, mushrooms and game. Even though the Governments have taken actions to limit radioactive contamination of food and declared all food in the market to be safe, consumers still have a substantial fear of consuming these foods. This implies that even though countermeasures have been effective in reducing radioactive contamination, the efforts in communicating the real risk to the consumers have not been sufficient. The consumers' perceived risk seems to be much higher than the experts' calculated risk. This implies that the impact on market demand and consumer welfare loss due to high risk perception might be significantly higher than previously anticipated.

In a future radioactive emergency situation the impact on market demand will depend on whether it is possible to reduce the consumers' perceived risk by improving information and communication. If not, Governments and food markets have to take into account the consumers' «overestimated» perceived risk in order to limit costs due to its influence on market demand. The consumer survey shows that both Scottish and Norwegian consumers prefer to buy «clean» food from non-contaminated areas, and that they are willing to pay an extra premium for having that option.

Three possible strategies seem suitable for the food market in a radioactive fallout situation, as summarised in Table 22 (page 55). No matter what strategy is chosen, enough and understandable information, adapted to all population groups, must be provided. The trustworthiness of the messenger will also be crucial. The merits and limitations of each strategy must be evaluated in relation to population characteristics and the severity of the situation. The consumers' food choices are likely to be affected by the severity of the contamination as well as the size of area contaminated. Minor foods, less important to the consumers, might be more easily substituted by clean food products from non-contaminated areas, whereas this could be difficult if major food groups are affected.

Table 22. Possible consumer strategies in a radioactive fallout situation with likely positive and negative effects.

Use of counter-measures	Food marketing	Information	Effects
1. Yes	All food within safety limits put on the market. Food from contaminated areas not separated from clean food.	No labelling of food. Uniform message at all levels. Easy understandable in lay terms From trusted sources: governmental authorities, experts. Channels: as many as possible	- Perceived risk reduces total consumption of affected foods. - Market costs of reduced consumption - Costs of consumer welfare loss due to increased fear + Market value of affected food, safe food sold in the market
2. Yes	All food within safety limits placed on the market. Consumer can choose whether to buy food from contaminated areas (within safety limits) or food from clean non-contaminated areas.	Food labelled, whether from contaminated areas or not. Uniform message at all levels. Easy understandable - lay terms From trusted sources: governmental authorities, experts. Channels: as many as possible	- Greater reduction in consumption of affected foods compared to option1. - Might increase risk attached to affected foods. - Costs of marketing and labelling. + Consumption rate may remain at pre-accident level + Higher price of clean food increases market value + Reduced costs of welfare loss due to fear in population + Consumer trust ?
3. No	Food from affected areas is withheld from the market. Only food from non-contaminated areas on the market.	No food labelling. Uniform message at all levels. Easily understandable in lay terms; From trusted sources: i.e. government authorities, experts. Channels: as many as possible	+ Reduces risk perception + Consumer trust survives + Higher food prices - Cost due to alternative uses of affected food products.

3.6. Decision Support Systems

The final step in the impact assessment of countermeasure side-effects is the development of a methodology that will permit the simultaneous evaluation of a range of countermeasures. This can be achieved through computer based decision support systems that incorporate a formal selection procedure. In order to accommodate varying levels of spatial data availability and technical sophistication, two types of countermeasure decision support system have been developed by the CESER project. The first is a non-spatial assessment tool for a single area/farm using a Windows-based Expert System/Decision Support System called CeserDSS. The second type, Spatial DSS (SDSS), is a more generic countermeasure assessment tool for larger, heterogeneous areas using a Geographic Information System (GIS). Both decision support systems have been developed for Scottish agricultural systems to demonstrate the benefits of a country specific countermeasure evaluation. They guide the user through a selection process which assesses countermeasure suitability for local or regional agricultural and environmental conditions while at the same time providing a tool for assessing environmental and agricultural side-effects. Multicriteria Decision Making (MCDM) methodology has been applied to assess the positive and negative impacts of employing different countermeasures in both the spatial and non-spatial systems. This methodology has been put forward because it has the ability to take into consideration conflicting objectives and views in the countermeasure assessment process (Carver 1991). It provides decision-makers with a set of countermeasure suitability rankings or suitability maps based on which remediation strategies can be optimised.

3.6.1. Multicriteria Decision Making

Multicriteria Decision Making (MCDM) is the methodology chosen to formally assess countermeasure suitability and side-effects in both decision support systems. MCDM is a well-known branch of decision-making techniques that logically structure and evaluate problems with multiple attributes and objectives. It has been endorsed by the International Commission on Radiological Protection for use in the appraisal of radiological protection problems (Merkhofer & Keeney, 1987). A recent example is the RESTRAT project where it has been used to evaluate restoration options for small but highly contaminated areas, such as radioactive waste disposal facilities (Hedeman Jensen, 1999).

MCDM is based on the evaluation of a two dimensional matrix in which one dimension consists of alternatives and the other of criteria (Voogd, 1983). In the context of the CESER project the alternatives are the different possible countermeasures from which the decision-maker must select. Criteria are the means by which the countermeasure alternatives are assessed. The criteria consist of a mixture of environmental and agricultural considerations with the alternatives represented in the columns and the criteria shown in the rows of the matrix. The chosen MCDM ranking technique Ideal Point Analysis, is compensatory in that it allows for a poor performance by a particular alternative on one or more criteria to be ‘compensated for’ by a good performance on other criteria (Jankowski, 1995). The user can change the degree of compensation permitted within each assessment. The ability to make ‘trade-offs’ in criteria performance, within the bounds of certain thresholds, is viewed as a key component of the assessment methodology, as it accurately simulates the real-world decision making environment in which losses in the one arena can be justified by the gains made in another.

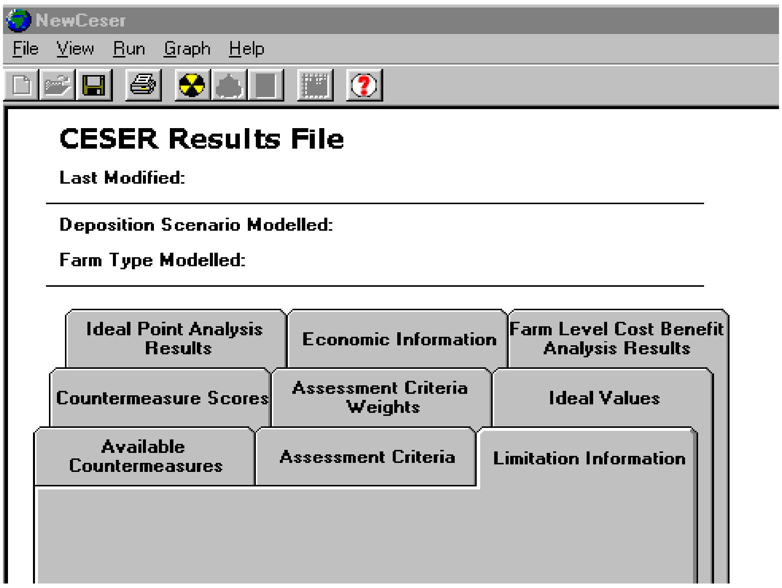
3.6.2. CeserDSS - a Non-Spatial Decision Support System

The CeserDSS (Salt *et al.* 1999a) is an interactive software package developed for typical Scottish agricultural systems, which enables assessments of:

- land suitability for countermeasures
- environmental and agricultural impacts, and
- on-farm costs and benefits.

The software is intended for application at the farm level, providing separate assessments for dairy, upland and lowland sheep, upland and lowland beef, and arable crop farms as well as enterprises involving management of red deer. The assessment process is facilitated through the use of a series of menu-driven wizards (Figure 42, page 57). After selecting a farm type and a radionuclide deposition scenario (see page 4, Table 1), the user is invited to choose from a list of basically suitable countermeasures that might be appropriate to their situation. In the expert system component of the software the limitations of each of these countermeasures are then explored by querying the user about their farm environment and management regime to accurately determine whether the countermeasure is suitable (Figure 43, page 57). A matrix of impact scores for all suitable countermeasures can then be viewed in the results file (Figure 44, page 58).

The decision support component of the software allows evaluation of the final list of countermeasures based on environmental and agricultural impact criteria by assessing them according to the user's own personal objectives. This is achieved by applying Ideal Point Analysis (Pitel, 1990), which incorporates user-specified weighted criteria to the analysis and ranks the countermeasures from best to worst according to the environmental/agricultural impact criteria.



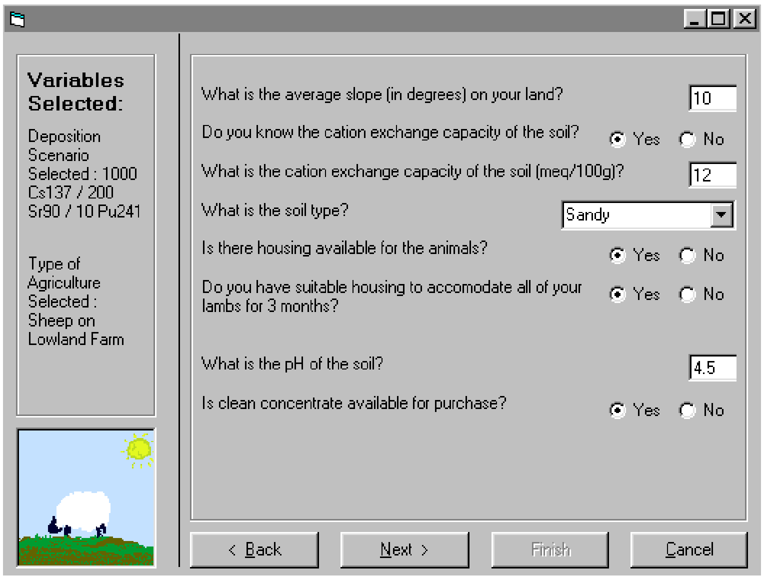
CESER Results File

Last Modified:

Deposition Scenario Modelled:

Farm Type Modelled:

Figure 37. CeserDSS menu and tool bar with results file



Variables Selected:

Deposition Scenario Selected : 1000 Cs137 / 200 Sr90 / 10 Pu241

Type of Agriculture Selected : Sheep on Lowland Farm

What is the average slope (in degrees) on your land? 10

Do you know the cation exchange capacity of the soil? ● Yes ○ No

What is the cation exchange capacity of the soil (meq/100g)? 12

What is the soil type? Sandy

Is there housing available for the animals? ● Yes ○ No

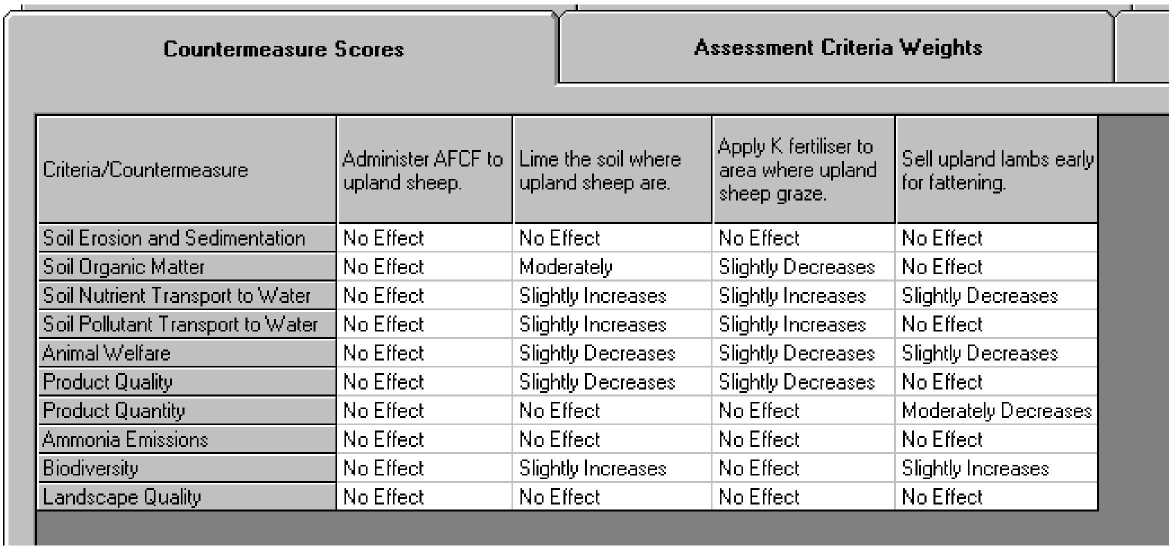
Do you have suitable housing to accomodate all of your lambs for 3 months? ● Yes ○ No

What is the pH of the soil? 4.5

Is clean concentrate available for purchase? ● Yes ○ No

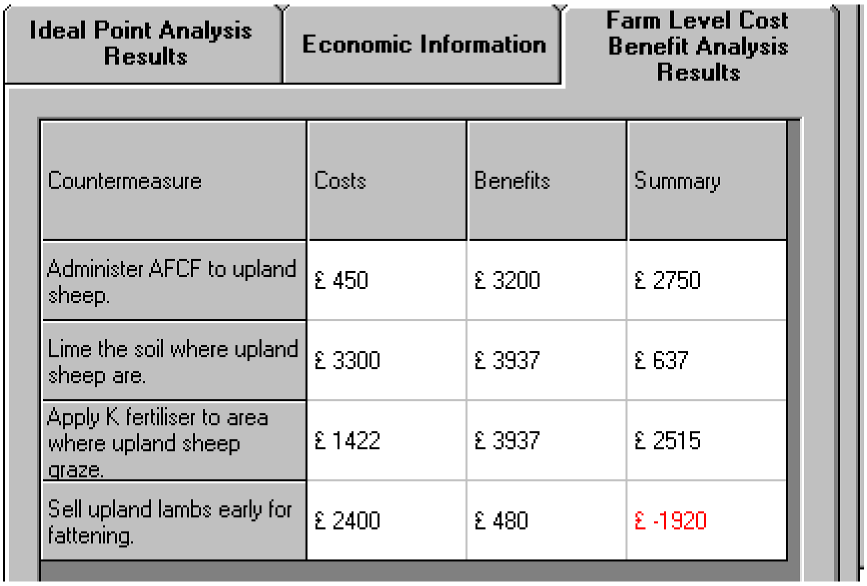
Figure 38. Limitations assessment.

The user has the additional option of carrying out a detailed economic analysis of on-farm costs and benefits of the final countermeasures (Wilson *et al.*, 1999). Costs are those private costs discussed in Section 3.4.2., while benefits are associated with the value of saved food products. Basic information such as the number of animals or the area to be treated, is entered by the user. All other default economic variables in the software e.g. prices or yields, can be edited by the user to take into account variability in farming circumstances. Farm-level costs and benefits are then calculated by the model and the results displayed as shown in Figure 45 (page 58). The environmental costs of the countermeasures were not directly included in the DSS as more research is required to produce cost estimates suitable for inclusion. However, the results of the Contingent Valuation study (see Section 3.4.4) were used to set relative impact scores for changes in landscape quality. An overview of the entire countermeasure evaluation process in the CeserDSS is given in Figure 46 (page 59).



Criteria/Countermeasure	Administer AFCF to upland sheep.	Lime the soil where upland sheep are.	Apply K fertiliser to area where upland sheep graze.	Sell upland lambs early for fattening.
Soil Erosion and Sedimentation	No Effect	No Effect	No Effect	No Effect
Soil Organic Matter	No Effect	Moderately	Slightly Decreases	No Effect
Soil Nutrient Transport to Water	No Effect	Slightly Increases	Slightly Increases	Slightly Decreases
Soil Pollutant Transport to Water	No Effect	Slightly Increases	Slightly Increases	No Effect
Animal Welfare	No Effect	Slightly Decreases	Slightly Decreases	Slightly Decreases
Product Quality	No Effect	Slightly Decreases	Slightly Decreases	No Effect
Product Quantity	No Effect	No Effect	No Effect	Moderately Decreases
Ammonia Emissions	No Effect	No Effect	No Effect	No Effect
Biodiversity	No Effect	Slightly Increases	No Effect	Slightly Increases
Landscape Quality	No Effect	No Effect	No Effect	No Effect

Figure 39. Example of an evaluation matrix of countermeasure alternatives and assessment criteria with impact scores from the CeserDSS.



Countermeasure	Costs	Benefits	Summary
Administer AFCF to upland sheep.	£ 450	£ 3200	£ 2750
Lime the soil where upland sheep are.	£ 3300	£ 3937	£ 637
Apply K fertiliser to area where upland sheep graze.	£ 1422	£ 3937	£ 2515
Sell upland lambs early for fattening.	£ 2400	£ 480	£ -1920

Figure 40. Example of economic assessment results in the CeserDSS for an upland sheep farm that normally finishes 100 lambs and has 50 ha of land suitable for liming and K application.

3.6.3. A Spatial Decision Support System (SDSS)

The formal integration of the spatial assessment of land suitability for countermeasure application and the assessment of potential environmental impacts into a GIS-based Spatial Decision Support System (SDSS) represents a potentially powerful tool for planning and evaluating countermeasures at the local, regional and national level (Salt & Culligan Dunsmore, submitted). This should encourage better decision-making strategies by improving the way in which substantial data sets are integrated and assessed (O'Callaghan, 1995). The integration of GIS and MCDM has previously been applied in agricultural land use (Jansen & Rietveld, 1990) and ecological planning (Grabaum & Meyer, 1998). Within the CESER project, we have designed and partially implemented such a system for the Scottish study sites, primarily intended for the optimisation of countermeasure strategies at the regional scale.

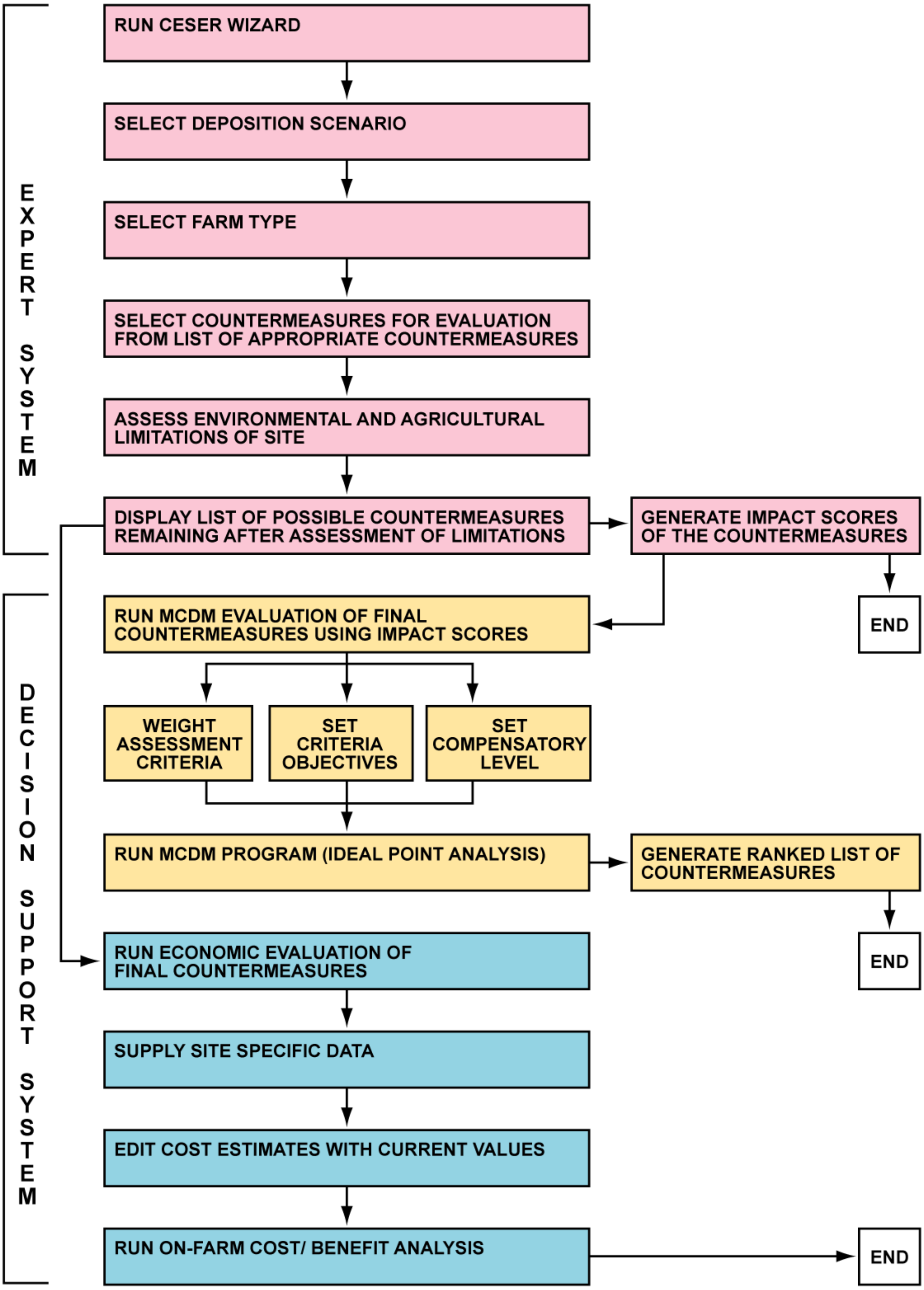


Figure 41. Overview of the countermeasure evaluation process in the non-spatial CeserDSS.

The GIS software package used to develop the SDSS is ArcView™ , version 3.1 (ESRI, 1997), a widely available PC-based system. The flexibility and user friendliness of the SDSS are key components in ensuring its success as a decision-making tool. In keeping with this objective, the inner workings of the spatial assessment process are shielded from the decision-maker by the use of a flexible, user-friendly interface, created using the programming language 'Avenue', available in ArcView™.

In the SDSS the environmental impacts quantified for each study catchment are combined with the topography, soil and land use data to create spatial data coverages depicting the magnitude of ‘impact risk’ posed by each countermeasure (see Figures 29-32, page 39-40). For each combination of countermeasure and assessment criterion an individual impact map is generated. These maps form the basis of the suitability scores calculated using Ideal Point Analysis (Salt *et al.*, 1999c). Due to a number of modelling, time and data constraints, it was necessary to pre-process these maps.

The impact maps used by the SDSS are raster-based maps resulting from the land suitability and environmental impact assessment undertaken for each combination of countermeasure and assessment criterion. Land suitability is determined using the set of limiting factors of the physical environment that exclude the implementation of the countermeasure (Table 13 & 14, page 34,35). The defined thresholds of implementation are used to 'mask out' cells from within the study areas that are deemed unsuitable. For example, deep ploughing on slopes > 15° is not recommended. Therefore, all cells with a slope greater than this value are excluded from the spatial assessment. Figure 47 and 48 (page 61) show examples of suitability maps for a Scottish catchment.

The values on the impact maps range from between –1.0 (greatly decreases impact on criterion) and +1.0 (greatly increases impact on criterion) with a score of zero indicating that no impact has been incurred (Fig. 26, page 34). Both qualitatively and quantitatively assessed impact maps are portrayed in this way. It is necessary to first normalise the results from the quantitatively assessed criteria, such as the soil loss figures generated by the erosion model in ICECREAM, to fit this impact scale.

The countermeasure selection process within the SDSS is spatially specific and begins by asking the user to select the co-ordinates of their study catchment, the resolution at which they would like to work and one of the 4 deposition scenarios (Table 1, page 4). Then, based on the farm types that occur within the catchment boundaries and the deposition scenario selected, the user is presented with a list of countermeasures that can be applied. From this list, the user can opt to either undertake a suitability assessment for one or several countermeasures. After this, the user is asked to define the weights and ‘ideals’ for each of the assessment criteria. The ideal values use the same scale as the impact maps (Figure 26, page 33). The ideal value for the criterion ‘soil erosion and sedimentation’, for example, would most likely be the objective ‘greatly decrease’. The weights range on a scale of 1-10 and should be used to reflect the decision-makers own biases and objectives in the decision-making process. For example, a farmer might rate product quality and animal welfare highly in order to reflect a personal objective to ensure his/her own economic welfare.

Once the weights and ideals have been defined, the MCDM programme calculates a final score for each alternative (raster cell) based on its specific distance away from the ideal criteria vector. The resulting scores for the alternatives are then stored as a raster map for further analysis and display. Once this process has been completed, there will be a raster map for each countermeasure. Each cell within these coverages will contain a value relating to the calculated suitability based on the assessment of all impacts. By comparing the values of each of the raster cells across the coverages, a map depicting the ‘most suitable’ countermeasures, i.e. with the lowest overall impact on all criteria, for the study area can be created. The final output from the SDSS will be either a suitability map for a single countermeasure or a thematic map depicting the ‘most suitable’ countermeasures for a given area, based on the outcome of the land suitability and environmental impact assessment. An overview of the entire countermeasure evaluation process in the SDSS is given in Figure 49 (page 62).

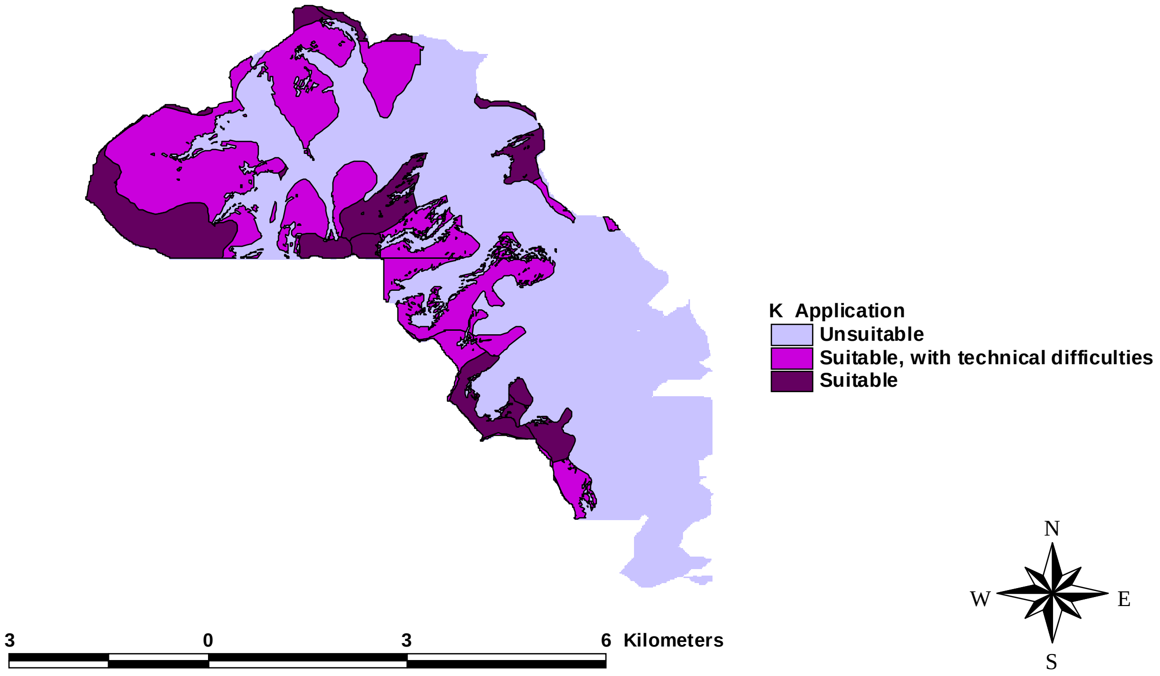


Figure 47. Land suitability map for soil application of potassium in the catchment of the Lugate Water, south-east Scotland. (Suitable areas are defined on the basis of soil pH and CEC, slope and height of vegetation. Areas with dwarf shrub communities are defined as 'suitable, with technical difficulties' due to potential difficulties for spreading equipment.).

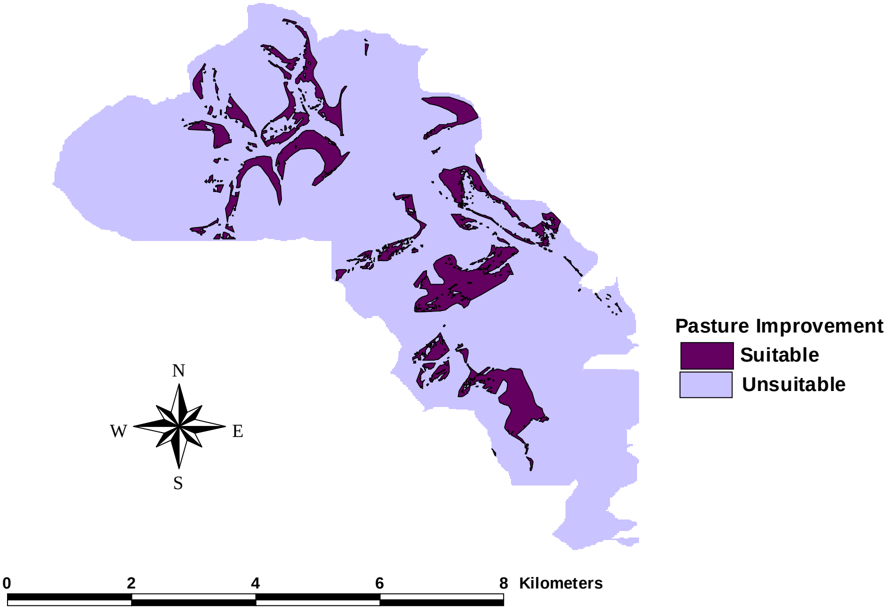


Figure 48. Land suitability map for pasture improvement in the catchment of the Lugate Water, south-east Scotland. (The scope for pasture improvement on rough grazing is based on slope, soil depth, stoniness, soil type and water regime.).

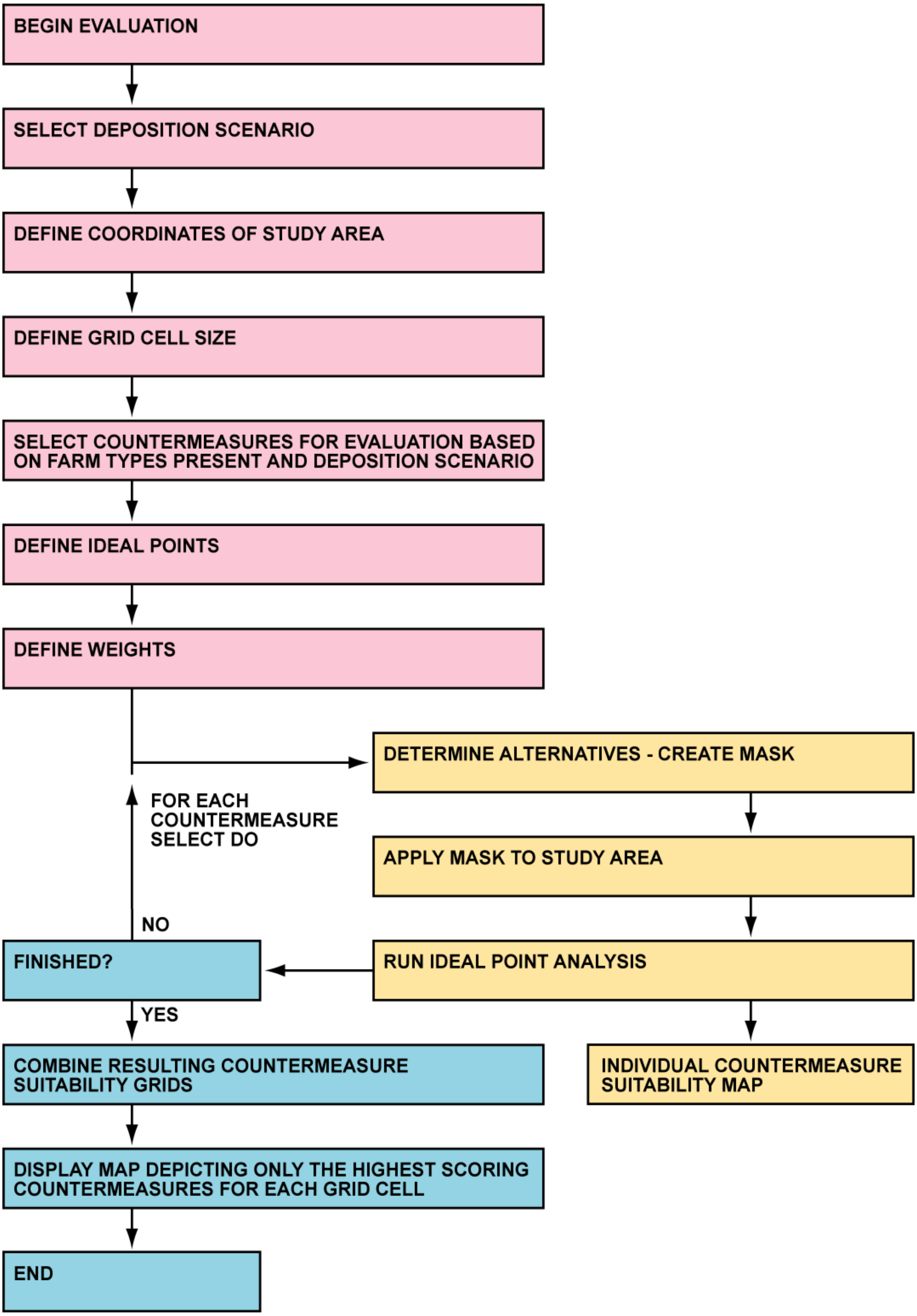


Figure 42. Overview of the countermeasure evaluation process within the CESER Spatial Decision Support System.

4. MAIN ACHIEVEMENTS AND LIMITATIONS

4.1. Project Contribution to Radiation Protection

The CESER project has made significant progress in the development of holistic countermeasure strategies by integrating previously neglected issues of private and environmental costs and benefits, environmental management, and consumer attitudes and behaviour into the countermeasure selection process. The project's decision-aiding tools will assist decision makers in achieving the required reductions in food contamination, whilst taking account of the suitability of countermeasures for local conditions, and allowing environmental and socio-economic impacts to be minimised.

The CESER methodology for the assessment of environmental and socio-economic side-effects of countermeasures has been successfully applied in realistic case study scenarios for Austria, Finland and Scotland. Generic criteria were selected to characterise the most significant side-effects on water, air, soil and landscape quality, biodiversity and agricultural productivity. To provide quantitative estimates of these side-effects, a combination of mathematical simulation modelling, calculations, experimentation, contingent valuation, landscape structure analysis and expert judgement was applied. A formal selection procedure was used to identify the countermeasure to be included in the impact quantification. Individual and combined countermeasures against radiostrontium and radiocaesium were allocated to farm types, based on radiological effectiveness under different radionuclide deposition scenarios and applicability to specific production systems and environments.

Experiments with AFCF demonstrated that in peat soils FCF-bound radiocaesium in animal manure can migrate more rapidly than caesium chloride. AFCF partially degrades when exposed to light, producing toxic hydrocyanide gas, though concentrations under field conditions when animal manure is spread are unlikely to exceed occupational exposure limits. After application of countermeasures such as liming and ploughing, the increased mineralisation of soil organic matter can promote leaching of fulvic acid-bound nutrients, radionuclides and heavy metals in sandy and some peat soils. Geochemical speciation modelling indicates that liming and application of potassium fertiliser may also imbalance ionic ratios in soil solution thereby interfering with plant nutrition and uptake of toxic metals. Experiments with mycorrhiza showed that potassium had no effect on mycorrhizal infection of host plants but depressed calcium uptake.

Model simulations for arable land show that skim and bury ploughing has no major side-effects provided a good vegetation cover is subsequently established to minimise erosion. Deep ploughing in comparison leads to more significant changes. Depending on the nature of the subsoil long-term rates of soil erosion may increase or decrease, while in general phosphorus losses to water bodies and thus the risk of eutrophication will decrease. This is likely to be accompanied by lower crop yields due to poor soil structure, lower organic matter content and lower nutrient supplies. Modelling results also demonstrate that changes in land use can seriously increase soil erosion when permanent grassland is converted to arable production, e.g. when grass in the animal diet is partly replaced with cereal feed. Inputs of phosphorus and nitrogen to water bodies may also increase depending on the intensity of the original grassland production and the mode of fertilisation. Increased feeding of concentrates to dairy cows is likely to increase nitrogen inputs to soils, however, if this concentrate is imported negative side-effects are offset by lower grass production within a catchment. In areas dominated by dairy production, increased feeding of concentrate will increase ammonia emissions from cows with potential negative effects on local ecosystems. National emissions would only rise significantly if feeding countermeasures were applied to a large proportion of the total herd.

Changes in biodiversity, assessed via landscape and habitat structure, were predicted to be negative when the countermeasures made the landscape more monotonous e.g. large scale afforestation or intensive cultivation of pastures. A more varied mosaic of land uses, e.g. through the introduction of barley and fallow into a grass-dominated landscape, would most likely increase biodiversity.

Quantitative estimates of environmental impacts were scaled up to catchment, regional or national level by applying GIS techniques. Impact maps were used to identify areas of high and low impact risk while catchment inventories were used to illustrate the net effects of selected countermeasure scenarios. Suitability maps were used to show the geographical distribution of areas suitable and unsuitable for a particular countermeasure.

For all countermeasures, calculation methods for on-farm costs and benefits were devised and incorporated into the non-spatial decision support system (CeserDSS). Environmental costs of countermeasures have for the first time been quantified, as follows: a) Contingent Valuation, used to value changes in landscape quality following afforestation and pasture improvement, showed clear differences in people's Willingness to Pay depending on the type of landscape; b) Transferable environmental costs in the literature were identified for soil erosion and nutrient transport to water. To quantify the benefits of countermeasures to society the avoided loss of product output, measured via people's willingness to pay for 'clean' food, was chosen in preference to health detriment costs.

The consumer survey in Norway and Scotland showed that the Chernobyl accident still has a negative impact on consumption levels of certain foods. Despite Government actions to limit contamination and assurances to consumers, people are still concerned about these foods and their perceived risk is higher than the experts’ calculated risk. Consumers prefer to buy 'clean' food from non-contaminated areas compared to areas where countermeasures have been implemented, and are willing to pay higher prices. In a future fallout situation the impacts on market demand will depend on whether it is possible to reduce the consumers’ perceived risk by improving information and communication. If not, Governments and food retailers must take into account the consumers’ 'overestimated' perceived risk to limit costs. Three consumer strategies for decision-makers are proposed in the report.

Two computer based decision support systems have been developed to provide formal procedures for selecting, evaluating and comparing countermeasures. In order to accommodate varying levels of spatial data availability and technical sophistication, two types of DSS have been designed: 1) the CeserDSS, a non-spatial assessment tool for a single area/farm using Windows-based software; and 2) the Spatial DSS, a more generic assessment tool for larger, heterogeneous areas using a GIS. Both systems have been developed for Scottish agriculture to demonstrate the benefits of a country specific countermeasure evaluation. The countermeasure selection process ensures suitability for local or regional agricultural and environmental conditions whilst providing a tool for judging environmental and agricultural side-effects and calculating on-farm costs and benefits. The incorporation of a Multicriteria Decision Making technique gives the user the opportunity to influence the assessment criteria and generate compromise alternatives. The final outcome is a set of countermeasure suitability rankings or suitability maps, with which remediation strategies can be optimised.

4.2. Limitations and Opportunities

CESER was the first project to be dedicated to the study of countermeasure side-effects and started from a poor knowledge base. It was not possible to quantify and spatially represent all side-effects from a wide range of countermeasures in the same detail, due to a lack of suitable models for all impacts and a limited understanding of the underlying environmental and biological processes, as well as time constraints. Although the models selected have been validated for normal agricultural practices, especially in the US, they have not been validated in terms of their suitability to model the effects of countermeasures. There is scope for major improvements in the validation and testing of models and the analyses of the errors involved. Despite these limitations the impact assessment methodology developed was shown to be suitable when applied to a series of case studies. Future research should expand it's application to more countries.

A full economic cost-benefit analysis was not possible since transferable cost estimates for many environmental impacts are lacking. Further original work should be undertaken to provide these estimates and thereby allow environmental costs to be included alongside farm-level costs, in the Decision Support System. A more complete picture of countermeasure benefits could be gained by investigating Willingness-to-Pay for a wider range of food products.

The analysis of the Scottish survey was restricted as only 200 people were interviewed. In Scotland interviews had to be conducted since mail surveys are ineffective, whereas in Norway excellent response rates are achieved with mail surveys. One disadvantage of mail surveys is the inability to validate respondents' understanding of the questions. The survey indicated that people had little confidence in countermeasures, but this could be influenced by their level knowledge of countermeasures. Further work should be conducted to study whether improved understanding could positively influence the degree of acceptability.

Decision Support Systems, such as the CeserDSS, cannot truly reflect the complexities of a decision making process and require some abstraction. The user inputs needed to run the software are therefore a compromise between what is scientifically desirable and practically possible. To produce a useable system it was necessary to include essential aspects of the countermeasure selection process such as the prediction of contamination levels in foodstuffs and the radiological effectiveness of countermeasures. These aspects had to be treated in less detail than would have been desirable from a radiation protection perspective. Many features in the software are pre-determined; i.e. the deposition scenarios and farm types, thereby restricting the applicability. A major improvement would be the option of entering real measurements of radionuclide deposition. These could serve as input to a mathematical simulation model that would predict the level of contamination in food products and thereby determine the required effectiveness of any countermeasures. A choice of appropriate countermeasures could then be offered with the option of allowing manipulation of the decontamination factors to reflect local conditions. A further significant improvement would be the incorporation of time-dependent processes. Currently the DSS assumes that countermeasures will be required for 10 years. Integration of a dynamic simulation model could provide estimates of the time over which countermeasures are required. These could be used to adjust the environmental impact scores accordingly.

The Spatial Decision Support System has similar weaknesses to the CeserDSS in terms of it's inflexibility. It was not feasible to dynamically link the models, used in the prediction of side-effects, with the GIS. This was partly due to the user-unfriendly format of the models but also due to the very large number of parameters a user would have to enter. Therefore all impact maps for the case study areas had to be pre-processed and the spatial assessment is restricted to the geographic areas included in the software. Due to time constraints a working version of the SDSS was not completed but important lessons have been learnt that will help to improve future systems.

The CESER project has shown that countermeasures can have significant environmental and socio-economic impacts and has developed methods that allow these impacts to be evaluated as an integral part of the countermeasure selection process. The relative importance of environmental impacts will be location specific and depend on factors such as existing environmental pressures, ecosystem sensitivity and environmental policies. It may be possible to mitigate many impacts with good environmental management. Decision-makers have the difficult task of balancing environmental costs to society with the direct costs of countermeasures, the benefits of dose reduction and of avoided loss of food production. The acceptability of policies to the consumer will be a crucial factor in ensuring the success of any countermeasure strategy.

4.3. Deliverables

Desmet, G., Gutierrez, J. , Vasquez, C., Salt, C. A., Vandehove, H., Voigt, G. & Zeevaert, T. (1998). Techniques and Management Strategies for Environmental Restoration. Mid-Term Report of the EURATOM-CIEMAT Association Contract. CIEMAT, Madrid. 215 p.

The following technical deliverables will be made available over the project web site: http://www.stir.ac.uk/envsci/ceser/ceser.htm

Grande J., Bjørnstand, E., Hanley, N.D. & Wilson, M.D. (1999). Assessment of Consumer Risk Attitudes and Behaviour Related to Countermeasures and Radioactive Contamination of Food. Nord-Trøndelag College, Steinkjer, Norway.

Salt, C.A., Culligan Dunsmore, M., Wilson, M., Hansen, H.S., Kirchner, G., Lettner, H. & Rekolainen, S. (1999). The CESER Decision Support System. University of Stirling, Stirling, UK.

Salt, C.A., Hansen, H.S., Kirchner,G., Lettner, H., Rekolainen, S. & Culligan Dunsmore, M. (1999). Impact Assessment Methodology for Side-Effects of Countermeasures against Radionuclide Contamination in Food Products. Research Report No 1, ISBN 82-7456-119-8, Nord-Troendelag College, Steinkjer, Norway.

Salt, C.A., Rekolainen, S., Culligan-Dunsmore, M., Bärlund, I. & Tattari, S. (1999). Spatial Assessment of Countermeasures. University of Stirling, Stirling, UK.

Wilson, M.D., Hanley, N.D. & Salt, C.A. (1999). Economic Assessment of Countermeasures. University of Stirling, UK.

4.4. Conference Publications and Reports

Bärlund, I. & Tattari, S. (1998): Can few parameters determine model output? Sensitivity analysis of ICECREAM. XX Nordic Hydrological Conference, Helsinki, Finland, 10.-13. August 1998, Kajander, J. (ed.), NHP-Report 44, Helsinki, Finland, Vol. 2, pp. 459-468. ISBN 952-11-03221.

Bärlund, I., Tattari, S. & Rekolainen S. (1998): Assessment of agricultural management practices on phosphorus loads using the ICECREAM model. In: Foy, R.H. and Dils, R. (eds.), Practical and Innovative Measures for the Control of Agricultural Phosphorus Losses to Water, OECD Workshop, Greenmount College of Agriculture and Horticulture, Northern Ireland, June 1998, pp. 36-37. ISBN 1-85527-354-3.

Bärlund, I. & Tattari, S. (1999): Modification of USLE for Northern European conditions. Geophysical Research Abstracts, Vol. 1, No. 2. European Geophysical Society, 24th General Assembly, p. 280. ISSN: 1029-7006

Bärlund, I., Tattari, S. & Rekolainen, S. (1999): CESER - radioaktiivisen laskeuman vastatoimenpiteiden pitkäaikaiset ympäristövaikutukset. Conference abstract (Finnish). In: Kultima, J. & Manninen, J. (eds.) XIX Geofysiikan päivät. Geofysiikan seura, Oulu, pp. 123-128. ISBN 951-97663-1-6

Culligan-Dunsmore, M. & Salt, C.A. (1998). A GIS-based spatial decision support system using multicriteria decision making methodology for radiological countermeasure suitability assessment. First International Conference on Geospatial Information in Agriculture and Forestry. 1-3 June 1998, Florida USA. 645-652. ISSN 1089-3155.

Grande, J. (1998). Consumer Risk Perception, Attitudes and Behaviour Related to Food Affected by Radioactive Contamination. Working Paper 55, Nord-Trøndelag College, Steinkjer, Norway.

Grande, J. (1998). Consumer risk perception, attitudes and behaviour related to food affected by radioactive contamination. Nordic Conference on Consumer Research: Forskning om konsumentarnas vilkor og värderingar i en ny tid. 11.-14. November 1998, Lillehammer, Norway.

Grande, J (1999). Consumer risk perception, attitudes and behaviour related to food affected by radioactive contamination. Nordisk Jordbruksforskning no. 2/1999, Vol 81. Nordic Association of Agricultural Scientists XXI Congress 1999. Agricultural University of Norway, Ås, 28/6 - 1/7.

Hanley, N., Salt, C.A., Wilson, M.D. & Culligan Dunsmore, M. (1999). Evalulating “countermeasures” against nuclear accidents: implications for the environment and food production systems. Agricultural Economics Society Conference, Belfast , 26-29 March 1999.

Hansen, H.S., Grande, J & Salt, C.A. (1998). Side effects of countermeasures for reducing the transfer of radioactive isotopes to food products (in Norwegian). Proceedings of the Animal Research Conference, Agricultural University of Norway, Ås, February 10-11.1998. pp 430-433.

Hansen, H. S., Salt, C.A, Kirchner, G., Rekolainen, S., Lettner, H., Grande, J., Wilson, M., Culligan-Dunsmore, M., Tattari, S., Barlund, I., Ehlers, H., Hormann, V., Gastberger, M., Hosner, F., Peer.

T. & Pintaric. M. (1999). Environmental and socio-economic impacts of agricultural countermeasures. Second International Symposium on Ionizing Radiation. Ottawa, Canada, May 1999.

Hormann, V.& Kirchner,G. (1999). Calculation of the impact of soil-based chemical countermeasures on soil solution chemistry. 7th Int. Conf. on the Chemistry and Migration Behaviour of Actinides and Fission Products in the Geosphere. Incline Village (USA), Sept. 26 - Oct. 1, 1999.

Kirchner, G., Salt, C.A., Lettner, H., Hansen, H.S., & Rekolainen, S. (1998). Integrated long-term management of radioactively contaminated land. International Radiological Post-Emergency Response Conference, Washington DC, USA. Sept. 1998. pp. 118-122. Environmental Protection Agency.

Lettner, H., Gastberger, M., Hosner, F., Peer, T., Pintaric, M., & Achleitner, A. (1999): Enhanced Cs-137 mobility in soils after AFCF application to animals. Book of abstracts. IRPA regional congress on radiation protection, 22-27 Aug. 1999, Budapest, Hungary.

Salt, C.A., Hansen, H.S., Kirchner, G, Lettner, H., Rekolainen, S. & Desmet, G. (1998). Integrating environmental and socio-economic impacts into countermeasure decision making. IUR Topical meeting, Mol, Belgium, 1-5 June 1998. Abstract.

Salt, C.A. & Rekolainen, S. (1998). Integrated long-term management of radioactively contaminated land: the CESER project. In: Contaminated Soil '98, 17-21 May, Edinburgh, Thomas Telford, London, pp.1113-1114. ISBN 0 7277 2675 7.

Tattari, S. & Bärlund, I. (1998): Modelling phosphorus transport in agricultural catchments. In: Foy, R.H. and Dils, R. (eds.), Practical and Innovative Measures for the Control of Agricultural Phosphorus Losses to Water, OECD workshop, Greenmount College of Agriculture and Horticulture, Northern Ireland, June 1998, pp. 34-35. ISBN 1-85527-354-3.

Tattari, S. & Bärlund, I. (1999): The concept of sensitivity in sediment yield modelling. Geophysical Research Abstracts, Vol. 1, No. 2. European Geophysical Society, 24th General Assembly, p. 279. ISSN: 1029-7006

Tattari, S. and Bärlund, I. (1999): USLE-mallin epävarmuus-ja herkkyysanalyysi. Conference abstract (Finnish). In: Kultima, J. and Manninen, J. (eds.) XIX Geofysiikan päivät. Geofysiikan seura, Oulu, pp. 129-134. ISBN 951-97663-1-6

4.5. Scientific Papers Submitted

Bärlund, I. & Tattari, S., (submitted). Can a limited number of parameters determine model output? - A sensitivity analysis of ICECREAM. Ecological Modelling.

Hanley, N., Salt, C.A., Wilson, M.D. & Culligan Dunsmore, M. (submitted). Evaluating the private and environmental costs of countermeasures against nuclear accidents. Journal of Agricultural Economics.

Luoto, M., Rekolainen, S., Salt, C.A. & Hansen, H.S. (submitted). Spatial modelling of changes in habitat diversity resulting from the management of radioactively contaminated agricultural land. Environmental Management.

Salt, C.A. & Culligan Dunsmore, M. (submitted). Development of a spatial decision support system for post-emergency management of radioactively contaminated land. Journal of Environmental Management.

Tattari, S. & Bärlund, I. (submitted): The concept of sensitivity in sediment yield modelling. Physics and Chemistry of the Earth.

4.6. Software

The CESER Decision Support System has been delivered to the EC on CD-ROM and the software will be made freely available via the project web site at the University of Stirling (http://www.stir.ac.uk/envsci/ceser/ceser.htm). It is in a user-friendly format that will allow a wide range of users to access and test it.

5. REFERENCES

Amberger, A. (1983). Pflanzenernährung: Ökologische und Physiologische Grundlagen, Dynamik und Stoffwechsel der Nährelemente. Ulmer, Stuttgart.

Aubert, C. (1981). Organischer Landbau. Ulmer Verlag, Stuttgart, pp248

Auerswald, K. & Schmid, F. (1986). Atlas der Erosionsgefährdung in Bayern. Fachberichte. Geologisches Landesamt. München

Brünjes, F., Barnewitz, H. & Kirchner, G. (in press). Diffusion and diffusion-convection experiments for studying the sorption of radionuclides in soils. Czechoslovak Journal of Physics.

BMU-Bundesministerium fuer Umwelt, Naturschutz und Reaktorsicherheit (1989). Bekanntmachung der Dosisfaktoren Aeussere Exposition – Erwachsene und Kleinkinder (1 Jahr). Bundesanzeiger, Jahrgang 41, Nr. 185a.

Carver, S.J. (1991). Integrating multicriteria evaluation with geographical information systems. International Journal of GIS, 5, 321-339.

CEC (1989). Council Regulation (Euratom) No. 2218/89 amending Regulation (Euratom) No.3954/87 laying down maximum permitted levels of radioactive contamination of foodstuffs and of feedingstuffs following a nuclear accident or any other case of radiological emergency. Official Journal of the European Communities, L211/1.

Czerwinka, W. (1951). Veränderungen von Grünlandgesellschaften durch Kulturmaßnahmen. Angewandte Pflanzensoziologie, 1,93-107.

ESRI (1997) ArcView, Version 3.1 Environmental Systems Research Institute, Inc., Redlands, California, USA.

EU - Council of the European Union (1996). Basic Safety Standards for the Protection of the Health of Workers and of the Public against the Dangers arising from Ionising Radiation. Council Directive 96/29/EURATOM, 26 May 1996. Official Journal of the European Communities L 159.

Evans, R. (1981). Assessments of soil erosion and peat wastage for parts of East Anglia, England: A field visit. In: R. P. C. Morgan. Soil Conservation: Problems and Prospects. Chichester, Wiley, pp. 520-530.

Evans, R. & Cook, S. (1987). Soil erosion in Britain. SEESOIL, 3, 28-59.

Fishbein, M. (1980). An overview of the attitude construct. In: G.B. Hafer (Ed.). A Look Back, A Look Ahead. American Marketing Association, Chicago.

Frost, C.A., Speirs, R.B. and McLean, J. (1990). Erosion control for the UK: Strategies and short-term costs and benefits. In: J. Boardman, I.D.L. Foster & J.A. Dearing. Soil Erosion on Agricultural Land. Chichester, Wiley, pp. 559-567.

Grabaum, R. & Meyer, B.C. (1998). Multicriteria optimization of landscapes using GIS-based functional assessments. Landscape and Urban Planning, 43, 21-34.

Grande J., Bjørnstand, E., Hanley, N.D. & Wilson, M.D. (1999). Assessment of Consumer Risk Attitudes and Behaviour Related to Countermeasures and Radioactive Contamination of Food. Contract Deliverable of the CESER Project (FI4P-CT95-0021), EU Nuclear Fission Safety Programme, Nord-Trøndelag College, Steinkjer, Norway.

Gren, I., Elofsson, K. and Jannke, P. (1995). Costs of Nutrient Reductions to the Baltic Sea. Beijer Discussion Paper Series No 70.

Grobe, D. & Douhitt, R. (1995). Consumer acceptance of recombinant bovine growth hormone: interplay between beliefs and perceived risk. The Journal of Consumer Affairs, 29, 128-143.

Grönroos, J., Nikander, A., Syri, S., Rekolainen, S. & Ekqvist, M. (1998). Ammonia Emissions from Agriculture. Part 1: Trends in Emissions. Part 2: Measures and Costs for Abatement of Emissions. Suomen Ympäristö 206. 68 s. Helsinki. (In Finnish).

Hanley, N. & Spash, C. (1994). Cost-Benefit Analysis and the Environment. Edward Elgar, Cheltenham,.

Hanley, N., Shogren, J. & White, B. (1997). Environmental Economics in Theory and Practice. MacMillan, Basingstoke.

Haselwandter, K. & Berreck, M. (1994). Accumulation of radionuclides in fungi. In: Metal Ions in Fungi (G. Winkelmann & D.R. Winge, eds.), Marcel Dekker, Inc. New York, pp. 259-277.

Hedeman Jensen, P. (1999). Methodology for Ranking Restoration Options. RESTRAT Technical Deliverable 8, Risø National Laboratory, Roskilde.

Henson, S. (1995). Demand-side constraints on the introduction of new food technologies: the case of food irradiation. Food Policy, 20, 111-127.

Hove, K., Lønsjø, H., Andersson, I., Sormunen-Cristian, R., Hansen, H.S., Indriadson, K., Joensen, H., P., Kossila, V., Liken, A., Magnusson, S., Nielsen, S.P., Passikallio, A., Palsson, S.E., Rósen, K., Strand, P.& Vestergaard, T. (1994). Radiocaesium transfer to grazing sheep in Nordic environments. In: H. Dahlgaard (ed), Nordic Radioecology. Transfer of Radionuclides through Nordic Ecosystems to Man. Elsevier, Amsterdam. pp. 211-227.

IAEA (1994a). Guidelines for Agricultural Countermeasures Following an Accidental Release of Radionuclides. Technical Report Series No.363. IAEA, Vienna.

IAEA (1994b). Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments. Technical Report Series No 364, IAEA, Vienna.

Jankowski, P. (1995). Integrating geographical information systems and multiple-criteria decision-making methods. International Journal of Geographical Information Systems, 9, 251-273.

Jansen, R. & Rietveld, P. (1990). Multicriteria analysis and geographical information systems: an application to agricultural land use in the Netherlands. In: Scholten, H.J.& Stillwell, J.C.H. (eds). Geographical Information Systems for Urban and Regional Planning, pp. 129-139. Kluwer.

Kirchner, G., Baumgartner, D., Delitzsch, V., Schabl, G. & Wellner, R. (1993). Laboratory studies on the sorption behaviour of fallout radionuclides in agricultural used soil. Modelling Geo-Biosphere Processes, 2, 115-127.

Knisel, W.G. (ed.) (1980). CREAMS, A Field Scale Model for Chemicals, Runoff and Erosion from Agricultural Management Systems, USDA, Conservation Research Report No. 26, 643 pp.

Knisel, W.G. (1993). GLEAMS, Groundwater Loading Effects of Agricultural Management Systems, Version 2.1. UGA-CPES-BAED Publ. No. 5. University of Georgia, Tifton, GA.

Kölling, M. (1992). Modellierung geogener Grundwasserbeschaffenheit an Beispielen aus dem norddeutschen Flachland. In: DVWK (ed.): Anwendung hydrogeochemischer Modelle, DVWK-Schriften 100, Verlag Paul Parey, Hamburg, pp.97-200.

Lettner, H. (1990). Post-Chernobyl distribution of the ^{137}Cs concentration in soil and environmental samples in mountainous and plain areas of the Province of Salzburg, Austria. Proc. of the Int. Symp. on Environmental Contamination Following a Major Nuclear Accident, Rep.No. IAEA-SM-306/60, Vienna, 193- 203.

Luoto, M., Rekolainen, S., Salt, C.A., Hansen, H.S. (submitted). Spatial modelling of changes in habitat diversity resulting from the management of radioactively contaminated agricultural land. Environmental Management.

McGarical, K. & Marks, B.J.. (1994). Fragstats, Spatial Pattern Analysis Programme for Quantifying Landscape Structure. Version 2.0. Forest Science Department, Oregon State University, Corvallis, Oregon. 67 pp.

MAK-Werteliste (1994). Kundmachung des BM f. Arbeit und Soziales, 28.12.1994 über maximale Arbeitsplatzkonzentrationen und technische Richtkonzentrationen (MAK-Werteliste). Amtl. Nachrichten / Arbeit-Gesundheit-Soziales. 48.Jg.,SNr.2/1993.

Meisel, K. (1977). Auswirkungen landwirtschaftlicher Intensivierungsmaßnahmen auf die Acker- und Grünlandvegetation und die Bedeutung landwirtschaftlicher Problemgebiete für den Artenschutz. Jahrbuch. Naturschutz und. Landschaftspflege. 27, 63-74.

Merkhofer, M.W. & Keeney, R.L (1987). A multi-attribute utility analysis of alternative sites for the disposal of nuclear waste. Risk Analysis, 7, 173-194

Nisbet, A. F. (1995). Evaluation of the Applicability of Agricultural Countermeasures for Use in the UK. NRPB Report M551, National Radiation Protection Board, Didcot.

O'Callaghan, J.R. (1995). NELUP: An introduction. Journal of Environmental Planning and Management, 38, 5-20.

Österreichische Bodenkartierung (1978). Kartierungsbereich Neumarkt am Wallersee. Bundesministerium für Land- und Forstwirtschaft, Salzburg.

Österreichische Bodenkartierung (1986). Kartierungsbereich Radstadt. Bundesministerium für Land- und Forstwirtschaft. Salzburg.

Pain, B.F., Misselbrook, T.H., Jarvis, S.C., Chambers, B.J., Smith, K.A., Webb, J., Phillips, V.R., Sneath, R.W. & Demmers, T.G.M. (1997). Inventory of Ammonia Emission from UK Agriculture. MAFF Contract WA0630.

Parkhurst, D. L. (1982). User's Guide to PHREEQC - a Computer Program for Speciation, Reaction-Path, Advective-Transport and Inverse Geochemical Calculations,U.S. Geological Survey, Water-Resources Investigations Report 95-4227, 1995.

Paul, J.W., Dinn, N.E., Kannangara, T.& Fisher, L.J. (1998). Protein content in dairy cattle diets affects ammonia losses and fertilizer nitrogen value. Journal of Environmental Quality, 27, 528-534.

Pirklhuber, W. & Gründlinger, K. (1993). Der biologische Landbau in Österreich. Umweltbundesamt, Austrian Ministry for Environment, Vienna.

Pitel, J. (1990). Multicriterion Optimization and Its Utilization in Agriculture. Elsevier, Oxford.

Quade, J. (1993). Faustzahlen für Landwirtschaft und Gartenbau. Landwirtschaftsverlag, Münster-Hiltrup.

Quine, C.P. & White, I.M.S. (1993). Revised Windiness Scores for the Windthrow Hazard Classification; the Revised Scoring Method. Research Information Note 230, Forestry Commission, Edinburgh.

Rekolainen, S. & Posch, M. (1993). Adapting the CREAMS model for Finnish conditions. Nordic Hydrology, 24, 309-322.

Ribaudo, M. O. (1986). Reducing Soil Erosion: Offsite Benefits. AER-561. ERS, USDA. Washington, DC.

Roed, J., Andersson, K.G. & Prip, H. (1995). Practical Means for Decontamination 9 years after a Nuclear Accident. Risø-R-828 (EN) Risø National Laboratory.

Roed, J., Andersson, K.G. & Prip, H. (1996). The skim and burial plough: a new implement for reclamation of radioactively contaminated land. Journal of Environmental Radioactivity, 33, 117-128.

Rogers, R.D. & Williams, S.E. (1986). Vesicular-arbuscular mycorrhiza: Influence on plant uptake of cesium and cobalt. Soil Biology and Biochemistry 18/4, 371-376.

Rumack, B.H. & Lovejoy, F.H. (1991). Clinical toxicology. In: Casarett and Doull´s Toxicology. The Basic Science of Poisons. Amdurm, M.O., Doull, J. & Klaassen, C.D. (eds.) Pergamon Press, New York, pp.924-946.

SAC (1998). The Farm Management Handbook 1998/99. Scottish Agricultural College. Edinburgh.

Salt, C.A. & Culligan Dunsmore, M. (submitted). Development of a spatial decision support system for post-emergency management of radioactively contaminated land. Journal of Environmental Management.

Salt, C.A., Culligan Dunsmore, M., Wilson, M., Hansen, H.S., Kirchner, G., Lettner, H. & Rekolainen, S. (1999a). The CESER Decision Support System. Contract Deliverable of the CESER Project (FI4P-CT95-0021), EU Nuclear Fission Safety Programme. University of Stirling, Stirling, UK.

Salt, C.A., Hansen, H.S., Kirchner,G., Lettner, H., Rekolainen, S. & Culligan Dunsmore, M. (1999b). Impact Assessment Methodology for Side-Effects of Countermeasures against Radionuclide Contamination in Food Products. Research Report No 1, Nord-Troendelag College, Steinkjer, Norway.

Salt, C.A., Rekolainen, S., Culligan-Dunsmore, M., Bärlund, I. & Tattari, S. (1999c). Spatial Assessment of Countermeasures. Contract Deliverable of the CESER Project (FI4P-CT95-0021), EU Nuclear Fission Safety Programme. University of Stirling, Stirling, UK.

Schwertmann, U. (1981). Die Vorausschätzung des Bodenabtrags durch Wasser in Bayern. Verlag: Techn. Univ., Lehrstuhl f. Bodenkunde. München.

Sharpley, A.N., Jones, C.A., Gray, C. & Cole, C.V. (1984). A simplified soil and plant phosphorus model: II. Prediction of labile, organic and sorbed phosphorus. Soil Science Society of America Journal 48, 805-809.

Slovic, P. (1987). Perception of risk. Science. 236, 280-285.

Sparks, P. & Shepherd, R. (1994). Public perception of the potential hazards associated with food production and food consumption: An empirical study. Risk Analysis. 14, 799-806.

Speirs, R.B. & Frost, C.A. (1985). The increasing incidence of accelerated soil water erosion on arable land in the east of Scotland. Research and Development in Agriculture, 2, 161-167.

Tattari, S., Bärlund, I., Rekolainen, S., Posch, M., Siimes, K., Tuhkanen, H-R. & Yli-Halla, M. (In prep). Modelling sediment yield and phosphorus transport using ICECREAM.

Tveten, U., Brynildsen, L.I., Amundsen, I. & Bergan, T.D.S. (1998) Economic consequences of the Chernobyl accident in Norway in the decade 1986-1995. Journal of Environmental Radioactivity 41, 233-255.

Tønnesen, A., Reitan, J. B, Strand, P., Waldahl, R. & Weisæth L. (1995). Interpretation of radiation risk by the Norwegian population: A national survey in 1993. In: G. Sundnes. (Ed.). Biomedical and Psychosocial Consequences of Radiation from Man-Made Radionuclides in the Biosphere. Tapir Publishers, Trondheim

UNEP (United Nations Environment Programme) (1993). Guidelines for Country Studies on Biodiversity. Nairobi, UNEP.

Voogd, H. (1983). Multicriteria Evaluation for Urban and Regional Planning. Pion, London.

Weisæth, L. (1990). Reactions in Norway from the Chernobyl Disaster. In: Brustad, T. Langmark, F. & Reitan, J. B. (Eds.). Radiation and Cancer Risk. Hemisphere Publishing Corporation, New York.

Weisæth, L. (1991). Psychological reactions in Norway to nuclear fallout from the Chernobyl disaster. In: Couch, S.R. & Kroll-Smith, J. S. (Eds.) Communities at Risk. Collective Responses to Technological Hazards. New York, Peter Lang Publishing.

Wilkerson, V.A., Mertens, D.R. & Casper, D. P. (1997). Prediction of excretion of manure and nitrogen by Holstein dairy cattle. Journal of Dairy Science, 80, 3193-3204.

Wilson, M.D., Hanley, N.D. & Salt, C.A. (1999). Economic Assessment of Countermeasures. Contract Deliverable of the CESER Project (FI4P-CT95-0021), EU Nuclear Fission Safety Programme. University of Stirling, UK.

APPENDIX I - CONTACT ADDRESSES

Co-ordinator - United Kingdom

Dr Carol A. Salt Email: c.a.salt@stir.ac.uk
University of Stirling
Department of Environmental Science
Stirling
FK9 4LA
Tel 0044 1786 467852
Fax 0044 1786 467843

Finland

Dr Seppo Rekolainen Email: seppo.rekolainen@vyh.fi
Finnish Environment Institute
Impact Research Division
P.O.Box 140
FIN-00251 Helsinki
Tel. 00358-9-40300246
Fax. 00358-9-40300291

Norway

Dr Hanne Solheim Hansen Email: hanne.hansen@hint.no
Høgskolen i Nord-Trøndelag (HiNT)
Deaprtment of Resource Sciences
P. O. Box 145
N - 7700 Steinkjer
Tel 0047 74 11 21 18
Fax 0047 74 11 21 01

Germany

Dr Gerald Kirchner Email Kirchner@theo.physik.uni-bremen.de
Universitaet Bremen
Fachbereich Physik
Postfach 33 04 40
D-28334 Bremen
Tel 0049 421 218 3266
Fax 0049 421 218 3601

Austria

Dr Herbert Lettner Email herbert.lettner@mh.sbg.ac.at
University of Salzburg
Institute of Physics and Biophysics
Hellbrunnerstraße 34
5020 Salzburg
Austria
Tel 0043 662 8044 5702
Fax 0043 662 8044 5704