Forskningsrapport

Impact Assessment Methodology for Side-Effects of Countermeasures against Radionuclide Contamination of Food Products

Nord-Trøndelag College
Research Report No. 1

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Impact Assessment Methodology for Side-Effects of Countermeasures against Radionuclide Contamination of Food Products

The CESER Project

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Foreword

This document presents the methodology developed and applied in the CESER research project, «Countermeasures: Environmental and Socio-Economic Responses- A Long-Term Evaluation», and is a deliverable from this project to the European Commission. The project is organised and part funded by the Nuclear Fission Safety Programme under the IVth Framework Programme of the European Commission. The present research programme is co-ordinated by Dr. C. A Salt from the University of Stirling, UK and includes partners from the Finnish Environmental Institute, Finland; the University of Bremen, Germany; the University of Salzburg, Austria and the Nord-Trøndelag College, Norway. The duration of the project is from January 1997 to June 1999.

The project aims to quantify side-effects connected with the implementation of agricultural countermeasures after deposition of radionuclides in an area. This report documents the methodology developed and implemented to assess environmental and agricultural side-effects. The project also encompasses studies of socio-economic side-effects. These methodologies, however, are not documented in the present report. To quantify and evaluate environmental and agricultural side-effects of countermeasures, methods originally developed in environmental and agricultural sciences, have been adapted to countermeasures and their use under farm and catchment specific conditions. The process of selecting suitable countermeasures and assessing their agri-environmental impacts is formalised in a spatial and a non-spatial decision support system intended for use by decision makers after deposition of radionuclides in an area. We foresee that the methodology could be beneficial in other research areas involving interdisciplinary assessments, and the methodology is therefore made available through this publication. The present report describes the applied methodology, while results from the project will be published in the final report.

Sammendrag

Denne rapport er en del av et prosjektet som har som mål å kvantifisere bi-effekter av tiltak som settes i verk for å redusere overføring av radioaktive isotoper til matvarer. På lang sikt har overføring av ^{137}Cs og ^{90}Sr til matvarer størst betydning for akkumulering av radioaktivitet hos mennesker. Prosjektet har derfor konsentrert seg om tiltak for å redusere overføring av ^{137}Cs og ^{90}Sr til landbruksprodukter. I denne rapport beskrives metoden som ble utviklet for å kvantifisere mulige bi-effekter av aktuelle tiltak innen landbruket. Resultatene fra prosjektet vil bli publisert senere.

Bi-effekter på miljøet vil være helt avhengige av de lokale miljøforhold, driftssystemene på gården og hvilke tiltak som settes i verk. Metodisk tok vi derfor utgangspunkt i studieområder i Skottland (9), Finland (4) og Østerrike (2). Hvert studie område utgjorde et helt eller et avgrenset område av et nedslagsfelt. For hvert område ble det samlet informasjon om klima, jordtype, typer landbruksproduksjon, og produksjonsmetoder. Vi utviklet 4 ulike scenarier for nedfall av ^{137}Cs, ^{90}Sr og alfa-plutonium, for å simulere de mest sannsynlige situasjoner etter et fremtidig nedfall. Den minst dramatiske nedfallssituasjon (scenarie1) tilsvarer det som kom i områder i Norden med mest nedfall etter Tsjernobyl ulykken, mens det mest dramatiske scenarium tilsvarer situasjonen i nærområdet til Tsjernobyl kjernekraftverk.

Landbruksproduksjonen i de utvalgte studieområdene var korn, oljefrø, gras, egg, melk og kjøtt av kalv, okse, lam, svin, kylling og hjort. På grunnlag av nedfallsscenariene, type landbruksproduksjon og miljøforhold i området, tiltakenes effektivitet mot overføring av radioaktivitet til matvarer, direkte kostnader og gjennomførbarhet ble det valgt ut en rekke tiltak. Tiltakene er spesifikt tilpasset lokale produksjonsmetoder innen hvert studieområde. De tiltak som ble valgt ut som mest relevante for å redusere overføring av radioaktivitet fra jord til planter var dyppløying (0,5-1 m), avskraping av toppjordlaget (5 cm) og begraving av dette samtidig med pløying, pløying (20 cm) og kalium gjødsling, pløying kombinert med kalium gjødsling og kalking, pløying og kalking, dyrking av raps til energiproduksjon, brakklegging og planting av skog. De tiltak som ble valgt ut som mest relevante for å redusere overføring fra fôr til husdyrprodukter var tildeling av berlinerblått (ammonium jern-hexacyannoferrate, AFCF), ekstra tildeling av kalsium (ca. 200 g Ca per dag), fôring med ikke forurenset melkeerstatning, kraftfôr eller grovfôr, økning i bruk av kraftfôr, produksjon av livdyr som fôres opp andre steder, økning av produktiviteten i beitene, økning av beitetiden på jorder med høy produktivitet eller avviking

av husdyrproduksjonen.

For hver av de utvalgte tiltakene identifiserte vi sannsynlige bi-effekter for miljø**,** produkt og produsent ved hjelp av litteraturstudier. Dernest ble de bi-effekter med store konsekvenser og eller lang varighet plukket ut for videre analyse under ulike miljø- og produksjonsforhold. For å kvantifisere bi-effektene ble det brukt ulike metoder avhengig av tilgjengelig kunnskap og tiltakets relevans generelt. Kvantifiseringsmetoden varierte fra gjennomføring av eksperimenter, modellering, beregning til ekspert vurderinger.

All kunnskapen om tiltakene ble avslutningsvis samlet i to typer beslutnings-støtte-systemer. Det ene er rettet mot gårdbrukere eller veiledningstjenesten. Ved hjelp av de aktuelle driftsforhold på gården, effekter og bi-effekter av tiltaket gir beslutnings-støtte-systemet som resultat en prioritert liste for aktuelle tiltak på den enkelte gård. Det andre beslutnings-støtte-systemet er rettet mot forvaltning på region nivå. Ved hjelp av data om miljøforhold og type landbruksproduksjon i området, effekter og bi-effekter av tiltaket gir beslutnings-støtte-systemet som resultat kartillustrasjoner over hvilke tiltak som er mest passende i de ulike deler av regionen. Beslutnings-støtte-systemene samler og vurderer akkumulerte kunnskaper i forhold til hverandre og gjør denne informasjonen direkte anvendelig ved en ny nedfallssituasjon.

Executive Summary

The aim of this report is to present the methodology used by the CESER project to assess environmental and agricultural impacts of long-term countermeasures employed to reduce the transfer of radionuclides into the human food chain.

Within this handbook, the authors discuss the selection process that was used to identify the most applicable countermeasures for the agricultural systems within the project's study areas. Likewise the main environmental and agricultural impacts resulting from the application of these countermeasures, are described alongside the methods used to quantify them within the context of this project. The data requirements for impact quantification and spatial representation in a Geographic Information System (GIS) are listed.

The results produced during the impact quantification stage of the project are being incorporated into two types of decision support system. The methodology used to create these systems is described. One of them uses a GIS to analyse spatial data and draw up countermeasure suitability maps on a regional scale, whilst the other is a non-spatial decision support system that ranks the countermeasures according to their suitability at the individual farm level based on user input about the farm. The creation of decision support systems is an important next step for the project to take following the countermeasure selection and impact quantification process. It opens this research up to a wider audience and delivers the results to agricultural decision-makers in a practical and usable format.

A critical appraisal of the methodology is provided.

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1. Introduction

Radioactive contamination of agricultural land may necessitate long-term countermeasures in food production systems to ensure that contamination levels in food do not exceed intervention limits. Since the nuclear accident at Chernobyl a range of research projects have contributed substantially to the optimisation of countermeasure strategies with respect to dose reduction to humans as well as cost, practicability and acceptability (e.g. Alexakhin, R. M. 1993; Hove *et al.* 1993; Nisbet 1995; Strand *et al.* 1997). However, commonly the risks of environmental, social and wider economic impacts, also termed side-effects, have been neglected. A full appraisal of countermeasures has to take into account the potential for both negative and positive non-radiological effects.

Only long-term countermeasures and their impacts are evaluated, focusing on long-lived isotopes of caesium and strontium. The aim is to devise a flexible methodology which can be applied to circumstances different to those used in the CESER case study areas. Only the methodology can be transferred to other geographical areas. The specific results generated by this research apply only to the particular case study areas, since the side-effects caused by each countermeasure depend greatly on the environmental and agricultural conditions under which it is applied. The purpose of this handbook is to introduce the reader to the generic approach used by the CESER project to assess the positive and negative side-effects of applying countermeasures in agricultural and semi-natural environments. The description of the generic methodology is accompanied by specific examples and details of the methodology which are mostly presented in text boxes. Social and economic aspects are not included. A preliminary report on these can be found in Desmet *et al.* (1998).

The CESER methodology is summarised in Figure 1 (page 7).

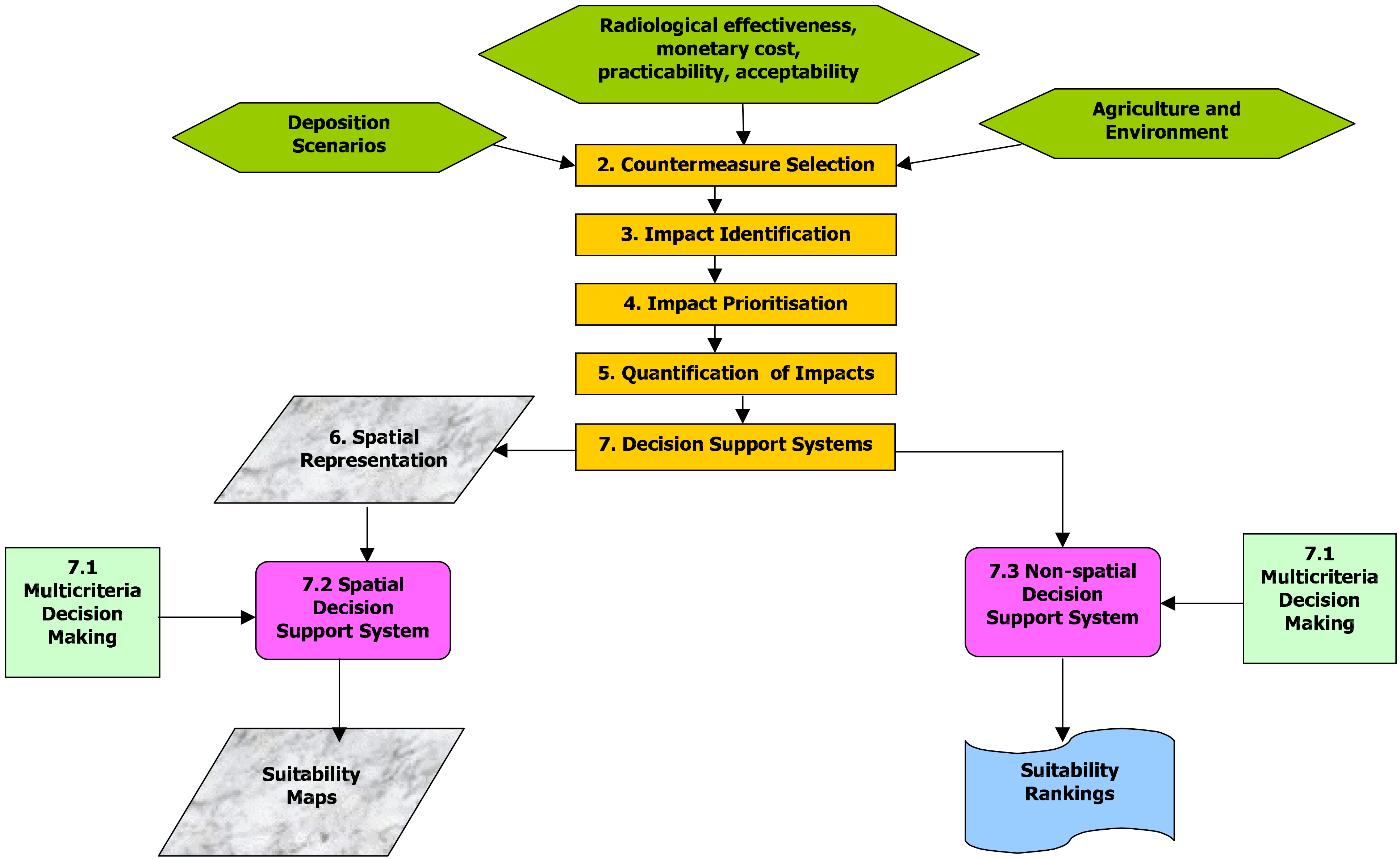


Figure 1. Overview of CESER methodology for environmental impact assessment of countermeasures. Numbers refer to chapter sections within this handbook.

2. Criteria for Countermeasure Selection

2.1 Initial screening

The countermeasure selection process aims to identify suitable measures for a given fallout situation which will ensure that food products do not exceed the CEC intervention limits for radiocaesium and radiostrontium (CEC 1989). A large number of possible countermeasures exist, but not all are realistic to use. The first step is to eliminate countermeasures that are unlikely to be used in practice. This is achieved through a screening of the literature on a wide range of countermeasures using the following general criteria (adapted from Nisbet 1995):

- Radiological effectiveness (relative reduction in human dose or soil-plant-animal transfer)
- Direct monetary costs (e.g. labour, materials)
- Practicability (ease of execution)
- Acceptability (e.g. animal welfare, toxicity)

Emphasis was given to evaluating the extensive experience gained after the Chernobyl reactor accident, but laboratory experiments were also taken into account where information from practical applications was not available. This initial screening process enables the choice of countermeasures to be narrowed down to those most worthy of more detailed examination (see examples in Box 1.). Radiological effectiveness should be maximised. Where several measures have a similar radiological effectiveness, the cheapest option is selected.

Box 1. Examples of screening process

For instance, potassium fertilisation is cheaper than soil application of clay minerals or AFCF (ammonium-ferric-hexacyano-ferrate) and has a similar reported effectiveness. It is also likely to be more acceptable to farmers due to familiarity. Alternatively, direct administration of AFCF to animals is favoured over clay minerals because animal health effects have been reported for the latter. Use of fencing to prevent grazing of highly contaminated areas, was excluded because of the practical problems of localising hot spot areas and the cost of fencing off large areas.

The following categories of countermeasures were examined:

- Soil-plant based countermeasures
    - Application of fertilisers
    - Application of chemical binders
    - Mechanical/physical treatment

    - Crop and land use change
- Animal based countermeasures
    - Chemical treatment
    - Feeding regime
    - Animal management
    - Land use change

For soil based countermeasures the radiological effectiveness is highly dependent on the soil type. A broad classification was used to assign countermeasure suitability to soil types as described in Box 2.

Box 2. Categorisation for soil-based countermeasures

- soils with low content of organic matter and high cation exchange capacity,
- soils with low content of organic matter and low cation exchange capacity,
- soils with high content of organic matter and high cation exchange capacity.

High CEC was defined as > 100 meq/kg of soil and high organic matter was defined as > 10%.

For each of the soil-based countermeasures reviewed the radiological effectiveness was ranked according to: high reduction of root uptake (of radioactive Sr or Cs) - low reduction - no effect - low increase of radionuclide uptake - high increase. Emphasis was given to identifying the key physical and chemical mechanisms of the priority countermeasures because their understanding is essential for modelling environmental impacts.

2.2 Consideration of location specific conditions

The next step in the countermeasure selection process requires characterisation of the agricultural systems and deposition scenarios under which countermeasures are to be applied. Countermeasures have to be tailored as closely as possible to local farming conditions to ensure maximum effectiveness. Detailed knowledge of the agricultural management and environmental conditions is also one of the prerequisites for quantification of side effects. Knowledge of the magnitude and composition of the fallout is required to predict which food products are most likely to exceed intervention limits and thus identify which production systems most urgently require application of countermeasures.

Prior to proceeding with the identification of potential non-radiological impacts, a detailed description of each countermeasure was made. This entailed for example the specification of type, depth and timing of ploughing; amount, timing and type of fertiliser application; amount, frequency and timing of feed supplementation to animals.

Study sites representative of a range of nationally important production systems were selected for Finland and Scotland and for each of these the local agricultural practices were documented through consultation of national and regional statistics, interviews with agricultural advisors and farmers and site visits. In addition alpine environments are represented through case study areas in Austria. The breadth of information required is illustrated in Appendix I (page 42) for animal production systems. The main agricultural production systems considered are summarised in Table 1.

Table 1. Agricultural production systems 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

* hunting of wild deer

Four deposition scenarios were selected to represent a range of post-accident conditions from contamination levels typical of the far field to levels expected close to a nuclear reactor accident (see Table 2.).

Table 2. Deposition scenarios

	^{137}Cs	^{90}Sr	alpha-Pu	Situation
	kBq m^{-2}	kBq m^{-2}	kBq m^{-2}	
Scenario 1	100	2	0.02	Far-field of Chernobyl-like source term
Scenario 2	100	100	0.02	Far-field of source term with higher Sr fraction
Scenario 3	1000	200	0.2	Close to site of accident
Scenario 4	5000	500	1	Very close to site of accident

The selection of countermeasures for different types of agricultural production systems is based on the following steps:

1) For each deposition scenario contamination levels in food products are predicted using 95% confidence intervals of transfer factors from IAEA (1994). Where CFIL's (Community Food Intervention Levels) 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 were affected.
2) Only countermeasures are selected which are feasible under the prevailing local farming conditions. This is particularly important for animal production systems where the feeding regime and farm management (e.g. stock movement; time spent indoors and outdoors) may determine whether a countermeasure is feasible.
3) Some countermeasures were found to be too expensive or drastic under certain deposition scenarios and are therefore not always recommended (e.g. cease agricultural production).
4) The additional dose to farmers executing the countermeasures is calculated for each deposition scenario. Calculations are based on average times required to execute countermeasures that were taken from a compilation by Roed *et al.* (1995). If these seemed to be unreliable, they were modified by location specific information. Dose conversion factors are taken from BMU (1989) for external and from EU (1996) for internal irradiation. In deposition scenario four the external dose to the population will exceed 1 mSv/year and the only option in this situation is evacuation of the population and termination of agriculture. The area may be converted to forestry.

The same approach was used for crop and animal production systems. The countermeasures recommended for the case study sites are summarised in Tables 3 and 4 (page 12). The selection process is implemented more specifically within the decision support systems developed for the Scottish case study areas (see Chapter 7.).

Table 3. Selected countermeasures recommended for 4 deposition scenarios (see Table 2) in the case study areas (A = Austria, F = Finland, S = Scotland)

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

		Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 4**	
		Cs	*Sr*	*Cs*	*Sr*	*Cs*	*Sr*	*Cs*	*Sr*
Shallow ploughing	A, F, S	R	NR	R	R	NSE	NSE	NSE	NSE
Deep ploughing	S, F	TE	TE	TE	TE	R	R	NSE	NSE
Skim & burial	S, F	TE	TE	TE	TE	R	R	NSE	NSE
K fertilisation	S. A	R	NE	R	NE	NSE	NE	NSE	NE
Liming	A, S	NE	NR	NE	R	NE	NSE	NE	NSE
Change to oil seed rape	S, A	TE	TE	TE	TE	R	R	NSE	NSE
Fallow	A, F, S	TE	TE	TE	TE	TE	TE	R	R
Afforestation	A, F, S	TE	TE	TE	TE	TE	TE	R	R

Table 4. Additional countermeasures recommended for 4 deposition scenarios (see Table 2) for lamb, dairy and beef production systems and management of wild deer.

		Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 4**	
		Cs	Sr	Cs	Sr	Cs	Sr	Cs	Sr
Feed AFCF	A, F, S	R	NE	R	NE	R	NE	NSE	NE
Feed Ca	A, F, S	NE	NR	NE	R	NE	R	NE	NSE
Feed clean roughage***	A, S	TE	NR	R	R	R	R	NSE	NSE
Feed more concentrate**	A, F, S	TE	NR	R	R	R	R	NSE	NSE
Intensify pasture use*	S	NR	NR	R	R	R	R	NSE	NSE
Improve pasture	S	TE	NR	R	R	R	R	NSE	NSE
Produce live animals &									
a) fatten on concentrate*	A, S	TE	NR	R	R	R	R	NSE	NSE
b) sell to other farms*	A, F, S	TE	NR	R	R	R	R	NSE	NSE
Cease animal production	A, F, S	TE	NR	TE	TE	TE	TE	R	R

* not for deer

*** for lambs and in Scotland also for deer

** for dairy cows only

For production of eggs, chicken and pork the radiocaesium and radiostrontium levels were below the CFIL's for deposition scenario 1, 2 and 3, and no countermeasures were therefore required. In deposition scenario 4 evacuation and termination of animal production is the only option.

3. Identification of Non-Radiological Impacts

Potential non-radiological effects of countermeasures include both positive (e.g. growth stimulation of plants due to fertiliser addition) and negative impacts (e.g. lower food quality, erosion). A thorough literature review was performed to identify potentially significant side-effects of those countermeasures which were selected according to the criteria described in Chapter 2. Many countermeasures involve operations that are similar to those carried out routinely in agriculture e.g. ploughing, application of fertilisers, changes in the diet of animals. Thus the literature on environmental impacts of agriculture (and forestry) gives an indication of potential impacts of countermeasures. However, countermeasures often represent extreme forms of agricultural management, e.g. deep ploughing or application of untypical high rates of lime or fertiliser which may give rise to different impacts compared to normal agricultural practices. In addition to reliance on literature, group discussions within the project and with outside experts were used to draw up a comprehensive list of potential side-effects. It is recognised that this process may be limited by the expertise of the persons involved.

The broad impact categories identified are:

- Soil quality
- Water quality
- Air quality
- Biodiversity
- Landscape diversity
- Agricultural product quantity
- Agricultural product quality
- Animal welfare

3.1 Soil-plant-based countermeasures

The literature review revealed that many non-radiological effects of soil-based countermeasures depend on site-specific soil and management related factors. In these cases, the literature review focused on understanding the basic mechanisms of the interaction between countermeasures and environment. Only once these mechanisms are understood can adequate models be selected which enable quantification of site effects (for details, see Chapter 5.1).

The side-effects included in the literature review are listed in Box 3. For certain potential non-radiological effects of soil-based countermeasures, however, information in the literature was lacking or insufficient to allow quantification. Some of these areas are targeted through laboratory experiments designed to investigate secondary effects which were judged as being of considerable importance (for details, see Chapter 5.2).

Box 3. Side-effects of soil-plant-based countermeasures included in the literature review

(a) for addition of fertilisers (potassium) and liming

- leaching of major and trace nutrients and of toxic trace elements
- changes in soil pH and in the availability of nutrients to plants
- mineralisation of organic matter
- influence on the stability of the soil structure
- changes in yield and quality of crops
- effects on soil organisms, mycorrhiza and plant communities

(b) for different types of ploughing

- leaching of major and trace nutrients and of toxic trace elements
- degradation of organic matter
- changes in yield and quality of crops
- effects on soil organisms and plant communities
- influence on hydraulic properties
- soil loss (erosion)

(c) for changes in pasture use or in crop type or afforestation

- any effects linked to fertilisation
- any effects linked to ploughing
- biodiversity and landscape changes

3.2 Animal-based countermeasures

The animal-based countermeasures were split into chemical treatments and management related measures. The side-effects of chemical treatments, ie. AFCF (Cs-binder) or high levels of Ca supplementation (Sr transfer reduction), are mainly related to nutrition and health of the animal and to possible environmental pollution once the chemical compound has been spread through manure (see also Box 4). AFCF has a particularly high radiological efficiency and is one of the most likely countermeasures to be used in the event of a future release of radiocaesium. Therefore identification of possible side-effects related to the use of AFCF was given a high priority. Radiological as well as general agricultural literature was studied. Studies on the fate of AFCF within the animal are mainly performed with laboratory and not farms animals. However, this is acceptable since the general metabolism is similar, even though the quantification of the different breakdown compounds is likely to change between laboratory and farm animals. Similarly for Ca supplementation, a range of studies are available for normal supplementation levels, whereas for Ca supplementation used as a countermeasure the side-effects might be different compared to those observed for normal Ca levels.

Box 4. Potential soil-related side-effects of AFCF administration to animals

AFCF administered to livestock will be excreted with the faeces and urine. In situations where animals are housed for a considerable time of the year and manure has to be spread onto land, AFCF and caesium-FCF complexes will reach the soil. The same applies to grazing but the inputs are less concentrated over time.

Potential side- effects considered are:

- Release of toxic HCN through decomposition of AFCF-/CsFCFcomplexes
- Release of other toxic degradation products
- Enhanced migration of AFCF-bound radiocaesium in soil
- Effects of AFCF on the nutrients and trace elements in the animals.

Management related countermeasures are changes in feeding, in management of animals (breeding, feeding intensity, time for purchasing and selling) and termination of animal production. The performance, effectiveness, practicability and side effects of these countermeasures are highly dependent on the current farm management. Therefore a thorough understanding of the farming practice within the study areas is crucial and forms the basis for selecting countermeasures and for quantifying side-effects. The potential side effects included in the literature study are listed in Box 5 (page 15).

Box 5. Side-effects of animal management considered

(a) higher feeding rate of uncontaminated feed (roughage and concentrate)

- digestive disorders and diseases
- changes in utilisation of the diet
- changes in meat and milk quality and quantity
- changes in nutrient excretion in manure

(b) early weaning of fattening lambs for indoor feeding or early sale

- reduced growth rate
- animal body condition and diseases
- changes in stocking density

(c) production of young fattening animals for sale

- changes in stocking density

(d) excluding animal production

- landscape changes
- biodiversity changes

Side effects relevant to a, b, c, and d

- impacts on water quality (eutrophication) relating to changes in grazing pressure and land spreading of manure
- impacts on air quality from changes in ammonia emissions

4. Prioritisation of Non-Radiological Impacts

The literature review indicated that a great variety of non-radiological effects may accompany the application of countermeasures both in crop and animal production systems. Since the CESER project is for the first time including these effects formally in the comparative evaluation of countermeasures, emphasis has been put on the most important environmental and agricultural impacts. This has allowed the project to both develop the methodology and to quantify and compare the dominant benefits and limitations of selected countermeasures. The identified impacts ranged from well-documented dose-response relationships to only theoretically likely impacts. As part of the prioritisation well described relationships were given greater importance relative to hypothesised side-effects. A sub-selection was made prior to proceeding with the task of impact quantification. Prioritisation was based on the following criteria:

- Body of knowledge
- Likely severity of the impact
- Availability of validated models

The same methodology was used for soil-plant- and animal-based countermeasures:

(i) Non-radiological effects were excluded from the environmental impact assessment if the information found in the literature was too incomplete to even estimate their impact. For example, data on the influence of potassium application and liming on the diversity of soil organisms other than nematodes were unavailable.

(ii) Non-radiological effects were included if the literature review documented that impacts have been observed which could be of potential significance in the selected study areas. An example is the influence of fertilising and ploughing practices on nutrient losses and soil erosion.

(iii) Laboratory experiments were initiated as part of the project in selected cases where the literature review showed that countermeasures are very effective in reducing contamination levels via food chains, but knowledge of potential environmental impacts was found to be incomplete. This was the case for the use of AFCF as an animal feed additive which significantly decreases the caesium contamination of animal products, but subsequent deposition of excreta to soil may result in toxic degradation products being set free.

(iv) It was also decided to perform laboratory experiments if potential non-radiological impacts were documented in the literature, but data were lacking to allow quantification by modelling. This was the case for the degradation of soil organic matter which is known to be enhanced by fertilising, liming and ploughing: only few data were available on the role of mobile organic degradation products as a carrier for leaching complexes trace nutrients and toxic substances.

5. Quantification of Impacts

The impacts prioritised, as outlined in Chapter 4, were carried forward into the process of quantification through either modelling, calculations, experimentation or expert judgement (see Table 5, page 18, for examples).

Table 5. Examples of the methods selected for impact quantification

Countermeasure	Likely side effects	Method of quantification
K application to soil	Changes in nutrient and pollutant availability and mobility	Modelling
Feed AFCF to animals	Toxic breakdown products in animals Toxic breakdown products in soil	Literature study and expert judgement Laboratory experiments
Increased concentrate feeding to animals	Animal health problems Decrease in water quality due to increased manure spreading (N & P) Increased milk and meat yield	Expert judgement Modelling Expert judgement and calculations

5.1 Modelling and calculations

5.1.1 Issues in model selection

Mathematical simulation models can serve as a general tool for assessing various environmental impacts of changes in land use and land management, such as erosion and nutrient losses. The selection of the models to be used depends on the purpose of the exercise, on the data availability and accessibility, and on the scale of the assessment. The typical feature of the countermeasure impact assessment is to compare the effects of different management practices, such as different ploughing methods and manure applications, and effects of the land use and crop rotation changes. Therefore management-oriented models (instead of research-oriented models) or their extensions are most suited to this purpose. The scale of the model (soil profile - field parcel - drainage basin) depends on the modelling scale. In case of predicting the changes in a single watershed, a drainage basin scale model might be the best selection. For handling larger areas, or for making nation wide assessments, the use of field-scale models is often a more versatile solution. Often the selection of the model scale depends also on the availability and accessibility of the spatial data.

For modelling within the CESER project it was decided to use a small number of models which group participants had prior experience of (see also Box 6, page 19). These models are not specifically developed for the conditions and purposes required to simulate countermeasure impacts, however, every effort was made to adapt the models to the unique conditions of the study sites and countermeasure scenarios. As a result of the prioritisation (see Chapter 4), it was determined that in order to quantify key non-radiological effects mechanistic models must be included of:

- soil hydrology to estimate erosion and nutrient leaching
- plant growth which influences soil hydrology and nutrient cycling
- soil chemistry to evaluate effects of fertilising and liming
- agricultural management operations.

Box 6. Models selected for impact quantification:

(1) OPUS (Smith 1992) and ICECREAM (Rekolainen and Posch 1993):

Both codes are versatile catchment management models which include sub-models to simulate soil hydrology, soil erosion, surface loss and sub-surface transport of nutrients and trace substances, plant growth and impact of agricultural management operations (e.g. ploughing, application of manure or pesticides). ICECREAM is a Finnish adaptation of the CREAMS/GLEAMS model (Knisel 1989). The basis for its selection was mainly its adaptations made to the conditions were the model is used in this context, and its user-interface that allows a series of model runs over wide climate-soil-crop-management combinations. OPUS was selected because of its better hydrology component of water movement in soil and its higher flexibility considering the organic matter content in soil, which both are important for soil hydrology and nutrient loss assessments.

(2) PHREEQC (Parkhurst 1982):

PHREEQC simulates the equilibrium chemical composition of multi-species systems taking into account a variety of chemical reactions. PHREEQC can model the influence of potassium fertilisation and liming on soil chemistry, including pH and concentrations of major and trace nutrients and of toxic substances in soil solution and consequently their plant availability.

To ensure the applicability of the modelling approach in areas where no calibration data is available, it is important that the selected models are physically based instead of statistical models. However, in certain cases, simple transfer functions might be applicable. In this handbook we give an example of using the latter approach for assessing changes in ammonia emissions, see Box 7 (page 20).

Box 7. Quantification of ammonia emissions

The use of simple transfer functions in assessing side-effects can be appropriate in cases where no physical models can be applied or data for parameter estimation for these models does not exist. However, the transfer functions and coefficients are usually derived from statistical correlations and regressions of local data, and the use of these relationships outside original conditions should be carefully studied.

As an example transfer coefficients can be used when assessing the changes in atmospheric ammonia emissions from livestock due to changes in diet and animal densities. Regional ammonia emissions from livestock farming are generally estimated using emission coefficients derived from experimental data for each animal type, and then multiplying the number of animals with this specific coefficient (Sutton *et al.* 1995). The values of these coefficients depend to some extent on diets, and manure storage and handling systems. The changes in these can be taken into account by changing the values of coefficients accordingly. This, however, requires, information on the impacts of countermeasures on these coefficients.

Changes in animal densities, e.g. due to movement of animals to less contaminated areas, can be easily taken into account in regional (or wider) assessments.

Calculations require data on livestock numbers, period of housing, manure storage application systems and feeding regimes (see Appendix I)

5.1.2 Data requirements for modelling

The data requirements for modelling depend on the model selected and on the scale of the modelling exercise. A list of the data requirements for the ICECREAM model is shown in Appendix II (page 42). The OPUS model has very similar requirements.

ICECREAM/OPUS

The first phase of data collection consists of input weather data and input parameter estimations. In the up-scaling phase, spatial data of the relevant variables are needed. The models require daily weather variables as driving forces; most commonly precipitation, temperature (mean, or minimum and maximum), and radiation or cloudiness. Where available, relative humidity and wind speed can also be entered. When modelling large areas, or the whole nation, several meteorological data sets are required if the climate differs much within the modelling area. Since the inter-annual meteorological variations might be high, it is recommended to use a minimum of 10-year (preferably 30-year) weather records for calculating the yearly averages. Instead of historical records it is also possible to use generated weather data.

The most important input parameters consist of hydrological, soil, crop, and erosion parameters and initial values for nutrient pools in the soil. The hydrological parameters consist of hydraulic conductivity and pF-related parameters. Often measurements of these are not readily available, but their estimation may be based on the use of pedotransfer functions, in which the soil texture (clay, silt, sand) and organic matter content are used as input. Soil parameters have to be supplied for each soil horizon and soil type. Erosion is calculated by the Universal Soil Loss Equation (USLE) or its revisions, and it requires estimates of rainfall erosivity and soil erodibility. Rainfall erosivity depends on rainfall characteristics, and can be estimated from breakpoint rainfall data, which are not frequently available. Where breakpoint data is lacking, the comparison of loss estimates between regions with different rainfall characteristics is a problem. Soil erodibility can be estimated from soil texture, structure, permeability, and organic matter content.

Since the two models contain only simple crop growth routines, they require an estimate of the maximum or typical yield and leaf area index (LAI) for each crop at various stages of the crop growth. Transpiration of soil water by plants may significantly influence the soil water balance. To simulate plant growth and transpiration, data is needed on the dependence of the growth rate on temperature, on the solar radiation, on season (including senescence) and on the transpiration rate as a function of leaf area. All data have to be crop type specific. Management data is also required: dates of sowing/planting, harvesting, fertilising, manure application and tilling, as well as amounts of fertiliser/manure applied, depths, mixing and incorporations properties of the used tillage implements.

For the nutrient sub-models the most important input data are the initial nutrient pools at the beginning of modelling. These consist of organic nitrogen and phosphorus, and stable and labile inorganic phosphorus pools. Usually, data exist only for labile phosphorus, the other fractions can be estimated by assuming an equilibrium between the pools at the beginning of the modelling period.

PHREEQC

Calculations of equilibrium chemistry of soil/solution systems are performed with PHREEQC taking into account ion exchange and redox reactions. Ideally, this requires information on the concentrations of all chemical species of the substances (e.g. metals) included in the calculations both in solution and sorbed to the soil matrix for all soils for which calculations are performed. These data, however, were not available. Therefore, simulations had to be based on species concentrations found in the literature for the soil types for which calculations were performed. This introduces some uncertainty which, however, can not be quantified, since in the absence of site-specific data it is impossible to assess whether the literature data used can be regarded as representative of the study sites. In addition, depending on the time of the year and soil moisture, the composition of soil water can be different. These factors were also not taken into account in the PHREEQC calculations. Stability constants for the reactions included were always taken from the PHREEQC libraries.

5.1.3 Model applicability

Process-oriented models describing soil and nutrient transport from soil to ground and surface waters differ much from each other in terms of complexity and scale (soil profile-field-watershed). The selection of the model scale has to be based on the purpose and the potential applicability of the models. Many existing soil profile models are valid for predicting losses from soil profile to drainage water and/or to groundwater, but they usually have limited potential to handle overland processes. Field-scale models usually simulate both losses through overland flow and through the soil column. These models do not take into account the routing of materials from one compartment (field) to another nor the channel and pond processes, while these features are included in many watershed scale models. Thus watershed models might be the best selection, if the purpose is to predict absolute amounts of material inputs from watersheds to river or lake systems. However, in these models the watershed is often treated in a more or less lumped way, not distributing it into homogeneous units in terms of soil, slope, and crop. Thus, where the aim is to compare the impacts of various management practices, field-scale or soil profile models can be more justifiable. The selected models ICECREAM and OPUS are both field-scale models.

As with other similar field-scale models, applicability of the hydrological sub-models of OPUS and ICECREAM is limited to mineral soils. Since the selected study sites include soils which are rich in organic matter, the OPUS code was modified to include a hydrological model based on the Vereecken pedo-transfer function (Vereecken *et al.* 1989) which is applicable for both mineral and organic soils (up to 40% OM).

5.2 The role of expert judgement in non-quantifiable impact assessment

In cases where impact quantification is not currently feasible, it is usually possible to determine the direction and relative degree of change and apply a relative scale of impact: e.g. greatly/

moderately/ slightly increasing/ no change/ slightly/ moderately/ greatly decreasing. For instance, the impacts of countermeasures on species diversity cannot be quantified in absolute terms. The diversity of plants, animals and micro-organisms in agricultural biotopes, such as crop fields, pastures, field-margins, hedgerows, wetlands, and its dependency on abiotic factors is poorly understood. In addition only limited data is available on species diversity in specific locations. Thus, there is little data available with which quantitative assessments could be performed. However, many of the countermeasures change the landscape structure, and there is information available on whether these changes affect species diversity positively or negatively. This information can be used to present the potential impacts of certain countermeasures on biodiversity such as changes in land use (e.g. afforestation; change from grassland to arable crops to increase production of concentrate feeds: conversion of rough grassland to improved pasture).

5.3 Experimental methods

Laboratory experiments were deemed the most appropriate method of quantification in selected areas where current knowledge of side-effects was found to be too incomplete to allow ready quantification of side-effects (see Chapter 4). The areas of experimentation pursued in the CESER project are detailed in Boxes 8, 9 and 10.

Box 8. Transport of trace elements with humic substances

Ploughing, fertilising and liming have been observed to cause enhanced degradation of soil organic matter resulting in mobile organic colloids (fulvic acids). It is also well known that trace nutrients and toxic substances form stabile complexes with these molecules resulting in increased mobility of the metals. Little information, however, is available on the transport of the carriers, the fulvic acid molecules, in soils. Therefore, the mobility of fulvic acids was studied in laboratory experiments.

Two different fulvic acids were used - a commercial fulvic acid (Aldrich) and a fulvic acid which was extracted from a peat bog near Bremen using standard procedures recommended by the IHSS (International Humic Substances Society). The fulvic acid molecules were labeled with Am-241. Transport of the radiolabeled fulvic acids through soil was studied using the through-diffusion technique as described by Kirchner *et al.* (1993). Since first results of these experiments showed that diffusion rates of fulvic acids are very low, a modified experimental technique (Bruenjes *et al.* in press) was used which allows to study the influence of convectional water flow on the fulvic acids' transport in soils.

Box 9. AFCF – environmental degradation and influence on radiocaesium mobility

AFCF is one of the most effective chemical binders for Cs when directly fed to animals. Widespread use of AFCF in a post-accident situation could lead to significant quantities of Cs-FCF and AFCF reaching the soil via spreading of slurry and manure on the land and direct deposition of faeces and urine on grazed pasture. Potential side-effects of AFCF application to soil are studied in two types of experiment:

(a) Potential occupational exposure of humans to free cyanide may occur as a result of the degradation of AFCF and CsFCF on the soil surface. This process is being quantified via experiments in a specifically designed gas –tight cylinder in which manure containing AFCF and CsFCF is exposed to light to determine the rate of degradation these complexes and the release of free cyanide into the atmosphere.

(b) Potential enhanced mobility of radiocaesium bound to FCF and the influence of light on the degradation of AFCF and Cs-FCF is being studied in soil column experiments using sandy, loamy and organic soils. Leachates are collected and cores will be sectioned to compare the mobility of Cs-FCF complexes in comparison with AFCF alone and Cs alone.

Box 10. Influence of K fertilization on VA-mycorrhizal uptake of caesium

Mycorrhiza play a central role in all terrestrial ecosystems. They affect plant growth, nutrient uptake and mobilisation; enhance the resistance of the host plants to pathogens, aid colonisation and stabilise the soil. Potential effects of fertilisation on the functioning of mycorrhiza and the transfer of radionuclides into the host plant are studied in experiments, designed to investigate the effects of potassium application on plant uptake of radiocaesium and other processes linked to the activity of VAM (vesicular-arbuscular-mycorrhiza) such as uptake of nutrients.

Pot experiments were carried out involving two grass species, *Agrostis tenuis* and *Festuca ovina* as host plants. The plants were grown in pots under moderate nutrient levels applying stable Cs concentrations in the ppb range, and with and without K-fertilisation.

6. Spatial Representation of Impacts

Soil profile and field-scale models as well as results from experimental fields produce information on losses (e.g. soil, nutrients) and/or changes in losses in units which are uniform in terms of soil, topography, climate, crop, management. However, these losses/changes over larger areas are also governed by the proportion and distribution of these characteristics. In addition the relationship between losses and these characteristics are often non-linear. To obtain assessments of regional changes the results from model calculations and experimental results have to be up-scaled.

Environmental impacts of countermeasures can be spatially presented either by using a regional (e.g. basin scale) model which is a part of a commercial GIS-software package, or by combining the field-scale model results with spatial data via GIS software. The CESER project has taken the latter approach to modelling the environmental impacts caused by the application of countermeasures. Non-spatial models such as ICECREAM are used to predict soil and nutrient losses. These are mapped onto spatial data coverages according to parameters such as slope and soil type. The model output is used to create maps depicting the risk of soil and nutrient loss within each study area. These risk maps illustrate which geographic areas are most/least suited to a particular countermeasure. Depending on the available data and also on the working scale, the regional impacts can be presented for natural units (field parcels or other natural polygons with uniform soil-slope-crop) or for grids. Grid size presented depends on the scale. For example a 25 m * 25 m grid is usually valid up to a scale of 1:250000.

To up-scale modelling results from single fields in order to present regional estimates, the model results with all relevant climate-soil-slope-crop-management combinations have to be combined with spatial data of these variables. For climate, the modelled region has to be divided into climatologically representative sub-areas, in each of which a meteorological station can provide input data for modelling. Soil texture requires a soil map based on texture, or other soil classification from which the texture can be estimated. Slope of the fields can be estimated using the Digital Elevation Model (DEM). Crops are not frequently known for each field or grid, and moreover this is not very stable over the years due to crop rotation. Instead, the statistics of crop cultivation within administrative units (counties, municipalities, parishes) can be used, and that data can be taken into account by calculating weighted means over the cropping systems.

The models and up-scaling procedures can be used for example to produce estimates of water erosion and nutrient losses to waters at a relative scale, i.e. showing the potential risk for losses from different areas, and predicting the changes in losses due to the relative changes in land use or in management practice. The requirements for spatial data are listed in Appendix III (page 43).

7. Decision Support Systems

The final step in the impact assessment of countermeasure side-effects is the development of a methodology which will permit the simultaneous evaluation of a range of countermeasures and their impacts. This can be achieved via a computer based decision support system.

In order to accommodate varying levels of spatial data availability and technical sophistication, two types of countermeasure decision support system are being developed by the CESER project. The first is a non-spatial assessment of the countermeasures for a single area using a Windows-based Expert System/Decision Support System (ES/DSS). The second type is a more generic suitability assessment of a larger, heterogeneous area for a particular countermeasure using a Geographic Information System. 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 assessment methodology has been put forward because it has the ability to take into consideration conflicting objectives and views in its assessment (Carver 1991). It provides decision-makers with a set of countermeasure suitability rankings based on the qualitative and quantitative data input for each alternative and criteria**.**

7.1 Multicriteria Decision Making

At the basis of all MCDM techniques is the evaluation of a two dimensional matrix in which one dimension is made up of alternatives and the other consists of criteria (Voogd 1983). Alternatives are in this case the different possible countermeasures from which the decision-maker must select. Criteria are the means by which the countermeasure alternatives are assessed. In the CESER project, the criteria consist of a mixture of environmental and agricultural considerations. An example evaluation matrix, *p*, is shown in Figure 2 (page 27), with the alternatives represented in the columns (*i*) and the criteria in the rows (*j*). Figure 3 (page 27) shows the type of MCDM matrix that is being used in the CESER project.

Compensatory MCDM ranking techniques will be used in this project, which allow 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 1989). This ability to make ‘trade-offs’ in criteria performance, within the bounds of certain thresholds, is viewed as a key component of the assessment methodology. 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.

ALTERNATIVES (*i*)

CRITERIA (*j*)

$$P = \begin{bmatrix} p_{11} & \cdots & p_{1I} \\ \vdots & & \vdots \\ p_{J1} & \cdots & p_{JI} \end{bmatrix}$$

Figure 2. Alternative/ criteria matrix

Alternatives (i) and Criteria (j) for Countermeasure Decision Making	SHALLOW PLOUGHING	DEEP PLOUGHING	SKIM & BURY	K APPLICATION	LIME APPLICATION	IMPROVE PASTURE	INTENSIFY PASTURE	FEED AFCF	FEED CA	FEED CLEAN FEED	FEEDMORE CONCENTRATE	EARLY SALE FOR FATTENING	CHANGE CROP TYPE	CEASE PRODCUTION	AFFORESTATION
Erosion + Sedimentation															
Soil Organic Matter															
Soil Nutrients + Water Quality															
Soil Pollutants + Water Quality															
Animal Welfare															
Product Quality															
Product Quantity															
Ammonia Emissions															
Biodiversity															
Landscape Change															

Figure 3. MCDM matrix for countermeasure alternatives and assessment criteria

7.2 Decision support systems for countermeasure selection and impact assessment

7.2.1 Non-Spatial Decision Support System

A flexible, PC-based expert system/decision support system (ES/DSS) has been developed using Visual Basic 6.0 (see specifications in Box 11, page 29). This system is intended to be an easy to use decision making tool for those involved in planning countermeasure work for small areas, who do not have at their disposal the GIS software and data needed to run the Spatial Decision Support System.

The expert system component of this software guides the user through a range of land management questions. Based on their responses to these questions, a broad list of countermeasures that might be appropriate to their situation is produced. The limitations of each of these countermeasures are then explored by querying the user about their particular piece of land and farm management regime. In this way, the system can more specifically determine whether the countermeasure is suitable. For example, if the countermeasure 'Increase the Amount of Improved Land' is selected as a countermeasure for further evaluation, the user will then be prompted to answer a series of questions about the soil type, drainage, soil wetness and slope on their site. If the user's responses fall within the limitations for the application of this countermeasure, the countermeasure can then be included in the final list of possible countermeasures.

The decision support component of the software allows the decision maker to further evaluate the final list of countermeasures, by assessing them according to the user's own personal objectives. Using a Multicriteria Decision Making methodology (MCDM) called Ideal Point Analysis, this component incorporates user-specified weighted criteria to the analysis and ranks the countermeasures from best to worst. After this process is complete, the user then has the added option of carrying out a detailed economic analysis of the final countermeasure. This includes both the direct costs of implementing the countermeasure as well as indirect environmental costs where possible. The selection of an MCDM method is discussed in Box 12 (page 29). The entire process is illustrated in Figure 4 (page 30).

Box 11. DSS specifications

The Windows-based DSS has been written using Visual Basic 6.0. The user must have Windows 95 (32 bit) on their PC in order to use the programme. The software fulfils the following requirements:

- is user-friendly and intuitive to use,
- leads the decision-maker through the assessment methodology with the use of 'wizards',
- allows the user to weight assessment criteria according to their importance and to specify the 'ideal' criteria scores or objectives ,
- is flexible enough to easily handle alterations in the countermeasures being modelled and their associated impacts,
- provides an algorithm for ranking suitability of countermeasures based on an assessment of side-effects
- produces a ranked list of potential countermeasures at the end of the assessment for a particular site.

Box 12. MCDM method selection

The importance of choosing an MCDM technique should not be underestimated; the successful appraisal of criteria and alternatives is entirely dependent upon the application of a technique appropriate to the problem (Overnoy 1992). There are at least fifty different recognised MCDM techniques, each of which will be appropriate for application to certain problems. These techniques can be distinguished by the types of data they use in their criterion scores: quantitative, qualitative, or a mixture of both quantitative and qualitative data (Jankowski 1989). They can be further divided into categories of compensatory and non-compensatory methods. If a method is said to be compensatory, it signifies that a poor performance by a particular alternative on one or more criteria can be 'compensated for' by a good performances on other criteria. The final outcome when using such an approach is largely dependent on the structure of the weighting and preferences that are imposed on the system by the decision-maker (Jankowski 1989). Non-compensatory methods, on the other hand, involve a criteria by criteria evaluation of the alternatives in which the strengths and deficiencies are taken at face value and evaluated as such. Therefore, if an alternative does not achieve good results on a particularly important criterion, that alternative would be excluded from further consideration. This is despite the fact that it might perform extremely well on the subsequent criteria. A range of MCDM techniques were tested for incorporation into the DSS. In the end, Ideal Point Analysis was selected because it proved to be easy and intuitive for the user to use without being overly simplistic in its analysis. This method not only allows the users to weight criteria based on their own agenda, but it also allows the users to specify the 'ideal' score (also referred to as the criteria objective) and the level of compensation. The compensatory level can be adjusted by manipulating the ***p*** parameter. It can be set to equal any number ranging from 1, which causes the assessment to be fully compensatory, to infinity, which makes it uncompensatory (Pitel 1990).

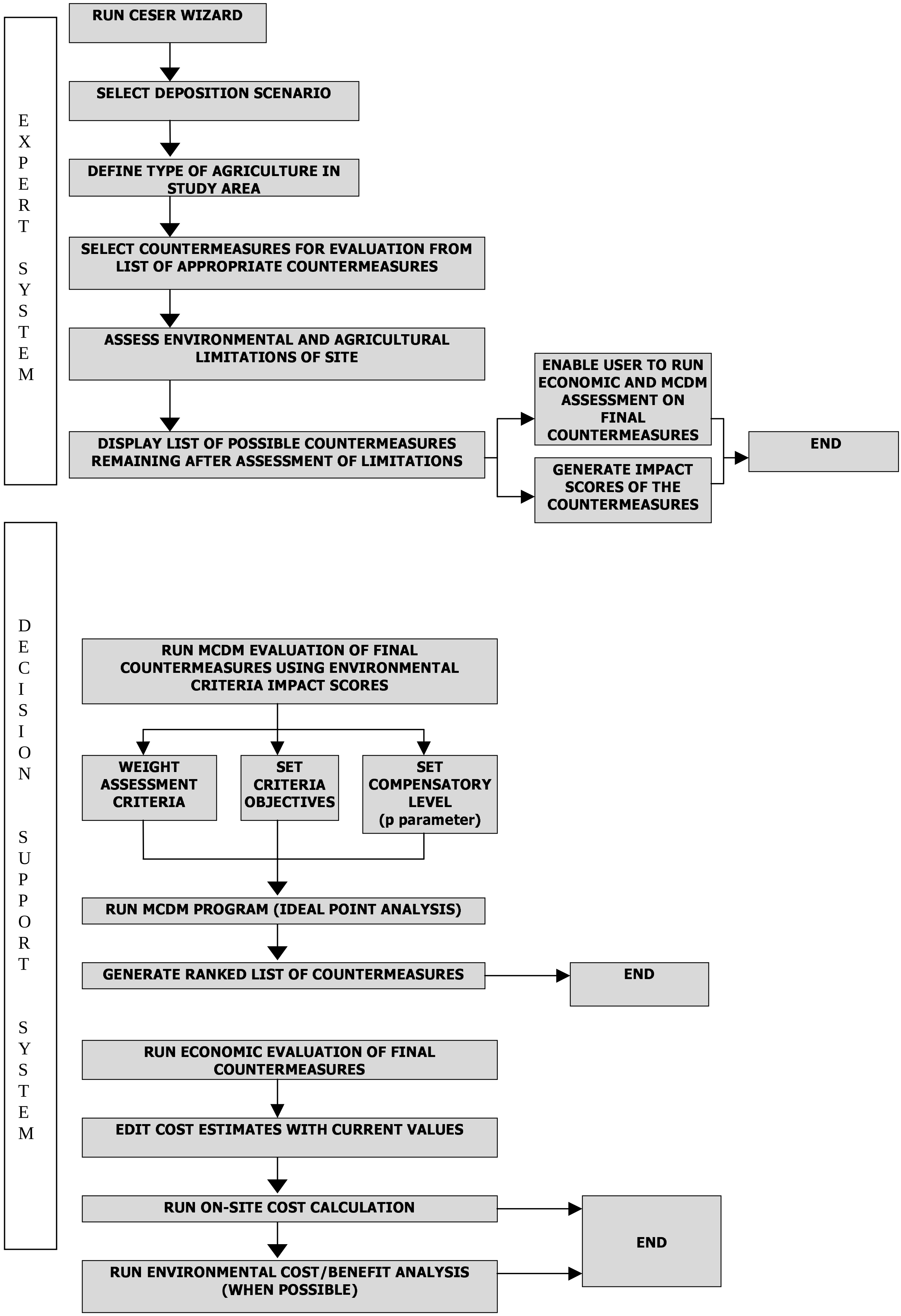


Figure 4. Overview of countermeasure evaluation process in the DSS

7.2.2 Spatial Decision Support System

The GIS-based Spatial Decision Support System (SDSS) is primarily intended for decision making at a regional or national level. It uses the same MCDM methodology as the non-spatial DSS for assessing the relative merits and disadvantages of each countermeasure. Due to the vast amount of data that must be processed when performing such a suitability assessment, the specific type of MCDM assessment methodology must be restricted to methods such as Ideal Point Analysis, which are based on a single calculation of the criteria/alternative scores and weights. The main difference from the non-spatial DSS is that the SDSS runs through a suitability assessment for each grid square of a contaminated area. The resulting output can then either be displayed as a suitability map for a particular countermeasure or a thematic map depicting the countermeasures deemed to be 'most suitable' for each area. This process is illustrated in Figure 5 (page 33). The desired specifications are listed in Box 13. The GIS software package used to develop this system is ArcView (version 3.1) and the MCDM programmes and user interface have been written using the ArcView's own programming language, AVENUE.

Box 13 Specifications for the MCDM-GIS SDSS

- the principles behind the evaluation must be well illustrated and explained within the system;
- the system should be easy to use;
- the system must be flexible in its ability to handle changes in the weights, ideals, objectives, criteria and masking definitions;
- it should also provide the option of using default selections based on expert opinion;
- individual evaluations should not be too demanding in terms of the resources (time, money, etc.) needed to run them;
- the final results should be displayed in a visual format which is both facilitates accurate interpretation and is aesthetically pleasing.

This type of multicriterion investigation should encourage better decision-making strategies by improving the ways in which vast amounts of data are integrated and assessed. The flexibility and user friendliness of the system are therefore key components in ensuring its success as a tool which people will elect to consult when faced with a countermeasure decision making problem.

7.2.2.1 The GIS/MCDM- based countermeasure evaluation process

The MCDM-GIS site selection process begins by asking the user to define the map extent of the study area and the GRID resolution at which the cells will be evaluated. As with the non-spatial DSS, they are also asked to select one of the deposition scenarios and the countermeasures that they wish to evaluate (i.e. afforestation, deep ploughing, lime application, etc).

For each of the countermeasure selected, a site suitability assessment is undertaken for the study area. This begins by creating a 'mask' to eliminate regions within the study area which are clearly unsuitable for the particular countermeasure. The criteria used in the evaluation of the area must also be defined. These should reflect the components that contribute to the overall suitability rating for the area according to the decision-maker's particular objectives (environmental and agricultural criteria).

The user is then asked to define their 'ideal' values and weights for each of the criteria that they have selected. At this stage, all of the files are ready for the ideal point analysis of the data to begin. The MCDM programme calculates a final score for each of the alternatives (GRID cells) based on their distance away from the ideal criteria vector. The resulting scores for all of the alternatives are then converted into a single GRID coverage showing the varying suitability or a region for a single countermeasure. Once this assessment has been completed for all the applicable countermeasures, a map depicting the 'most suitable' countermeasures for the study area can be created. This is done by comparing the values of each GRID cell across the individual countermeasure suitability coverages. The coverage with the highest score for a single cell is deemed the 'most suitable' countermeasure for that cell. The results from these single cell comparisons are then combined to create the final 'most suitable' countermeasure map. An overview of the entire evaluation process is illustrated in Figure 5 (page 33). Figure 6 (page 34) shows a criteria/alternative matrix for afforestation. Figure 7 (page 35) shows a cartographic map for one example countermeasure assessment, afforestation and Figure 8 (page 36) is a diagram of how three countermeasure assessment GRIDS would then be combined to create a GRID depicting 'the most suitable countermeasure'.

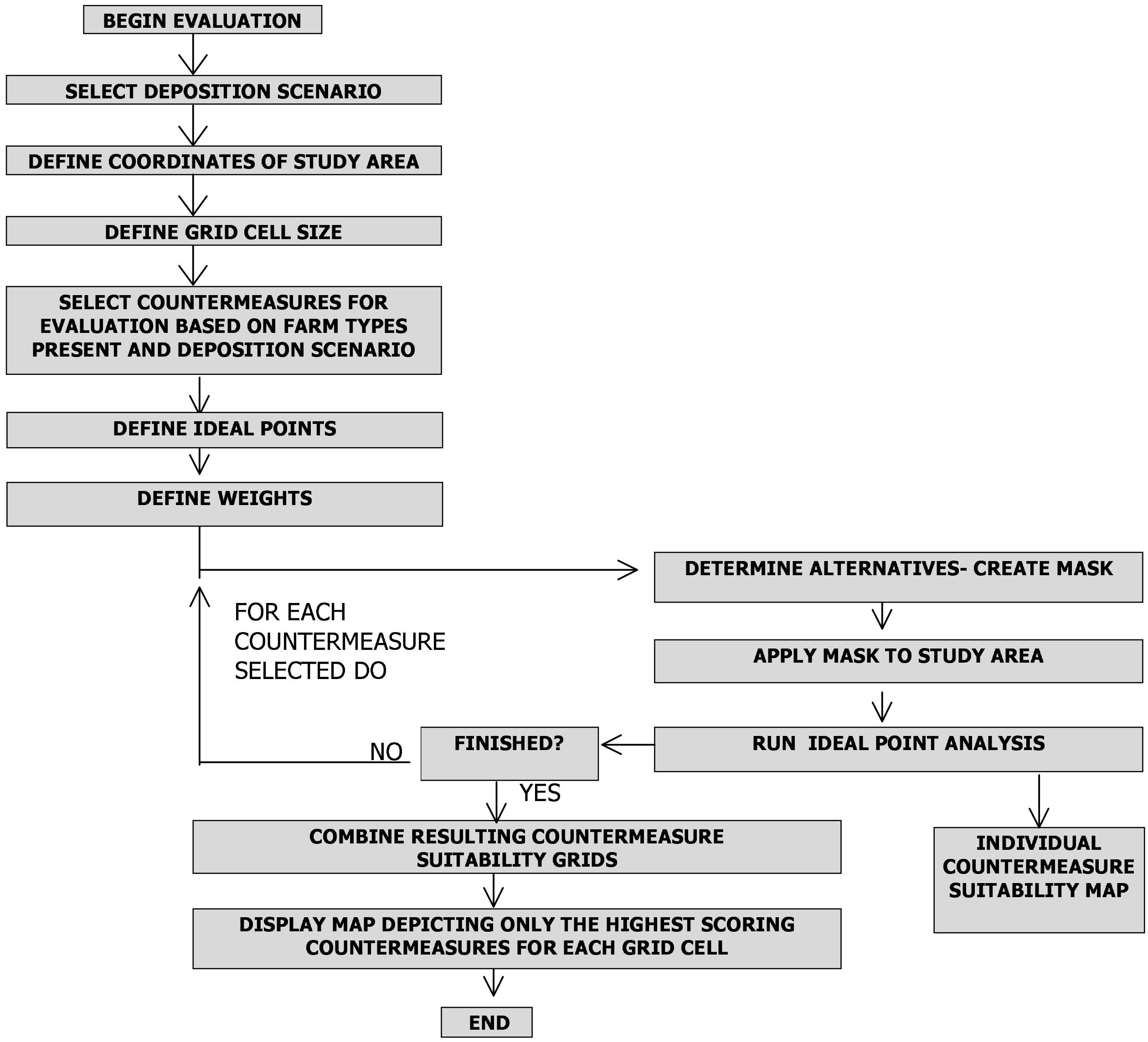


Figure 5. Overview of MCDM/GIS countermeasure evaluation process

P =

I (GRID CELLS) by J (Assessment Criteria)	*i* = 1	**...**	**...**	...	*i* = n
(*j* =1) Erosion Risk					
(*j* =2) Landscape Change					
(*j* =3) Water Quality Change					
(*j* =4) Soil Nutrient Change					
(*j* =5) Soil Organic Matter					

Figure 6. Alternatives (i) and criteria (j) for assessing afforestation suitability

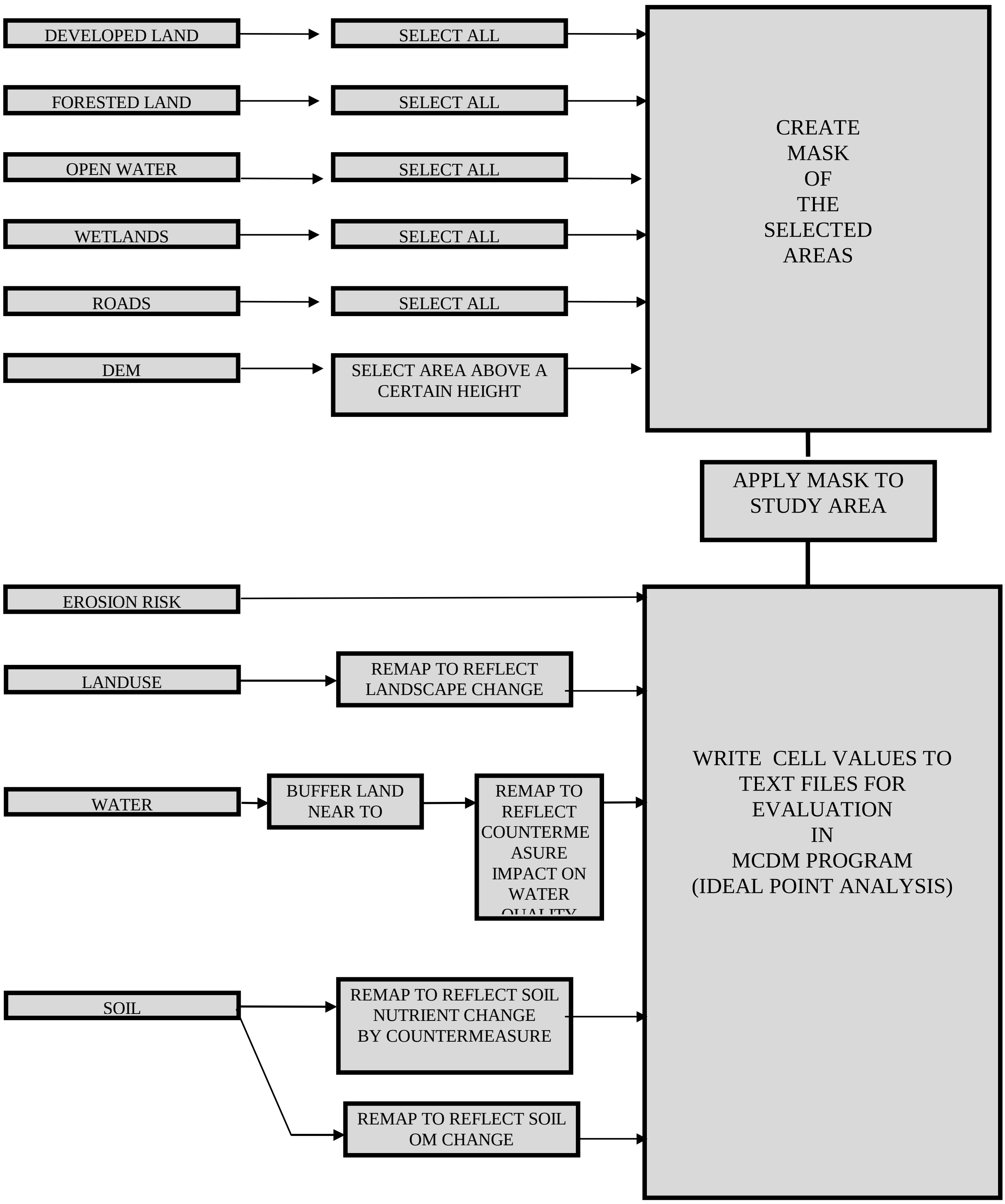


Figure 7. Cartographic map of suitability assessment for afforestation

Suitability for Afforestation

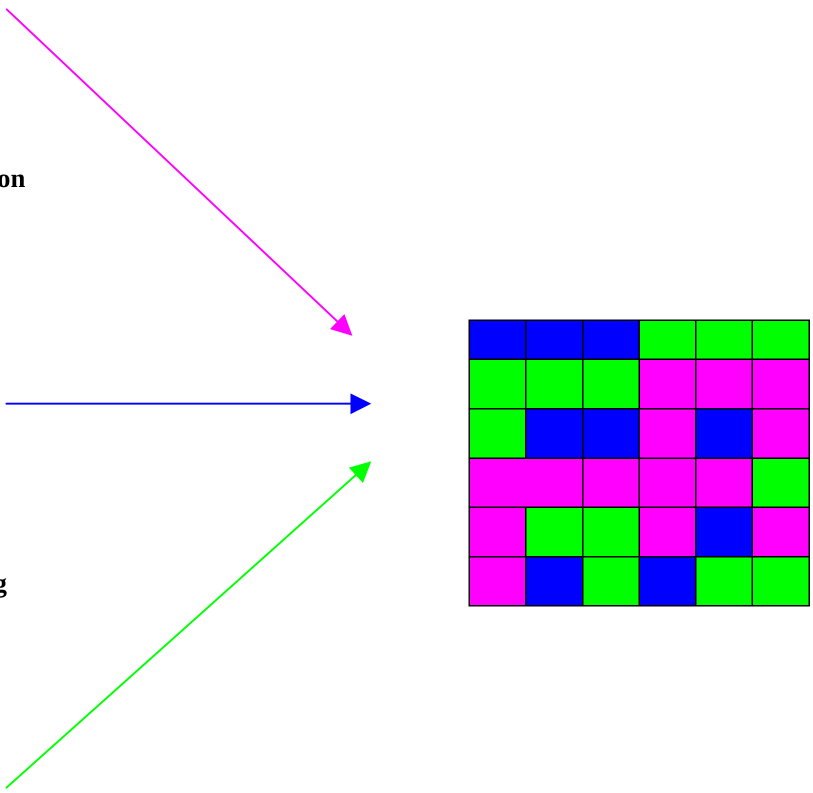
			2	23	65
			3	54	21
12	32	78	94	65	21
57	45	78	94	54	
37	76	54	87		78
54				42	

Suitability for Lime Application

78	87	65	45	12	
21	54	32	1	21	3
7	76	87		78	2
2	32		2		12
			12	46	34
45	24	23	45		1

Suitability for Deep Ploughing

14	15	3	54	48	97
45	57	57			
42	1		7		
24	25		39		99
	97	97		45	28
12	11	64		62	13



Where:
Black Cells = Clearly Not Suitable Cell, 'Masked' out of consideration
White Cells = Cells which have gone through the ideal point analysis
Numbers in White Cells = Suitability rating for that cell for the given Countermeasure. The scores here are ranging from zero (unsuitable) to one hundred (highly suitable).

= Most Suitable for Afforestation

= Most Suitable for Lime Application

= Most Suitable for Deep Ploughing

Figure 8. Example of 'most suitable' countermeasure selection for individual pixels using countermeasure suitability raster coverages.

8. Evaluation of the Methodology

The methodology that the CESER project has followed has both advantages and disadvantages. It is hoped that other projects will profit from our experiences and use them to avoid similar pitfalls in future work undertaken in this field.

The approach presented entails a considerable degree of interdisciplinary co-operation to fully understand the intricate relationships between the various environmental, social and economic impacts of countermeasure application. Bringing together people from such varied academic backgrounds undoubtedly makes for a stimulating working environment in which novel ideas can be explored. It also poses a significant challenge for the project participants to take a more holistic approach to the countermeasure assessment. Group members are required to put forth added effort towards being open to understanding and finding common ground between the various disciplines and goals. Owing to the applied and multi-disciplinary nature of the project it had to rely heavily on the results of existing research in a wide range of disciplines and there was little scope for original fundamental research.

In working with the proposed methodology our experience was that the linking the whole process of countermeasure selection and impact assessment to specific study sites had distinct advantages since it was possible to optimise countermeasure application to local environments and farming practices.

Another benefit is that one of the main outcomes of the methodology is the creation of a decision support system. This formalises the knowledge gained throughout the project and makes it accessible to a much wider audience. The decision support system allows the decision-maker to weigh both the benefits and costs of applying a range of appropriate countermeasures against each other. Every effort is made to ensure user-friendliness and practical relevance.

However, the participating researchers are also aware of a number of limitations in the presented methodology. Due to time constraints the decision support systems had to be restricted to pre-determined radionuclides deposition scenarios, agricultural production systems within one country and a sub-selection of potential impacts. The prediction of which food products are most likely to exceed intervention limits had to be based on a set of calculations which the user cannot modify. Future developments could include a facility for user-entry of specific deposition values of measured nuclide concentrations in animal feed and human food, dynamic modelling of radionuclide transfer into food products (if measurements are not available) and inclusion of a wider range of production scenarios and impacts.

A further weakness in the methodology is the unsophisticated treatment of the time factor. Two geographic areas with the same types of agriculture may require application of countermeasures for different time spans if soil types are significantly different in their radionuclide binding chemistry. For the DSS simplifications had to be made by assuming that Scottish upland and hill farms will typically have some organic soils, compared to none on lowland farms. This is a reasonable assumption upon which recommendations for soil based countermeasures were made. The assessment of side-effects was made for a ten year period and the frequency of application of each countermeasure was pre-defined, e.g. changes in the feeding regime of livestock would be continuous but deep ploughing would only be carried out once.

The models used to quantify some of the impacts required a great deal of parameterisation and estimation of certain required input data. This was a cumbersome and time-consuming task, in which a considerable amount of expert judgement was needed. Consequently, the way in which any decision support system could be implemented is significantly restricted, as it would not be possible to quantify countermeasure impacts at run-time using these models and methods. These system limitations were overcome in the SDSS by pre-processing all of the possible impact maps for a small number of case study areas. This limited the usefulness of the system by only allowing the user to run decision-making scenarios using the static results generated from this project. It also restricted the user to working within the project case study areas, as no countermeasure impact data exists outside these areas in the SDSS. Despite these shortcomings however, the approach taken here does test the validity of the methodology for possible use in a more comprehensive spatial decision support system. Ultimately, any future system should seek to seamlessly link spatial data for the whole of Europe with the environmental models used to assess countermeasure suitability. Likewise, it would seek to incorporate economic and social impacts to a greater extent into the assessment.

9. Conclusions

A generic methodology for the selection of countermeasures and assessment of their potential environmental and agricultural impacts has been presented. However, to illustrate the strengths of this methodology it was applied to specific study sites and agricultural production systems. Site specificity is a key factor in optimising countermeasure selection and enabling realistic estimation of impacts resulting from countermeasure application. This means that the methodological steps outlined have to be carefully followed through if a similar assessment were to be undertaken under different environmental and agricultural conditions.

10. References

Alexakhin, R. M. (1993). Countermeasures in agricultural production as an effective means of mitigating the radiological consequences of the Chernobyl accident. *Science of the Total Environment*, 137, 9-20.

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

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

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.

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

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.

Hove, K., Strand, P., Voigt, G., Jones, B. E. V., Howard, B. J., Segal, M. G., Pollaris, K. and Pearce, J. (1993). Countermeasures for reducing radioactive contamination of farm animals and farm animal products. Science of the Total Environment, 137, 261-271.

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

Jankowski, P (1989). Mixed data multicriteria evaluation for regional planning: a systematic approach to the decision making process. Environment and Planning A, 21(3), 349-362.

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

Knisel, W. G. (ed.) (1988). CREAMS: A field-scale model for chemicals, runoff, and erosion from agricultural management systems, U.S. Department of Agriculture, Conservation Research Report 26.

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

Overnoy, V. M. (1992). Choosing the ‘best’ multiple criteria decision making method. Information Systems and Operational Research, 30, 159-171.

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.

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

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

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

Smith, R.E. (1992). OPUS, an Integrated Simulation Model for Transport of Non-point Source Pollutants at the Field Scale. U.S. Department of Agriculture, Agricultural Research Service, ARS-98; Fort Collins.

Strand, P., Skuterud, L. & Melin, J. (eds) (1997). Reclamation of Contaminated Urban and Rural Environments Following a Severe Nuclear Accident, Nordic Nuclear Safety Research, BER 6. NKS(97)18.

Sutton, M. A., Place, C. J., Eager, M., Fowler, D. and Smith, R. I. (1995). Assessment of the magnitude of ammonia emissions in the United Kingdom, Atmospheric Environment 29, 1393 - 1411.

Vereecken, H., Maes, J., Feyen, J. and Darius, P (1989). Estimating the soil moisture retention characteristic from texture, bulk density and carbon content. Soil Science, 148, 389-403.

Voogd, H. (1983). Multicriteria evaluation for urban and regional planning. London, Pion.

Appendix I – Animal Production Data Requirements

For each animal production system:

- Yield
- Feeding regime
  - Quantity and type of concentrate fed (kg/head/day)
  - Quantity and type of roughage fed (kg/head/day)
  - Difference between summer and winter diet
- N and P concentration in the faeces
- Stocking rate
- Length of time spent grazing outdoors
- Length of time spent housed indoors
- Are animals sold for fattening or fattened on the farm
- How and when animals are finished for market

Appendix II – Non-Spatial Data Requirements for ICECREAM and OPUS models

Weather Data:

- Daily precipitation
- Daily temperature (mean, or min. and max.)
- Radiation or cloudiness
- Relative humidity
- Rainfall collection efficiency
- Rainfall intensity

Soil Data (for each horizon):

- Percentage of sand
- Percentage of silt
- Percentage of clay
- Percentage of organic matter (or organic carbon)
- Soil structure class
- Soil permeability class
- Saturated hydraulic conductivity
- Field capacity
- Wilting point
- Soil porosity
- pH
- Total P concentration
- Labile P concentration (derived from available P e.g. Olsen's or Bray)
- Organic P concentration
- Nitrogen concentration in rainfall
- Total N concentration
- Nitrate-nitrogen concentration in soil
- Organic nitrogen concentration

Crop Data:

- Typical active rooting depth
- Typical maximum rooting depth
- Typical yield
- Average N- concentration in biomass
- C:N ratio in biomass

N:P ratio in biomass
LAI (Leaf Area Index)
Canopy height
Canopy width
Crop row width
Crop harvest efficiency

Management Data:

- Typical dates for:
  - Planting/sowing
  - fertilisation
  - harvesting/grazing
- Fertilisation:
  - dates of fertilisation
  - type of fertilisation (organic/inorganic)
  - method of fertiliser application
  - amount of N applied
  - amount of P applied
- Tillage:
  - name of the implement
  - date used
  - tillage depth
  - mixing efficiency
  - incorporation efficiency

Appendix III – Spatial Data Requirements

Digitial Elevation Model
Agricultural Field Boundaries (optional)
Agricultural Census Boundaries
Soil Type Boundaries
Land Use Coverage
Water Coverage (rivers, lakes, etc.)

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