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

The CESER Decision Support System

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

THE CESER DECISION SUPPORT SYSTEM

A technical deliverable of the

CESER

-**C**ountermeasures**: E**nvironmental and **S**ocio**-E**conomic **R**esponses-

Project

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A CD-ROM with the software accompanies this manual.

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SUMMARY

The CeserDSS is a user friendly PC-based expert system/decision support system for countermeasure implementation in agricultural food production systems in Scotland. It is intended as a decision-aiding tool in the planning of long-term remediation at the level of a farm or small agricultural area. A range of countermeasures, aimed at reducing levels of radiocaesium and radiostrontium in food products, can be simultaneously evaluated in terms of their likely environmental, agricultural and economic impacts.

At the beginning of the countermeasure evaluation, the user has to choose one of four pre-set radionuclide deposition scenarios and one of seven farm types. This produces a list of basically suitable countermeasures, selected by the developers of the software as appropriate in terms of the required radiological effectiveness and general suitability for the farm type. To determine the specific suitability of each countermeasure for the land being assessed, the user has to provide information on environmental and agricultural conditions, which is compared with a pre-determined set of thresholds. Once all limiting factors have been checked, the suitable countermeasures can be evaluated in terms of their potential impacts on water, soil, air and landscape quality, biodiversity, animal welfare and agricultural product quantity and quality.

Ideal Point Analysis, a method for multicriteria decision making has been implemented to allow a formal comparison of the selected countermeasures with the option of applying user-defined preferences. This method permits the user to define the ideal objectives for each of nine assessment criteria and to apply weighting factors to each of these. The degree of compensation between poor performance on one or more criteria and good performance on others can also be chosen. The final output is a list of countermeasures ranked from best to worst with respect to their environmental and agricultural impacts taking into consideration any user-specified objectives and preferences. An economic assessment of countermeasures can be undertaken through a farm-level cost-benefit analysis. The user is given the opportunity to modify key economic variables to make the calculations as farm specific as possible.

The contents of this report are also available in the help files of the software. The key features of the software are introduced. The approach adopted in the pre-selection of countermeasures for inclusion in the CeserDSS is detailed. The identification of the most significant environmental and agricultural impacts and the methods used in quantifying them are explained. In some cases it was possible to employ mathematical modelling and spreadsheet calculations, while for others experimental work and economic surveys were necessary. In many cases expert judgement had to be applied. All estimates of likely impacts had to be converted to a common impact scale and entered as impact scores into a series of farm-specific and deposition scenario-specific evaluation matrices within the DSS. These default scores can be edited by the user.

Detailed descriptions of all countermeasures included in the CeserDSS in terms of their execution, effectiveness and side-effects are provided, together with an explanation of the environmental and agricultural limitations to their implementation. The merits and limitations of the software are discussed.

1. INTRODUCTION

In the event of radioactive contamination of agricultural production systems the primary aim is to protect human health. This is achieved in principle by ensuring that contamination levels in food do not exceed set intervention limits. A wide range of countermeasures has been critically evaluated in terms of their radiological effectiveness, cost and practicability (e.g. IAEA, 1994a; Roed *et al.*, 1995; Strand *et al.*, 1997). However, the decision maker is faced with a bewildering choice of countermeasures and lack of guidance on how to compare different remediation options. Recommendations for specific production systems and geographic areas are limited. There is also a little appreciation of the impact of countermeasures beyond their radiological effectiveness, immediate costs and the technicalities of the operation. Long-term use of countermeasures will 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.

The CESER project has developed an interactive software package to assist decision makers in the long-term management of radioactively contaminated agricultural areas. The CeserDSS is an expert system/decision support system (ES/DSS) designed as a planning tool for the application of land-based countermeasures in Scottish agricultural production systems. It's purpose is to assist in the selection of countermeasures suited to local agricultural and environmental conditions and to allow the user to apply environmental, agricultural and economic criteria. It is intended for application at the level of a farm or small agricultural area and relies on user input to determine any limitations that may exclude certain countermeasures from the assessment. In parallel, the CESER project is developing a GIS-based Spatial Decision Support System, primarily intended for decision making at a regional or national level (Salt *et al.*, 1999b; Salt & Culligan Dunsmore, submitted). This relies on having spatial environmental and agricultural information in an electronic format, to enable the generation of countermeasure impact and suitability maps

The CeserDSS is only intended for the assessment of countermeasures in Scotland on land falling into one of the categories of land use specified. The ES component of the software guides the user through a range of land management questions and produces a list of countermeasures that are suitable to their particular land and farm management regime. The DSS component of the software allows the decision maker to further evaluate the countermeasures by assessing them according to the user's own personal objectives using a Multicriteria Decision Making (MCDM) methodology called Ideal Point Analysis (Nijkamp *et al.*, 1990). This technique incorporates user-specified weighted criteria into the analysis and ranks the countermeasures from best to worst, based on their environmental and agricultural impacts. The user can also carry out a detailed economic analysis of the final countermeasures, including both the on-farm costs and benefits of implementing the countermeasure (Wilson *et al.,* 1999). The use of decision support systems and multicriteria decision-aiding techniques is seen as an important tool in post-emergency remediation (e.g. Morrey *et al.,* 1996; Borzenko & French, 1996), however, the systems developed so far have not been widely disseminated. The largest DSS in development, RODOS (Real-time On-line Decision Support System) is a generic system for the whole of Europe and requires large databases as well as a series of models (Ehrhardt *et al.,* 1996). As such, it's use will be restricted to experts in institutions responsible for radiation protection. In contrast the CeserDSS has been developed for farm level countermeasure planning in Scotland. It gives farmers, agricultural advisors and Government representatives the opportunity to work together in selecting countermeasures suited to local conditions.

An overview of the countermeasure assessment process implemented in the CESER Decision Support System is provided in Figure 1. The following documentation provides a compilation of the information available to the user in the help files of the software, as well as a critical discussion of the merits and limitations of the Decision Support System in it's current stage of development. The general methodology applied in the development of the CeserDSS is explained in more detail in Salt *et al.* (1999a).

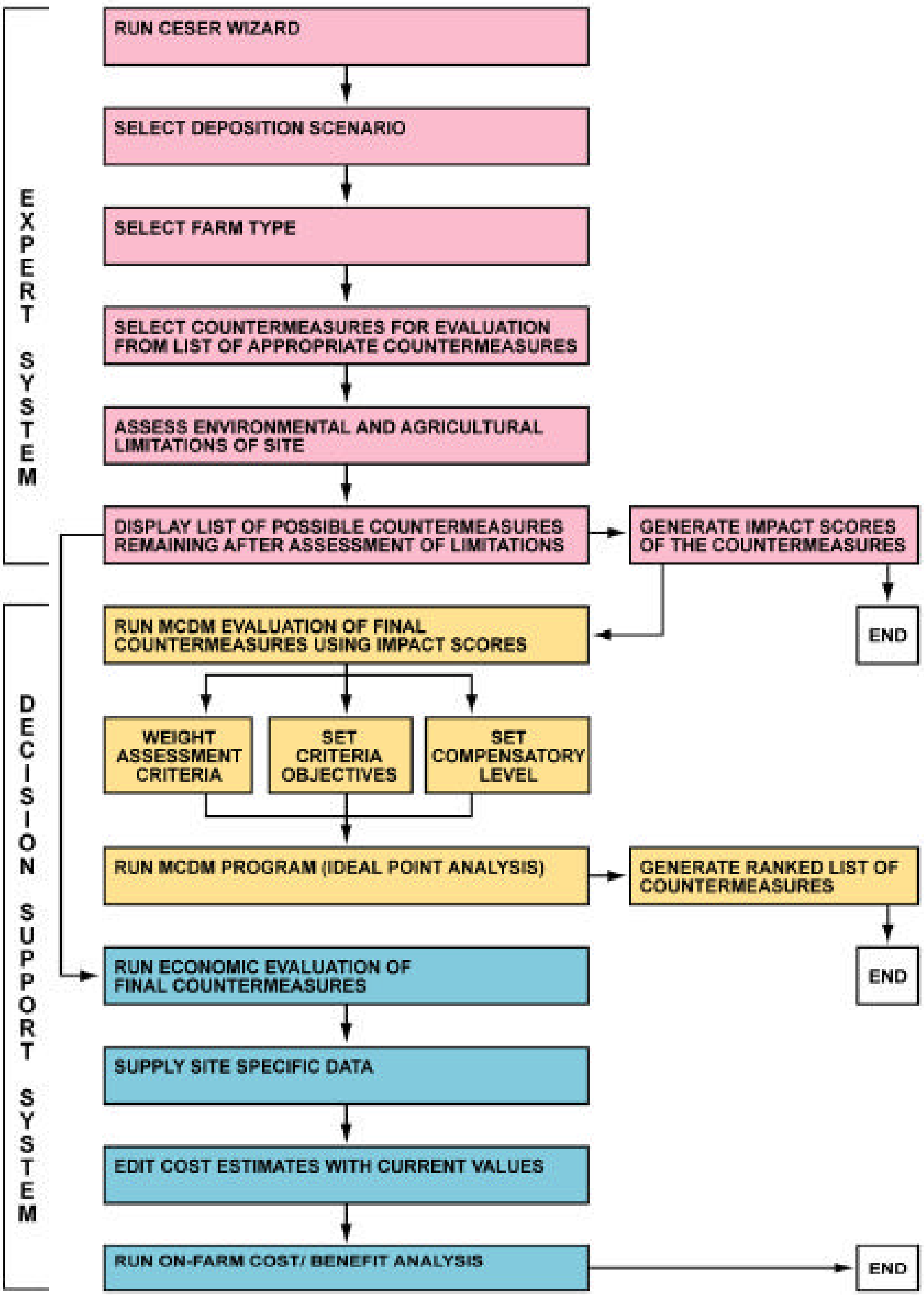


Figure 1. Overview of the countermeasure evaluation process in the CeserDSS

2. SOFTWARE DOCUMENTATION

This section gives the specifications of the software, explains how to run the CeserDSS and introduces the key features supported.

2.1. The Software

The CeserDSS is a flexible PC-based expert/decision support system (ES/DSS) developed using Visual Basic, version 5.0. Currently its use is restricted to a Windows 95 (32 bit) platform. To install the CeserDSS on a PC insert the CD-ROM and double-click on the setup.exe file. Automatic installation to a directory called c:\Program Files\Ceser will start. The user can change the location on which the software is installed. Alternatively the software can be downloaded from http://www.stir.ac.uk/envsci/ceser/ceser.htm.

2.2. Commands Supported in the Drop Down Menus

The menu and tool bar are shown in Figure 2 together with the layout of the results file.

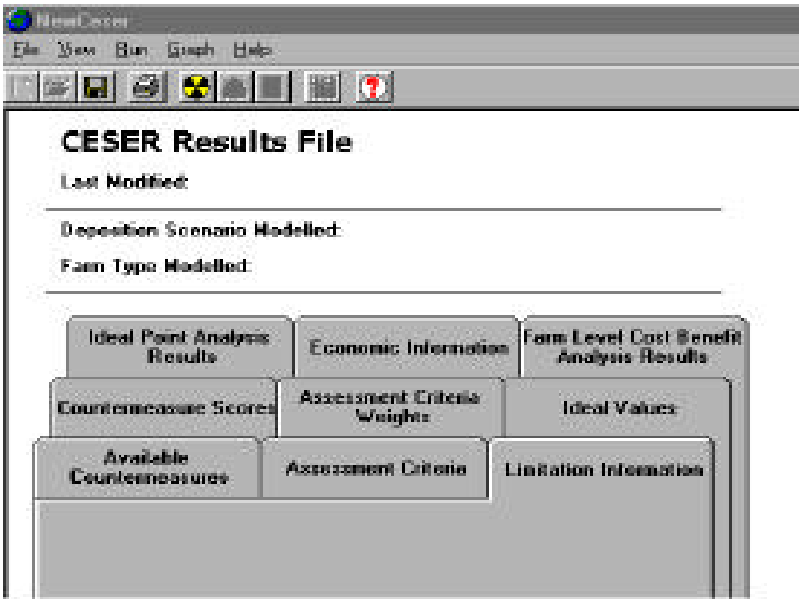


Figure 2. CeserDSS menu and tool bar with results file.

2.2.1. File

- New
  Opens a blank CeserDSS file. (Note: A file must be open in order for other functions such as 'Run CESER Selection Wizard' to be enabled.)

- Open
  Opens previously saved CeserDSS files. (Note: A file must be open in order for other functions such as 'Run CESER Selection Wizard' to be enabled.)

- Close
  Closes a CeserDSS file. (Note: The system does not automatically save changes when closing a file. It is necessary to save relevant changes before closing the file.)

- Save
  Brings up the 'Save' window. Select the filename and pathway of the file you would like to store the CeserDSS results in. The default file extension for CeserDSS files is *.ces.

- Save As
  Brings up the 'Save As' window. Select the filename and pathway of the file you would like to store the CeserDSS results in. The default file extension for CeserDSS files is *.ces.

- Export File As … Text Format (*.txt)
  Exports all information from the CeserDSS file to a formatted text file.

- Print
  Not implemented. To print results, export file in text format and print from outside the CeserDSS.

- Exit
  Closes any open CeserDSS files and exits from the programme.

2.2.2. View

- Toolbar
  Brings up / removes a toolbar which has buttons with shortcuts on it. The short cuts provide a direct link to: 'File', 'Open', 'Save', 'Run CESER Selection Wizard', 'Run MCDM Wizard, 'Run Cost/benefit Wizard', 'Graph' and 'Help'.

- Status Bar -Not implemented

2.2.3. Run - Ceser Selection Wizard

The Ceser Selection Wizard takes the user step-by-step through the selection of countermeasures and the assessment of their limitations. The final output generated by this wizard is a list of countermeasures that can be applied in the selected agricultural system. Impact scores are generated for these countermeasures (see Section 2.3.2.).

The Ceser Selection Wizard Step-by-step

- Step 1: Select Deposition Scenario
  Click on a Deposition Scenario (see Section 3.2.) that reflects how contaminated the land being assessed is. Then Click on the ‘Next’ button to advance the Wizard to the next step.

- Step 2: Select Farm Type
  Click on a Farm Type (see Section 6.3.) that is representative of the land being assessed, as shown in Figure 3. Then Click on the ‘Next’ button to advance the Wizard to the next step. For mixed farming situations, separate assessments should be run for each farming type.

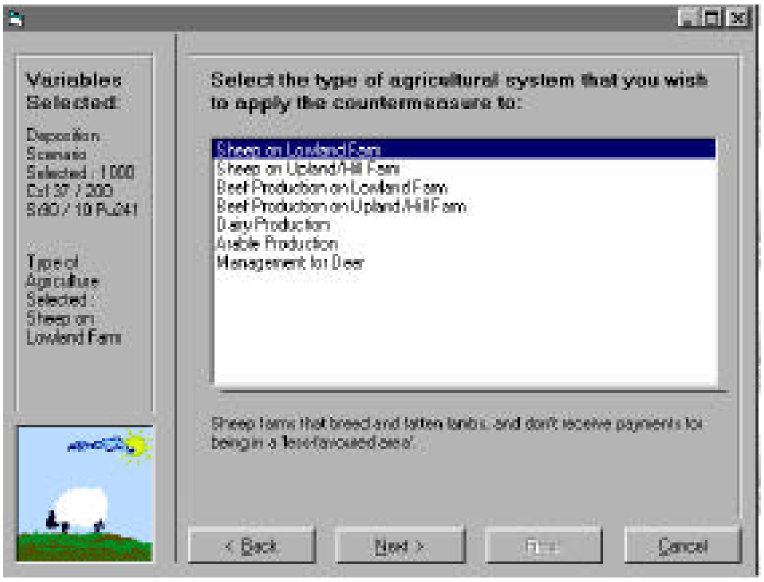


Figure 3. Selection of farm type.

- Step 3: Select Preliminary Countermeasures
  A preliminary list of appropriate countermeasures appears next on the screen (see Figure 4). These countermeasures have been evaluated in the CESER project and are deposition scenario and farm type specific. They were selected following an Initial Screening Process (see Section 3.1.) of a wide range of possible countermeasures, followed by a 4-Step Evaluation of Individual Countermeasures (see Section 3.3.). Click on the boxes to the left of the countermeasure names, to select which countermeasures you would like to have progress to the next step. At least one countermeasure must be selected in order to continue. Brief descriptions of the countermeasures appear at the bottom of the Wizard as the different countermeasure options are clicked. More detailed information on countermeasures is available in Chapter 4. Click on the 'Next' button to advance the Wizard to step 4.

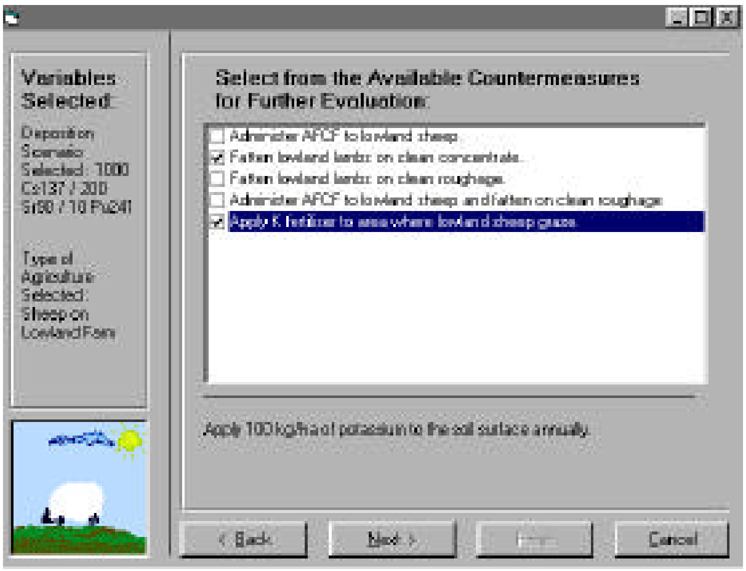


Figure 4. Selection of countermeasures

- Step 4: Limitations Assessment
  For each countermeasure selected, a number of questions have to be answered about the situation being modelled (see example in Figure 5). This is to ensure that each countermeasure falls within the specific limitations for its implementation (see Chapter 5.). Answer each question appropriately and then click on the ‘Next’ button to advance the Wizard.

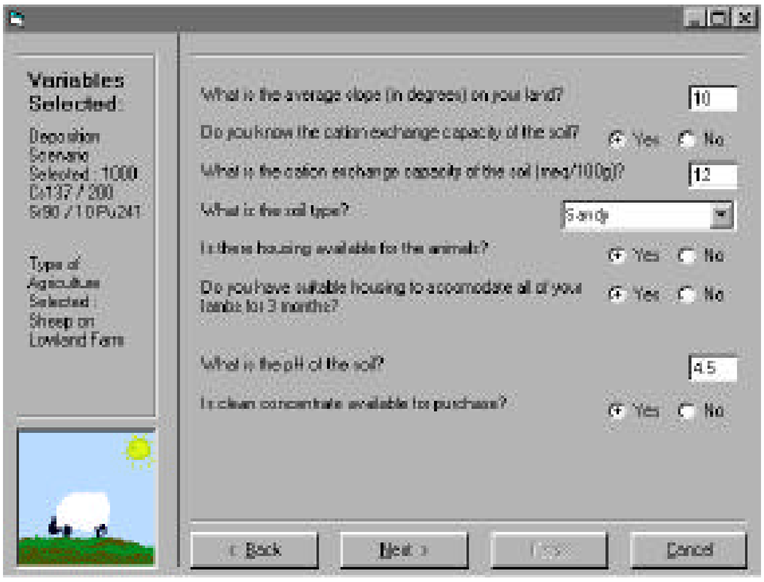


Figure 5. Limitations assessment

Note: There may be anywhere from zero limitation questions to up to three pages of limitation questions, depending on the number and type of preliminary countermeasures selected for assessment. You must answer all of the questions that appear in order to progress to the final step.

- Step 5: Final Countermeasures
  In the last screen of the CESER Selection Wizard, a final list of countermeasures that could be applied to the land being modelled appears. All of these countermeasures should be suitable, according to the information that has been provided. Press the ‘Finish’ Button to close the Wizard. This action also generates a matrix of Impact Scores (see Section 2.3.2.) for the final list of countermeasures and the Assessment Criteria (see Section 2.3.1.).

2.2.4. Run - Multicriteria Evaluation Wizard

The Multicriteria Evaluation Wizard is only enabled if the user 1.) has an open file and 2.) has impact scores for more than one countermeasure in that file (i.e. has run the CESER Selection Wizard). Once activated, this Wizard allows the user to set all of the parameters needed to run a multicriteria assessment (see Section 3.7.) which ranks the countermeasures in order of decreasing suitability based on the environmental/agricultural impact of each countermeasure and the users’ own decision-making objectives. The Multicriteria Decision Making algorithm, Ideal Point Analysis (see Section 3.7.), is used to evaluate the impact scores and generate countermeasure suitability rankings.

The Multicriteria Evaluation Wizard Step-by-step

- Step 1: Introduction to MCDM analysis
  Introductory explanation of MCDM (Multicriteria Decision Making). Click on the ‘Next’ button to advance the Wizard to the next step.

- Step 2: Enter P value
  Enter a p value to reflect how compensatory you wish the assessment to be. A p value of one will make the assessment fully compensatory, while values greater than one will make the assessment progressively less compensatory (Only p values ranging from one to ten are selectable). Click on the ‘Next’ button to advance the Wizard to the next step.

- Step 3: Set Criteria Objectives
  Enter the objectives for each assessment criterion (the default settings are illustrated in Figure 6). These values are used to specify what the ideal scenario would be in terms of the criteria (e.g. Erosion would be 'Greatly Reduced', Animal Welfare would be 'Greatly Increased', etc.). Click on the ‘Next’ button to advance the Wizard to the next step.

- Step 4: Set Criteria Weights
  Weight each of the assessment criteria from 0 … 10 (low - high) according to your own decision making objectives (the default settings are illustrated in Figure 6). A score of zero will exclude the criterion from consideration in the assessment, while a score of 10 will cause a particular criterion to have the greatest impact on the assessment. Click on the ‘Next’ button to advance the Wizard to step 5.

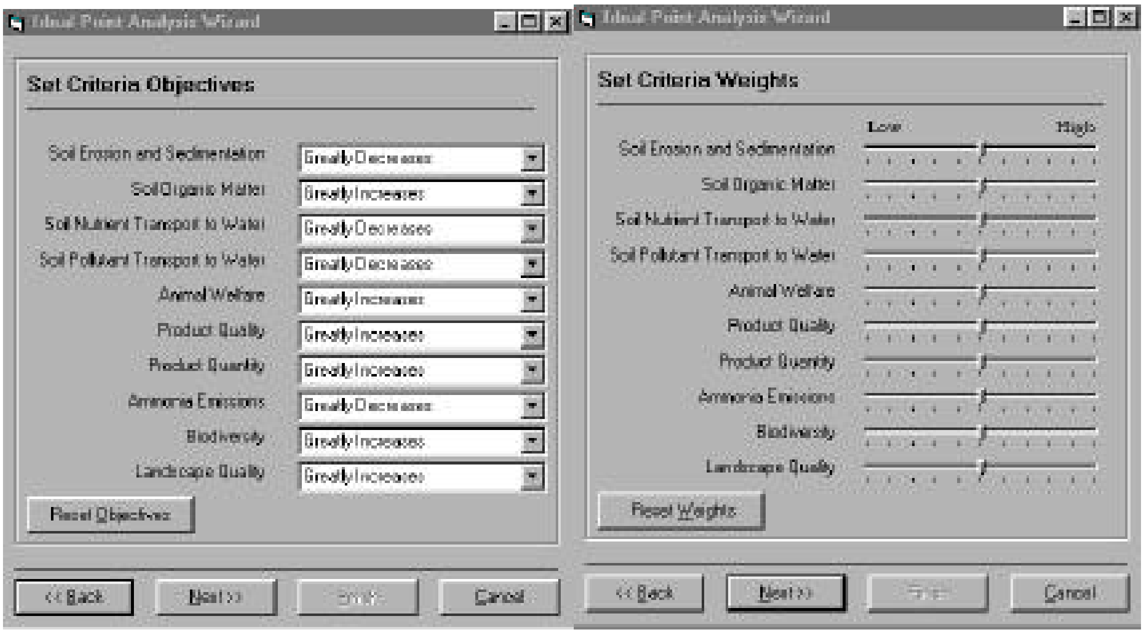


Figure 6. Screens showing default criteria objectives and weights.

- Step 5: Countermeasures Ranked by Suitability
  The final countermeasures are shown ranked from best (lowest score) to worst (highest score) according to their overall environmental/agricultural impact taking into account the p value, objectives, and weights assigned by the user. Click on the ‘Finish’ button to enter the MCDM results in the CESER file and close the Wizard.

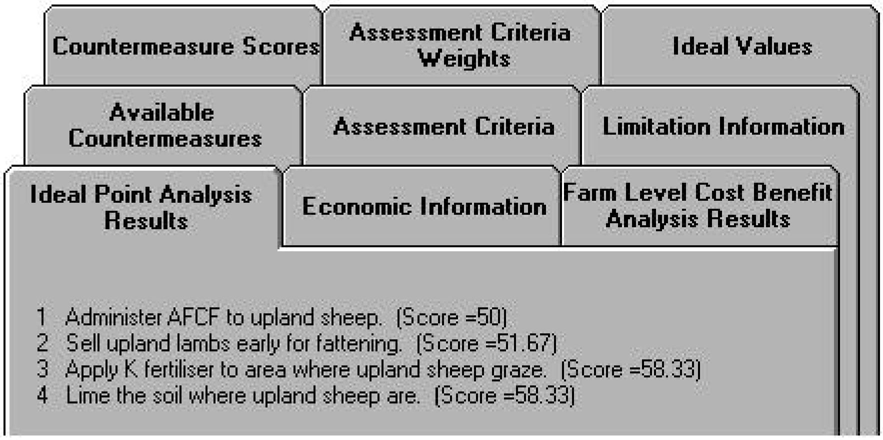


Figure 7. Example of final countermeasures ranked according to their environmental/agricultural impacts (all criteria equally weighted).

2.2.5. Run - Farm Level Cost/Benefit Wizard

The Farm Level Cost/Benefit Wizard is only enabled if the user 1.) has an open file and 2.) has impact scores in that file (i.e. has run the CESER Selection Wizard). Once activated, this Wizard asks the user a number of economic questions related to the final list of countermeasures generated for their farm type. The cost variables used in the calculations are then displayed. The user is able to change the default values shown, if they do not apply to their specific situation. Farm level cost and benefits are then calculated based on this information and a summary is given. It is recommended that users consult the report by Wilson *et al.* (1999) which explains the economic calculations and necessary assumptions in detail.

The Farm Level Cost/Benefit Wizard Step-by-Step

- Step 1: List of Countermeasures
  List of the final countermeasures generated using the CESER Selection Wizard step-by-step. Click on the ‘Next’ button to advance the Wizard to the next step.

- Step 2: Economic Questions
  For each final countermeasure the user must answer a number of questions about the economic situation being modelled. Answer each question appropriately and then click on the ‘Next’ button to advance the Wizard.

- Step 3: Costs
  For each final countermeasure, a number of economic variables are used to calculate the farm level costs and benefits (see example in Figure 8). The default values are shown and the user has the option of altering those values as appropriate to their particular situation. Click on the ‘Next’ button to advance the Wizard.

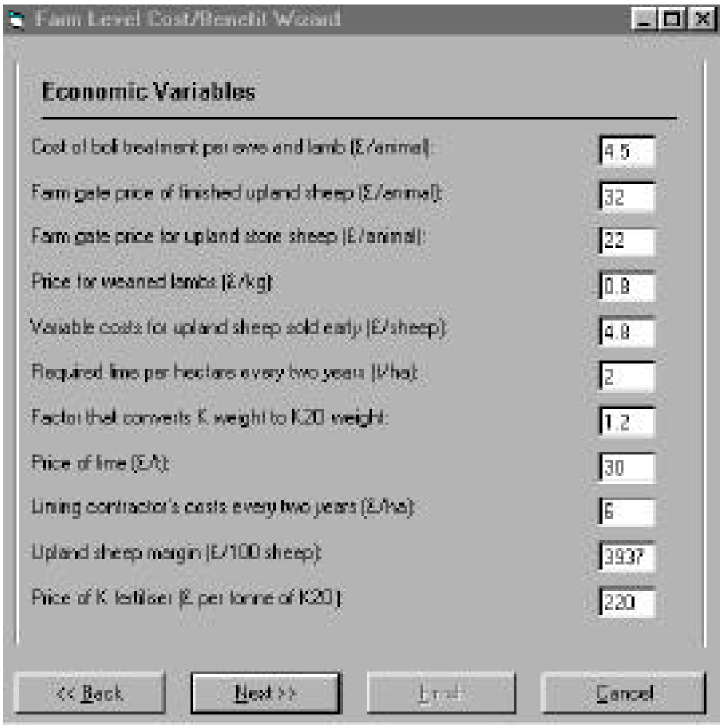
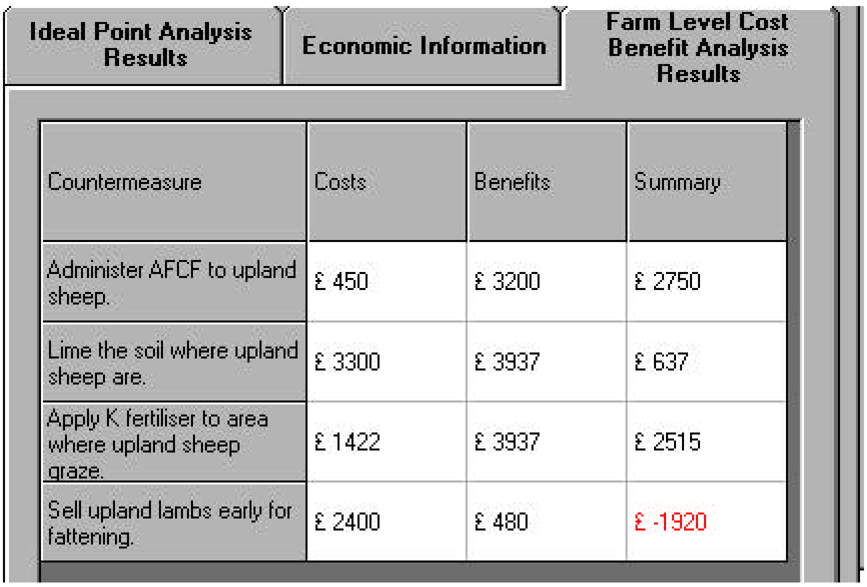


Figure 8. Example of editable economic variables.

- Step 4: Benefits
  A spreadsheet is produced with the total costs, benefits and an economic summary for each of the final countermeasures. Click 'Finish' to complete the assessment and write the results to the CeserDSS file (see Figure 9).



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 9. Example of economic assessment results for a sheep farm that normally finishes 100 lambs and has 50 ha of land suitable for liming and K application.

2.2.6. Graph

- Countermeasure Scores
  Brings up a window with a graph of all of the countermeasure/criteria impact scores.

2.2.7. Help

- Contents
  Provides the user with help information on topics related to the CeserDSS.

- Help Index
  Allows a search through help keywords.

- Help Find
  Brings up a Wizard that enables the user to search for specific words and phrases in the help topics, instead of searching for information by category.

- About CeserDSS
  Brings up a window with programme information.

2.3. Definitions of Key Features

2.3.1. Assessment Criteria

Assessment criteria are used in the CeserDSS to characterise the environmental and agricultural impacts of countermeasure application. Their selection was based on literature review and expert judgement. Once a comprehensive list of potential side-effects of soil-plant-based and animal-based countermeasures had been compiled, the side-effects were prioritised to yield the following list of final assessment criteria:

- 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 on drinking water quality or biological habitats may occur.

- Soil Organic Matter
  The humus content of the topsoil.

- Soil Nutrient Transport to Water
  The transport of soil nutrients in dissolved or particulate form in runoff and percolate which may enter surface or ground water and cause eutrophication (see explanation in Section 6.2.).

- Soil Pollutant Transport to Water
  The transport of soil pollutants such as heavy metals in dissolved or particulate form in runoff and percolate which may enter surface or ground water and cause water pollution.

- Animal Welfare
  The maintenance of animals in good health through humane handling, care and treatment. This entails a) freedom from thirst, hunger and malnutrition, b) provision of appropriate comfort and shelter, c)

prevention, or rapid diagnosis and treatment, of injury, disease or infestation with parasites, d) freedom from distress and e) ability to display normal patterns of behaviour

- Product Quality
  The quality of the agricultural product in terms of it's saleability (e.g. fat content of meat).

- Product Quantity
  The amount of food (milk, meat, grain, seed, root crop) produced for sale.

- Ammonia Emissions
  Emissions of ammonia due to volatilisation from nitrogen contained in animal faeces, urine or manure or in mineral fertilisers. The emissions from livestock occur during outdoor grazing and periods of housing, as well as during storage and land spreading of manure.

- Biodiversity
  'The variability among living organisms and the ecological complexes of which they are part' (UNEP 1993). In the context of the CeserDSS we have defined biodiversity as the ecological richness of a particular farm type which includes higher plant and animal diversity as well as rarity and distinctiveness of species and diversity of habitats/ecosystems.

- Landscape Quality
  The value of a landscape based on known and predicted preferences in Scottish people. Preference depends on cultural background, knowledge and educational level. Factors, which may play a role, are the perceived 'naturalness', diversity and fragility of an area and economic/recreational value.

2.3.2. Impact Scores

Impact scores represent the effects of implementing a particular countermeasure on the list of predefined assessment criteria (see previous chapter). These scores range from 'Greatly Decreasing' to 'Greatly Increasing' and have corresponding numeric values that range from -1 to +1, as shown in Figure 10.

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 10. Relative impact scores used in the CeserDSS.

The user can view the impact scores generated by running the CESER Selection Wizard (see Section 2.2.3.) and consulting the CESER file (see Figure 11). The default scores can be altered by double clicking on the cell that the user wishes to change. A small box will then appear which allows the user to select and accept a new impact relationship for that particular countermeasure and criterion.

Countermeasure Scores | Assessment Criteria Weights

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 11. Example of impact scores held in the CESER results file.

The default impact scores are designed to reflect the magnitude of each impact across all of the countermeasures and production systems. Additionally, scores have been calibrated across criteria with each countermeasure/production system combination. It is advised that the impact scores should only be altered in situations where the user is familiar with the system under evaluation and there is sufficient evidence that the default scores are not applicable.

The impact scores are held in a two-dimensional matrix, where columns represent the countermeasure alternatives and the rows represent the assessment criteria. The user has the option of carrying out a multicriteria assessment of the impact scores held in the matrix. Section 3.7. gives more details on the methodology as well as a generic matrix of all countermeasures (Fig. 13).

3. THE CESER METHODOLOGY

The CESER methodology was developed to assess the potential side-effects of long-term countermeasures in agricultural systems following a radionuclide deposition event. An overview is shown in Figure 12. Here a summary is provided of those aspects, which shaped the development of the CeserDSS. A full account of the methodology for environmental impact assessment is presented in Salt *et al.* (1999). Economic and social aspects are addressed in Wilson *et al.* (1999) and Grande *et. al.* (1999).

3.1. Initial Screening of Countermeasures

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. During the development of the DSS, the first step was to eliminate countermeasures that are unlikely to be used in practice. This was achieved through a screening of the literature on a wide range of countermeasures using the following general criteria (adapted from Nisbet, 1995):

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

The groups of countermeasures reviewed were:

Soil-plant based measures	*Animal based measures*
(1.) Application of fertilisers	(1.) Chemical treatment
(2.) Application of chemical binders	(2.) Feeding regime
(3.) Mechanical/physical treatment	(3.) Animal management
(4.) Crop and land use change	(4.) Land use change

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 enabled the choice of countermeasures to be narrowed down to those most worthy of more detailed examination. For instance, potassium fertilisation is cheaper than soil application of clay minerals or AFCF and has a similar reported effectiveness (WS Atkins Environment, 1996). It is also likely to be more acceptable to farmers due to familiarity. Direct administration of hexacyanoferrate compounds such as AFCF to animals was favoured over clay minerals since they are generally more effective and easier to administer (Voigt, 1993). Also some animal health effects have been reported when high doses of bentonite are used (Beresford *et al.,* 1989; Unsworth *et al.,* 1989). Use of fencing to prevent grazing of hot spot areas, was excluded because of the practical problems of localising hot spot areas and the cost of fencing large areas.

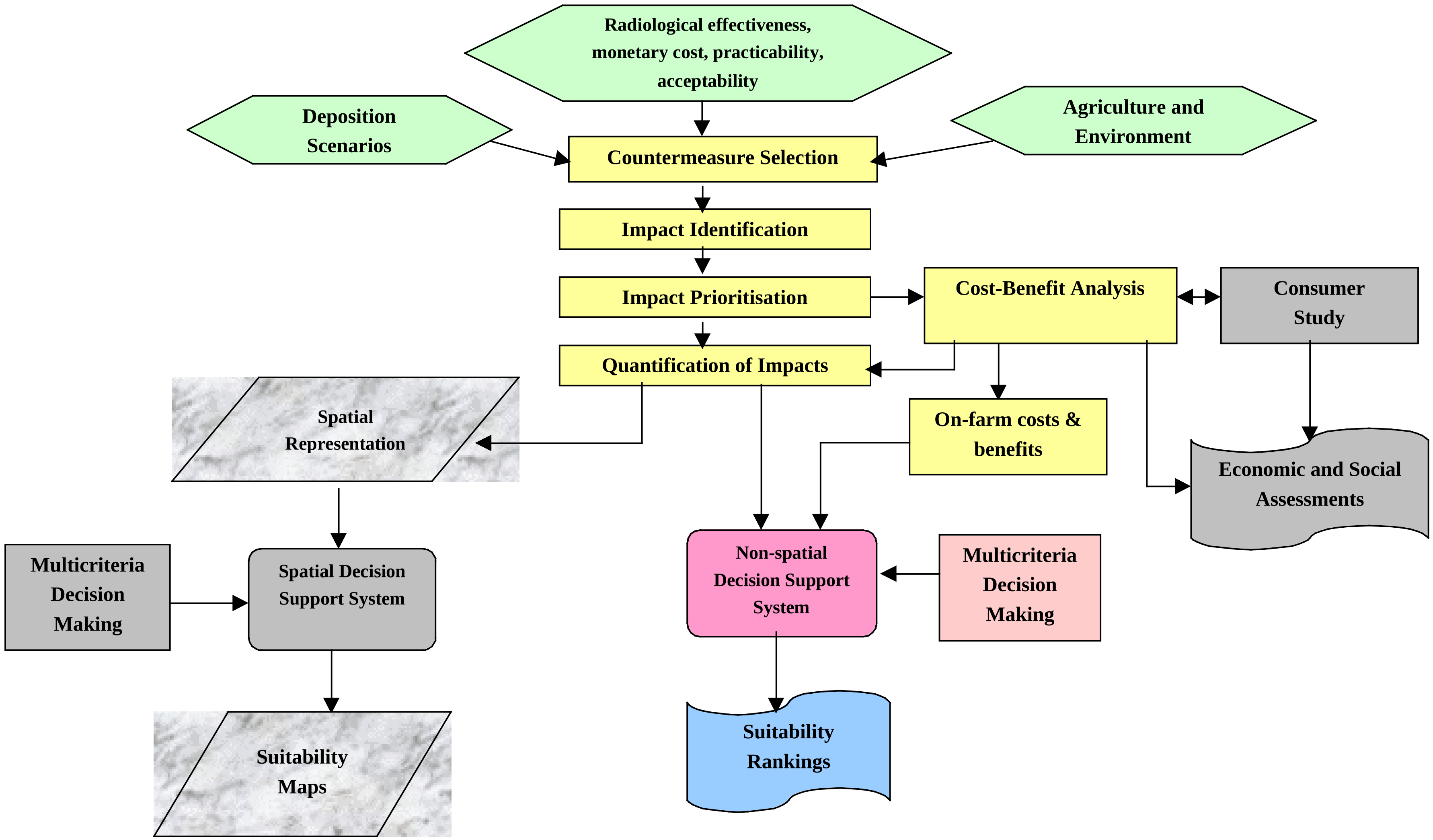


Figure 12. Overview of the CESER methodology. Aspects not directly relevant to this report are shaded in grey.

3.2. Deposition Scenarios

For the purpose of allocating appropriate countermeasures it was necessary to categorise the depositions of radionuclides. In this project, work was focused on environmental contamination being caused by atmospheric release and subsequent deposition of radionuclides. Of the various radionuclides, which may be emitted in the course of a nuclear accident, only few show high transfer rates to man via food chains and pose a long-term radiation problem due to long half lives. Therefore, the radionuclide deposition scenarios, developed within the project, focus on ^{137}Cs, and ^{90}Sr. They reflect different source terms and variable distances from the source of nuclide release.

Table 1. Radionuclide deposition scenarios in kilo bequerel per square metre.

	^{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

3.3. Four-Step Evaluation of Individual Countermeasures

Following on from the initial screening the choice of countermeasures for inclusion in the DSS was further restricted. Countermeasures have to be tailored as closely as possible to fit in with the local farming conditions in Scotland, to ensure maximum effectiveness. Detailed knowledge of the agricultural management and environmental conditions along with 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.

The selection of countermeasures for different types of Scottish agricultural production systems in the DSS was based on the following steps:

Step 1

For each deposition scenario (see Section 3.2.), contamination levels in food products were predicted using 95% confidence intervals of transfer factors from IAEA (1994b). Where CFIL’s (Community Food Intervention Levels) are likely to be exceeded countermeasures are necessary. The calculations agreed well with the post-Chernobyl experience regarding which production systems were affected.

Step 2

Only countermeasures were selected that 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.

Step 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).

Step 4

The additional dose to farmers executing the countermeasures was calculated for each deposition scenario. Calculations were 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 4 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 left fallow or be converted to forestry.

The same approach was used for crop and animal production systems.

3.4. 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). A thorough literature review was performed to identify potentially significant side-effects of those countermeasures which were selected according to the Initial Screening Process (see Section 3.1.) and the 4-step Countermeasure Selection Process (see Section 3.3.). 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. Non-radiological impacts on the environment and agricultural production are represented in the CeserDSS as Assessment Criteria (see Section 2.3.1.).

3.4.1. Soil-plant-based Countermeasures

The literature review indicated 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 methods be selected that enable quantification of side-effects and incorporation into the DSS. For many potential effects of soil-based countermeasures, however, neither suitable models nor calculation routines were available or information in the literature was insufficient to allow quantification. The following areas were therefore targeted through laboratory experiments:

a) Transport of trace elements with humic substances
b) Environmental degradation of AFCF and it’s influence on radiocaesium

Expert judgement (see Section 3.6.6.) was applied to determine the relative scale of impact of the remaining side-effects.

3.4.2. Side-effects of Soil-plant-based Countermeasures

The following potential side-effects were researched via a 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 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

3.4.3. Animal-based Countermeasures

The animal-based countermeasures were split into chemical treatments and management related measures. The potential side-effects of chemical treatments, such as AFCF (Cs-binder) or high levels of Ca supplementation (Sr transfer reduction), will mainly be related to nutrition and health of the animal and to possible environmental pollution once the chemical compound has been spread through manure. Therefore 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.

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.

3.4.4. Side-effects of Chemical Treatment of Animals

The following potential side-effects were investigated via a literature review:

Calcium administration to animals

Calcium supplementation is an effective means of reducing the radiostrontium contamination of the milk produced from dairy cows (Howard *et al.*, 1997). Regular high doses of Ca could, however, lead to side effects related to the following:

(a.) mineral absorption
(b.) vitamin K
(c.) animal growth rate
(d.) milk yield

AFCF administration to animals

When administered to livestock, ammonium-iron-hexacyanoferrate (AFCF), also called Prussian Blue, is excreted with the faeces and urine (Arnaud *et al.,* 1988). 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 therefore reach the soil. The same applies to grazing but the inputs are less concentrated over time.

Potential side-effects considered are:

(a.) release of toxic HCN through decomposition of AFCF-/CsFCFcomplexes
(b.) release of other toxic degradation products
(c.) enhanced migration of AFCF-bound radiocaesium in soil
(d.) effects of AFCF on the nutrients and trace elements in the animals

3.4.5. Side-effects of Changes in Animal Management

The following potential side-effects were reviewed in the literature:

(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

3.5. 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 placed on the most important environmental and agricultural impacts. This has allowed the project both to 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 final list of Assessment Criteria (see Section 2.3.1.) was agreed prior to proceeding with the task of impact quantification. Prioritisation was based on: a) body of knowledge, b) likely severity of the impact and c) availability of validated models.

3.6. Quantification of Impacts

The prioritised impacts were quantified using a combination of mathematical modelling, experimentation, expert judgement and contingent valuation, as listed below:

Modelling

- Soil Erosion and Sedimentation
- Soil Nutrient Transport to Water
- Soil Pollutant Transport to Water

Calculations

- Ammonia Emissions
- Product Quantity

Experimentation

- Soil Nutrient Transport to Water
- Soil Pollutant Transport to Water

Expert Judgement

- Soil Organic Matter
- Animal Welfare
- Product Quality
- Product Quantity
- Biodiversity
- Landscape Quality

Contingent Valuation

- Landscape Quality

3.6.1. 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 two models which group participants had prior experience of. 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 of impacts, it was determined that in order to quantify key non-radiological effects mechanistic models must be included of:

(1) soil hydrology to estimate erosion and nutrient losses
(2) plant growth which influences soil hydrology and nutrient cycling
(3) soil chemistry to evaluate effects of fertilising and liming
(4) agricultural management operations.

3.6.2. Models Selected for Impact Quantification

ICECREAM

ICECREAM is a versatile catchment management model, which includes 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 (Rekolainen & Posch, 1993) of the CREAMS/GLEAMS model (Knisel, 1988). 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. ICECREAM was used to model soil erosion and losses of phosphorus and nitrogen in response to ploughing countermeasures, changes in animal feeding regimes, changes in the number of livestock and cessation of crop/animal production. Simulations performed for case study areas in Scotland (Salt *et al.* 1999b) were used as a basis for selecting appropriate impact scores for the CeserDSS.

PHREEQC

PHREEQC (Parkhurst, 1995) simulates the equilibrium chemical composition of multi-species systems taking into account a variety of chemical reactions. PHREEQC was used to 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. Simulations performed over a wide range of soil properties for Scottish soils were used to set thresholds for soil suitability for liming and K application in the CeserDSS (see Section 5.2.). The results illustrate that in soils where these countermeasures are effective against radiostrontium and radiocaesium, they may promote leaching of nutrients (e.g. magnesium) and trace pollutants (e.g. cadmium). The impact scores for the criteria ‘nutrient transport to water’ and ‘pollutant transport to water’ were adjusted accordingly in the DSS.

Further details about the modelling and the associated data requirements are given in Salt *et al.* (1999b).

3.6.3. Impact Calculations - 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 form statistical correlations and regressions of local data, and the implications of using these relationships outside original conditions should be carefully examined.

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 (van der Weerden *et al.* In press). 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 ammonia emissions are likely to arise from countermeaures affecting the following parameters: number of animals, amount of inorganic and organic fertilisers spread on land, period of housing and feeding regime. Calculations for Scotland were based on a complex spreadsheet developed by Pain*et al.* (1997), using sample data from case study areas on livestock numbers, livestock statistics, management of manure, housing period and fertiliser applications.

The results were used to set impact scores in the DSS based on the absolute magnitude of ammonia emissions for all farm types. For instance the countermeasure 'cease animal production’ greatly reduces emissions from dairy farming but only slightly reduces emissions from sheep since the latter are much lower in absolute terms.

3.6.4. Experimental Quantification

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. The areas of experimentation pursued in the CESER project involve the transport of trace elements with humic substances, and the environmental degradation of AFCF and it’s influence on radiocaesium mobility.

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) (Angers *et al.,* 1993; Marschner & Wilczynsky, W. 1991). It is also well known that trace nutrients and toxic substances form stabile complexes with these molecules resulting in increased mobility of the metals (Frimmel & Christmann 1988). Little information, however, was available on the transport of the carriers, the fulvic acid molecules, in soils. Therefore, the mobility of fulvic acids in relation to diffusive and convective transport was studied in laboratory experiment with a sandy podsol soil.

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.

The results clearly demonstrated the influence of the flow regime in soils on the transport potential of fulvic acids 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 its ionic species.

These experimental results were, however, not utilised to make adjustments to the impact scores in the CeserDSS. For instance, sandy soils treated by liming already carry the score ‘slightly increasing’ with respect to pollutant transport to water. This is on the basis of PHREEQC modelling results (see Section 3.6.2.), which show an increase of pollutant metals in the soil solution in response to the calcium addition. It was decided that the additional impact from fulvic acid transport would not justify increasing the score to ‘moderately increasing’.

Environmental degradation of AFCF and it’s influence on radiocaesium mobility

AFCF (ammonium-iron-hexacyanoferrate) is one of the most effective chemical binders for Cs when directly fed to animals (Voigt, 1993). 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 were 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 was quantified via experiments in a specifically designed gas–tight cylinder in which manure containing AFCF and CsFCF was exposed to light to determine the rate of degradation of these complexes and the release of free cyanide into the atmosphere. Measurements demonstrated that under the influence of light, free cyanide was released. However, calculations showed that the maximum permitted occupational concentration (10 ppm) is unlikely to be exceeded outdoors and thus no impacts were included in the DSS.

(b) The potential for enhanced mobility of radiocaesium bound to FCF and the influence of light on the degradation of AFCF and Cs-FCF was studied in soil column experiments using sandy, loamy and organic soils. Leachates were collected and cores sectioned to compare the mobility of Cs-FCF complexes in comparison with AFCF alone and Cs alone. Peat columns showed enhanced mobility of Cs-FCF compared to CsCl independent of light treatment. The effect for sandy soil was small in comparison. Loamy soils showed no difference between soil columns.

Results were incorporated in the DSS by adjusting impact scores for ’Pollutant Transport to Water' in organic soils to ’slightly increasing’.

3.6.5. Contingent Valuation

Contingent valuation is one method of obtaining a value for a good, such as an environmental resource, for which a market does not exist (Hanley & Spash, 1994). A hypothetical market is created in which people are asked for either their maximum willingness to pay for an increase in quality (or to prevent the loss) of a good or their willingness to accept compensation to forgo such an increase (accept the loss). Because the willingness to pay value is contingent upon the particular hypothetical market described to the respondent, this approach came to be called the contingent valuation method (CVM).

In the CESER project the hypothetical markets presented to the public were for landscape changes resulting from two countermeasures: pasture improvement and afforestation. These were assumed to be applied to both heather moorland and rough grassland. To elicit willingness to pay valuations a market research company ran two surveys, one near Aberdeen and a second near Oban in Scotland. The results of these surveys, aggregated to derive per hectare valuations for each landscape change, are incorporated into the countermeasure cost and benefit analysis section of the CeserDSS. They have also been used to set selected impact scores for ‘Landscape Quality’ changes in the evaluation matrix.

The use of Contingent Valuation in the CESER project is explained in detail in Wilson *et al.* (1999).

3.6.6. Expert Judgement

In cases where impact quantification was not feasible, it was generally possible to determine the direction and relative degree of change and apply the relative scale of impact used in the CeserDSS (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 estimate 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).

Equally it was not possible to make detailed predictions of the changes in soil organic matter over a particular time through the various countermeasures. Nevertheless it was possible to make a judgement on whether there would be a long-term loss or gain based on existing research (e.g. Dewar & Cannell, 1992; Whitmore *et al.,* 1992; Simard *et al.,* 1994).

The direction of change and the relative differences between countermeasures and farm types were expressed on a simple impact scale for incorporation in the CeserDSS (see Figure 2, Section 2.3.2).

3.7. Multicriteria Decision Making

At the basis of all MCDM techniques is the evaluation of a two dimensional matrix (see Section 2.3.2.) in which one dimension is made up of alternatives and the other consists 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. In the CeserDSS, 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 (see Figure 13). A similar approach has been used in the RESTRAT project to evaluate restoration options for small but highly contaminated areas, such as waste disposal facilities (Hedeman Jensen, 1999).

Alternatives (i) and Criteria (j) for Countermeasure Decision Making	**ADD LIME +**	**ADD K + SHA**	**SKIM & BUR**	**DEEP PLOUG**	**IMPROVE PA**	**INTENSIFY**	**CHANGE TO**	**FEED AFCF**	**FEED CA**	**FEED CLEAN**	**FEED MORE**	**EARLY SALE**	**SELL FOR F**	**AFFORESTAT**	**CEASE PROD**

	SHALLOW PLOUGH	LLOW PLOUGH	Y	HING	STURE	PASTURE	OILSEED RAPE			FEED	CONCENTRATE	FOR FATTENING	ATTENING	ION	CUTION
Erosion + Sedimentation															
Soil Organic Matter															
Soil Nutrient Transport to Water															
Soil Pollutant Transport to Water															
Animal Welfare															
Product Quality															
Product Quantity															
Ammonia Emissions															
Biodiversity															
Landscape Quality															

Figure 13. Generic evaluation matrix of countermeasure alternatives and assessment criteria.

A range of specific MCDM algorithms was tested for incorporation into the CeserDSS. Ideal Point Analysis was selected because it proved to be easy and intuitive for the user to apply without being overly simplistic in its analysis. This method not only allows the user to weight criteria based on their own agenda, but it also allows the user to specify the ‘ideal’ score (also referred to as the criteria objective) and the compensatory level.

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 performance 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 criterion by criterion 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. The compensatory level can be adjusted by manipulating the ***p*** parameter. In the CeserDSS it can be set to equal any number ranging from 1, which causes the assessment to be fully compensatory, to ten, which makes it uncompensatory (Pitel, 1990).

Ideal point analysis (also called Goal Programming) measures the deviation between the scores for each set of ‘alternative’ solutions and the ‘ideal’ set of solutions. The alternative which minimises the distance between itself and the ideal is deemed the optimal solution (Carver, 1991). In the equation used to calculate the distance, d, between the actual and the ideal set of solutions, the variable h_j represents the standardised set of ideal point values and q_{ji} is the standardised set of alternative scores. The variable p in this equation symbolises the metric parameter. It is used to set the compensatory level of the assessment, with one being compensatory and numbers greater than one increasingly less compensatory (Zeleny, 1976).

The weighting function, γ_j, in the CeserDSS varies between zero and ten. The weights follow the ‘rating system’ in which the number of points allocated to each objective is representative of that objective’s relative importance in the decision making process (Nijkamp *et al.*, 1990).

$$\min d = \{ \sum_{j=1}^{j} \gamma_j^{\,p} \, (|h_j - q_{ji}|)^p \}^{1/p} \quad (1)$$

$$q_{ji} = \max_j \rho_{ji} - \rho_{ji} \;/\; \max_j \rho_{ji} - \min_j \rho_{ji} \,. \quad (2)$$

where:
d = distance score to be minimized
h_j = standardized ideal point value for criteria, *j*.
q_{ji}= standardized value, p_{ji}
γ_j = weight for criteria, *j*.
p = metric parameter (usually 1, 2 or ∞)

The ability to make ‘trade-offs’ in criteria performance, within the bounds of certain thresholds, is viewed as a key component of the CESER 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.

4. DEFINITIONS OF COUNTERMEASURES

Countermeasures are actions taken to reduce the transfer of radionuclides into the human food chain. This chapter gives project-specific definitions of the performance and effectiveness as well as potential side-effects of the countermeasures assessed in the CeserDSS:

Soil-plant-based countermeasures

- Shallow ploughing
- Deep ploughing
- Skim and burial
- Application of potassium
- Application of lime
- Pasture improvement
- Pasture intensification
- Change to oilseed rape
- Afforestation
- Leave land fallow

Animal-based countermeasures

- AFCF supplementation
- Ca supplementation
- Fatten on clean concentrate
- Fatten on clean roughage
- Fatten on clean feed
- Feed clean concentrate
- Feed concentrate grown on farm
- Early sale for fattening
- Sell for fattening
- Cease animal production

4.1. Shallow Ploughing

Shallow ploughing aims to bury the radionuclides that have been deposited on the soil surface, thus reducing root uptake by plants as well as external exposure and risk of inhalation from resuspension (e.g. Vovk *et al.*, 1993; Wilkins *et al.*, 1996). Repeated shallow ploughing has no added benefit.

Performance and effectiveness

Soils are ploughed with a mouldboard plough to 25 cm depth. On arable land it is recommended in combination with application of lime or potassium. The contaminated crop should either be removed before ploughing or if the biomass is not too great it can be ploughed in. On permanent vegetation shallow ploughing is part of the following countermeasures: a) creating improved grassland, b) intensifying the use of existing grassland, and c) converting improved grassland to cereal cultivation to produce concentrate for feeding to dairy cows. The decontamination factor is assumed to be 2-4.

Side-effects

Shallow ploughing will increase the risk of erosion where bare soil surfaces occur or the density of plant cover is reduced. Soil organic matter will decrease on soils that have been previously undisturbed such as those under semi-natural or improved pasture. Both erosion and loss of organic matter can lead to loss of nutrients (e.g. nitrate and particulate phosphorus) and toxic micro-pollutants in runoff and leachate. These substances may reach ground or surface water leading to eutrophication or pollution with potential impacts on fisheries, recreation, drinking water abstraction and functioning of ecosystems. Ploughing in areas of semi-natural vegetation as part of pasture improvement could change the biodiversity if large areas were treated.

4.2. Deep Ploughing

The aim of the countermeasure is to bury the contamination deeply by inverting the soil. This significantly reduces uptake by plant roots as well as external exposure to humans and risk of inhalation from resuspension (e.g. Vovk *et al.*, 1993).

Performance and effectiveness

The soil is ploughed once to 50 cm with implements such as forestry ploughs or other special ploughs. In the CeserDSS it is only recommended on arable land and is assumed to be followed by agricultural management as normal. The contaminated crop should either be removed before ploughing or, if the biomass is not too great it can be ploughed in. This type of ploughing may produce high ridges if the spacing is not narrow enough, and shallow mouldboard ploughing and other forms of tillage may be necessary to create an even surface. Ideally the spacing should be sufficiently narrow to invert the soil into the previous furrow. Poor structure of the subsoil brought to the surface may also necessitate further tillage e.g. harrowing and disking. A decontamination factor of 10 is assumed.

Side-effects

Side-effects on arable land will be loss of organic matter and of nutrients as the topsoil is buried. If after deep ploughing, fertilisation rates are kept at normal levels some nutrients may become deficient. Phosphorus losses in runoff are likely to decreases due to the lower P status of subsoils. It will take many years to build up organic matter and improve the soil structure. The quality and quantity of agricultural produce will be reduced. The impact on erosion will depend greatly on the nature of the subsoil which may be less or more erodible than the original to topsoil.

4.3. Skim and Burial

This technique aims to bury the contamination by skimming off the top 5 cm of soil and burying it at depth (Roed *et al.,* 1996). This significantly reduces uptake by plant roots as well as external exposure to humans and risk of inhalation from resuspension.

Performance and effectiveness

Using a specially designed skim and bury plough, the top 5 cm of soil including the contaminated surface layer are buried at 45-50 cm depth. In the CeserDSS it is only recommended on arable land and is assumed to be followed by normal agricultural management. The contaminated crop should either be removed before ploughing or, if the biomass is not too great, it can be buried (e.g. grass turf) in the process. A decontamination factor of 10 or better is assumed. Availability of the equipment may limit application of the countermeasure.

Side-effects

Side-effects on arable land will be some loss of organic matter and of nutrients, as part of the topsoil is deeply buried. It is assumed that the nutrient status can be restored through fertilisation but it will take longer to restore the organic matter status. No significant changes in losses of phosphorus and nitrogen are expected. The quality and quantity of agricultural produce will be reduced, but to a much lesser extent than after deep ploughing.

4.4. Application of Potassium

This countermeasure is designed to reduce the plant uptake of radiocaesium. Addition of potassium to soils with a low K status, significantly increases the pool of available potassium This lowers the ratio of Cs to K in the soil solution and thus reduces radiocaesium uptake by plant roots (e.g. Nisbet *et al.,* 1994; Paul & Jones 1995).

Performance and effectiveness
Potassium fertiliser in granular form is applied annually at a rate of 100 kg/ha of K, either to the soil surface of grazed pastures or ploughed into the soil on arable land. A decontamination factor of 2.5 is assumed for suitable soils.

Side-effects
Side-effects include slightly enhanced mineralisation of organic matter and a change in the composition of the soil solution which may lead to leaching of nutrients and pollutants. This could cause deficiencies or toxicities, thereby reducing the quality of agricultural products and adversely affecting animal health. Potassium may promote plant growth on K limited soils but changes in biodiversity are unlikely.

4.5. Application of Lime

This countermeasure is designed to reduce the plant uptake of radiostrontium. Addition of lime to soils with a low calcium status, significantly increases the pool of available calcium. This lowers the ratio of Sr to Ca in the soil solution and thus reduces radiostrontium uptake by plant roots (e.g. Lembrechts, 1993; Nisbet *et al.,* 1994).

Performance and effectiveness
Agricultural lime is applied bi-annually at a rate of 2t/ha of lime ($CaCO_3$) either to the soil surface of grazed pastures or ploughed into the soil on arable land. A decontamination factor of 2.5 is assumed for suitable soils.

Side- effects
Side-effects include enhanced mineralisation of organic matter and a change in the composition of the soil solution, which may lead to leaching of nutrients and pollutants. This could cause deficiencies or toxicities, thereby reducing the quality of agricultural products and adversely affecting animal health. Liming of acid soils may improve plant productivity and increase biodiversity.

4.6. Pasture Improvement (upland sheep/ beef/ red deer)

Rough grazing land may be converted to better quality pasture through improvement maesures (e.g. Prister *et al.,* 1993; Wilkins *et al.,* 1996). The countermeasure relies on a combination of effects. Through ploughing all radionuclides are buried. Fertilisation promotes ‘growth dilution’ of radionuclides in plants. Improvable soils typically have a fairly high mineral content and thus lower soil-plant transfer of radiocaesium. Application of potassium and lime increases K/Cs and Ca/Sr ratios in the soil solution thus lowering relative plant uptake of radiocaesium and radiostrontium. Sown grass/clover swards have a lower potential for radiocaesium uptake compared to some of the indigenous plant species (Salt & Mayes, 1991).

Performance and effectiveness
Small areas of rough grazing land on upland/hill farms are converted to better quality grassland by ploughing to 25 cm, fertilising (N-P-K), liming and sowing of a grass/clover mix. Nitrogen is applied as nitrate (NO_3^-)

rather than ammonia (NH_4^+) to avoid mobilisation of radiocaesium. It may be necessary to deep plough to destroy an existing iron pan. Woody vegetation may need to be burnt off initially. Improved areas need to be maintained by annual fertilisation and periodic liming and reseeding (a 5-year interval is assumed). Livestock would be grazed on these areas in order to lower their radiocaesium and radiostrontium contamination prior to sale or slaughter. A decontamination factor of 4 or better is assumed.

In the management of red deer this countermeasure should be used preferably on mineral soils in valleys. It is recommended to be combined with feeding of AFCF treated hay. The effectiveness very much depends on how many deer will be attracted to these areas. This is most likely when natural feed sources are scarce e.g. in autumn and winter. By this time stags are in poor body condition and have little market value, while hinds are generally in better condition. Thus it is suggested that the countermeasure will work best for hinds and they should not be hunted until at least 1 month after the feeding has started.

Side-effects

Scores in the DSS are based on small to medium sized areas being improved (less than 25% of the farm area). This limits the overall impact at the farm level. Side-effects are a combination of those described for shallow ploughing and for liming and K application with the additional risk of phosphorus and nitrogen losses. Positive effects on animal welfare as well as product quantity and quality are expected as more high quality grazing is provided. The impact on biodiversity may also be positive since a different habitat is introduced and grazing pressure on other land is slightly reduced. Based on the CESER contingent valuation study, the change in landscape quality was rated as negative if converting from heather moorland and positive if converting from rough grassland or blanket bog.

4.7. Pasture Intensification (upland sheep / beef)

Existing improved pasture on upland/hill farms may be managed more intensively to feed more livestock. The countermeasure is based on: a) dilution of radionuclides through enhanced plant growth, b) maximising the use of productive mineral soils which have lower radiocaesium transfer to plants, and c) less grazing on unimproved land where, due to the combination of soil type and vegetation, radiocaesium may be more plant available.

Performance and effectiveness

The application of fertiliser (NPK) and the stocking density are raised from the current to the highest recommended levels for upland/hill farms. These are 170 and 125 kg/ha of N and P (P_2O_5) respectively for mowing grass and 110 and 100 kg/ha of N and P (P_2O_5) respectively for grazing grass; 2 livestock units per ha.

Grassland productivity is maintained by regular ploughing, liming and reseeding, carried out approximately every 3 years. Nitrogen is applied as nitrate (NO_3^-) rather than ammonia (NH_4^+) to avoid mobilisation of radiocaesium. The decontamination factor for radiocaesium may be approx. 2 but depends on the specific circumstances. The effectiveness for radiostrontium is not known.

Side-effects

As the countermeasure is based on an intensification of already existing farm management, side-effects due to ploughing and application of lime/potassium are thought to be small. Higher application rates of phosphorus and nitrogen may increase the risk of eutrophication with potential impacts on fisheries, recreation, drinking water abstraction and functioning of ecosystems. Beneficial effects on product quality and quantity and animal welfare are expected due to increased intake of high quality grass by livestock.

4.8. Change to Oilseed Rape

The transfer of radiocaesium and radiostrontium into the food chain may be reduced on arable land by switching to an industrial food crop (Nisbet, 1995). Oilseed rape is used in the production of margarine and cooking fats. The processing removes a significant proportion of the radiocaesium contamination since it is not transferred to the oil/fat phase. The effectiveness for radiostrontium is uncertain.

Performance and effectiveness

Arable land where crops such as barley, wheat, potatoes or root crops are normally grown, can be used to produce winter oilseed rape. It is assumed that in the main arable areas of Scotland soil conditions are not a major limitation. However, it is recommended that oilseed rape is grown in rotation with other crops to prevent build-up of diseases. A market has to be found for the increased production. The reduction in contamination may be an order of magnitude or better, though detailed data is lacking.

Side-effects

Where the original crop was winter barley or winter wheat, erosion is expected to decrease by introducing oilseed rape. For other crop changes the effects will vary with soil type, climate etc and no definite trends can be given. Changes in nutrient losses are also highly dependent on the previous crops. Large areas of oilseed rape are likely to lower the landscape quality since the crop is not popular in Scotland due to its connection with allergies and its unpleasant smell. Side-effects from conversion to spring winter oilseed rape would be similar though erosion may be slightly lower.

4.9. Afforestation

In areas where the deposition is too high to continue agricultural food production and the external dose to humans has to be kept to a minimum, afforestation may be appropriate (IAEA, 1994a).

Performance and effectiveness

Forestry is established using planting preparation without ploughing to minimise erosion (mounding). Coniferous trees are planted, ideally by machine rather than by hand. Annual herbicide application may be required for several years. No fertiliser is applied. Planting is restricted to fairly well drained sites to avoid. Poorly drained sites are not suitable as the necessary drainage could mobilise radionuclides through erosion and runoff. Species choice depends on climate, soil type, exposure and soil nutrient status. On fertile soils it would be possible to plant a wider range of trees including broadleaves. This option is currently not included in the DSS but the impact scores could be adjusted to allow its assessment.

S*ide-effects*

Over the long-term erosion and nutrient input to water bodies are reduced. However, the biodiversity of conifer monoculture is low compared to agricultural land and the change in landscape is generally perceived as negative. If a wider range of trees species is planted, biodiversity will be relatively higher and landscape change may be regarded more positively. It is possible to adjust the scores in the DSS accordingly.

4.10. AFCF Supplementation

AFCF (ammonium-iron-hexacyanoferrate) is a prussian-blue type compound with very low toxicity. When fed to animals, it binds to radiocaesium making it less available for gut absorption (e.g. Giese, 1988; Hove 1993; Hansen *et al.*, 1996). This reduces radiocaesium contamination in milk and meat. The Cs ion remains bound to the iron-hexacyanoferrate when excreted in faeces. AFCF should be continuously present in the digestive tract for maximum effectiveness and ideally added at a rate of 1 g per kg to mixed concentrate. AFCF has no effect on radiostrontium contamination of milk and meat.

Performance and effectiveness
Dairy cows require approximately 0.4 g AFCF per day. This can be given with the concentrate ration during milking at least twice per day. This countermeasure is expected to reduce the radiocaesium level in milk by 80-90%.

Beef cattle should ideally be given AFCF with concentrate or roughage at a rate of 0.4 g per day. Alternatively it is possible to supply the AFCF as boli or in feed blocks. This countermeasure has to be used for a minimum of 60 days prior to sale for slaughter. It is expected to reduce the radiocaesium level in meat by approx. 80 %.

Lambs during fattening as well as ewes during lactation can be treated with AFCF. All sheep that are regularly handled or fed supplementary feed should be given approx. 0.1 g AFCF per day with the feed. Free ranging sheep can be given AFCF in rumen dwelling boli, in salt licks or feed blocks containing AFCF. AFCF given daily in feed is expected to reduce the radiocaesium in meat by approx. 80%, while for the boli, feed blocks and salt licks the expected reduction is 50%.

In free ranging red deer it is recommended that AFCF is supplied in conjunction with feeding of hay. The effectiveness of the countermeasure will depend on whether animals use the feeding places. This is only likely when natural feed sources are scarce e.g. in autumn and winter. By this time stags are in poor body condition and have little market value, while hinds are generally in better condition. Thus it is suggested that the countermeasure will work best for hinds and they should not be hunted until at least 1 month after the feeding has started.

Side-effects
There are no known direct effects of AFCF on animal welfare or the quality and quantity of the agricultural products (Giese 1988; Pearce, 1994). Soil erosion will occur locally around feeding areas but this has not been included in the DSS. In the experiments with animal manure it was found that radiocaesium bound to AFCF may leach faster in organic and possibly also sandy soils compared to CsCl. This has been included in the DSS.

4.11. Calcium Supplementation (dairy cows)

Dairy cows can be supplemented with high levels of calcium to reduce radiostrontium transfer to milk (Howard *et al.,* 1997). Increased levels of Ca compete with Sr, thus reducing the amount of Sr transferred to milk. Ca supplementation will not affect the transfer of radiocaesium to milk

Performance and effectiveness
This countermeasure is only recommended for dairy cows. A daily dose of 200 g per day is assumed to reduce the transfer of radiostrontium to milk by 40-60%. The higher efficiency will be observed where the present level of Ca in the diet is low (less than 60 g /d for dairy cows yielding ca. 20 L/d). The Ca must be given daily, ideally in two doses.

Side-effects

Side-effects on the animal are not expected if the following recommendations are followed: a) Ca should be given as $CaCO_3$ rather than $CaCl_2$, because of it's corrosive effect; b) the amount should not exceed 2% of the daily dry matter intake and c) the Ca:P should be between 1:1 and 2:1. However, Ca supplementation may need to be adjusted according to variations in feed (energy and minerals) utilisation.

4.12. Fatten on Clean Concentrate (sheep)

This involves early weaning of lambs followed by fattening indoors on clean concentrate and sale for slaughter. The clean concentrate almost wholly replaces consumption of grass or other roughage. This countermeasures is not specifically documented in the literature.

Performance and efficiency

Lambs may be weaned at 4-5 weeks provided that they have access to palatable creep feed before weaning and they consume about 200 g/d of solid feed. The feeding must be managed to allow maximum intake of concentrated feed in the lambs, ie fresh dry feed given twice daily, clean feeding troughs and easily available fresh water. Care has to be taken to prevent diseases such as coccidiosis, urinary calculi and muscular dystrophy. The lambs will only consume milk and concentrated feeds. Radiocaesium and radiostrontium contaminated roughage is therefore not used for meat production, but only for breeding animals.

The lambs are expected to accumulate radiocaesium and radiostrontium from the ewe during the prenatal period and from milk during the nursing period. Assuming a feeding period of 90 days after weaning the countermeasure reduces the body burden measured at weaning by up to 88%. The efficiency for radiostrontium is uncertain. Feeding and housing facilities are required. This is likely to limit the application of this countermeasure on upland/hill farms.

Side-effects

As the lambs never graze, the grazing pressure on the vegetation and the need for fertilisers are reduced. This may have positive effects on water quality and biodiversity. However, the manure produced indoors has to be spread onto land. Thus no net reduction in nutrient losses from land is expected. The housing and intensive feeding of the lambs may be perceived as negative with respect to animal welfare but is likely to improve product quality.

4.13. Fatten on Clean Roughage (sheep)

This countermeasure aims to reduce the intake of radiocaesium and radiostrontium through feed, and thereby reduce the transfer of these isotopes to meat (Jones, 1993; Brynhildsen *et al.*, 1996). This will also reduce the body content of already accumulated radiocaesium and/or radiostrontium.

Performance and effectiveness

This countermeasure is to be used during the fattening of lambs. The contaminated roughage in the diet, i.e. grass, silage or hay, is replaced with uncontaminated roughage without changing the composition of the diet. The feeding period varies between 60 and 105 days depending on the deposition scenario and farm type. A reduction of 80 to almost 100% in meat contamination is expected (assuming a biological half-life of 3 weeks). It may be cheaper to fatten on uncontaminated concentrate when roughage is more expensive due to higher transportation cost.

Side-effects

If roughage is bought in, an equivalent amount of grass on the farm is not needed. However, side-effects are likely to be small due to the limited period of feeding for lambs and the fact that the diet of the ewes is not changed.

4.14. Fatten on Clean Feed (beef cattle)

Beef cattle are typically fattened on a combination of roughage (grass, silage, hay or straw) and concentrated feeds, mainly grain and protein sources. To reduce the daily intake of both radiocaesium and radiostrontium during the last part of the fattening period it is recommended that both uncontaminated roughage and concentrate be supplied (Jones, 1993; Prister *et al.*, 1993).

Performance and effectiveness

Beef cattle (> 1 year old) are fed uncontaminated concentrate and silage in the same proportion as usual for 40-100 days as part of winter finishing indoors. Assuming an effective biological half-life of 19 days, the reduction in meat contamination is 75 to almost 100%.

Side-effects

Due to the short duration of the feeding period compared to the whole life span of the animal (approx. 2 years), the side-effects resulting from less use of farm-grown roughage and concentrate are small. As the type of diet is not changed no effects on the animal are expected.

4.15. Feed Clean Concentrate (dairy cows)

Diets for dairy cows are usually a combination of roughage (grass, silage, hay or straw) and concentrated feeds, mainly grain and protein sources. To reduce the level of contamination in milk the diet has to be altered over the whole year. In many cases it is likely to be more cost effective and practical to replace part of the roughage with uncontaminated concentrate rather than with uncontaminated roughage. This countermeasure reduces the daily intake of both radiocaesium and radiostrontium.

Performance and effectiveness

Dairy cows are supplied with uncontaminated concentrate to cover 80% of their energy intake instead of the typical level of 20-30% currently supplied in Scotland. The concentrate should not account for more than 80% of the net energy of the total ration because of possible health hazards to the animals (Bondi, 1987). At feeding levels exceeding 60% of net energy, the concentrate should be divided into at least 4 rations per day. As a result of this countermeasure a corresponding area of grassland will be left fallow. The effectiveness for Cs and Sr in milk is 60-80%.

Side-effects

Side-effects depend greatly on the current level of concentrate feeding and scores in the DSS are adjusted accordingly. Generally the land use change will lead to a decrease in erosion at the farm level and an increase in biodiversity through the introduction of fallow areas. The volume of faeces/manure will rise, increasing the need for land spreading and thus the risk of nitrogen and phosphorus losses to water bodies. Ammonia emissions and milk production will increase.

4.16. Feed Concentrate Grown on Farm (dairy cows)

Diets for dairy cows are usually a combination of roughage (grass, silage, hay or straw) and concentrated feeds, mainly grain and protein sources. To reduce the overall contamination in the diet it is possible to replace a significant proportion of the home grown roughage with home grown barley concentrate. This countermeasure relies on the generally lower contamination in grain compared to grass per unit of energy supplied to the animal. It reduces the daily intake of both radiocaesium and radiostrontium.

Performance and effectiveness

Dairy cows are supplied with home grown concentrate up to 80% of their energy intake. The concentrate should not account for more than 80% of the net energy of the total ration because of possible health hazards to the animals. At feeding levels above 60% of net energy the concentrate should be divided into at least 4 rations per day. The countermeasure involves converting some existing grassland to barley cultivation and leaving a small area fallow. It is assumed that the source of concentrate already fed to cows remains the same, i.e. imported or home-grown, but that additional concentrate required to raise the level to 80%, is home-grown. The effectiveness depends on the level of contamination in the home grown concentrate.

Side-effects

Side-effects depend greatly on the current level of concentrate feeding and scores in the DSS are adjusted accordingly. Generally the land use change from grassland to barley will lead to an increase in erosion and a decrease in soil organic matter. Nutrient losses to water are expected to increase though this will depend on the intensity of the original grassland production. The volume of faeces/manure will rise, increasing the need for land spreading and thus the risk of nitrogen and phosphorus losses to water bodies. Ammonia emissions and milk production will increase. The change from intensive grassland only, to a mixture of barley fields, intensive grassland and some fallow will create a greater diversity of biological habitats.

4.17. Early Sale for Fattening (upland sheep)

Lambs from upland/hill farms are weaned early and sold to areas that either received less deposition or have less contaminated pastures due to soil type. This requires intensification in those areas receiving the additional lambs. If the upland/hill farm has facilities to fatten early weaned lambs indoors on concentrate, this option can be alternatively assessed in the DSS.

Performance and effectiveness

Lambs may be weaned at 4-5 weeks providing they have access to palatable creep feed before weaning and consume about 200 g/d of the solid feed. The feeding must be managed to allow maximum intake of concentrated feed, ie fresh dry feed given twice daily, clean feeding troughs and easily available fresh water. Care has to be taken to prevent diseases such as coccidiosis, urinary calculi and muscular dystrophy. The lambs will only consume milk and concentrated feeds. Radiocaesium and radiostrontium contaminated roughage is therefore not used for meat production, but only for breeding animals. The effectiveness of the countermeasure depends on the fattening regime at the farms buying the lambs.

Side-effects

Since the lambs never graze, the grazing pressure on the vegetation and the need for fertilisers is reduced, which may have positive effects on water quality and biodiversity on the farm selling the lambs. The opposite effects may occur on those farms receiving the additional lambs. This is not included in the DSS. The early weaning of the lambs may be perceived as a reduction in animal welfare. Product quantity is greatly reduced and the lambs will fetch a much lower price compared to older lambs.

4.18. Sell for Fattening (upland sheep/beef)

On upland/hill farms that normally fatten animals it could be advantageous to sell lambs and calves for fattening on other farms. This would be the case if the roughage on the farm was too contaminated to be used for fattening, but less contaminated feeds were available in other areas of the country. On many upland/hill farms the sale of store animals for fattening on lowland farms is part of normal practice, however, it is still regarded as a countermeasure since it would be combined with monitoring and slaughter restrictions (Howard, 1993).

Performance and effectiveness

It is recommended that calves suckle for at least 3-4 weeks before they are weaned and sold for fattening. The milk feeding period may be extended depending on normal farm management. Lambs are typically weaned at 8 weeks onto pasture and sold after one grazing season. The efficiency of this countermeasure depends on the fattening regime at the farm buying the animals. The market for live animals for fattening could limit the number of farms that can use this countermeasure.

Side-effects

By selling store animals instead of fattened animals the farmer reduces the level of production and thus income. There will be a reduction in the demand for grass/silage/hay production, which could lower losses of nutrients to water, bodies and have some benefits in terms of biodiversity. Farms elsewhere buying in extra lambs will most likely have the opposite effects. This is not included in the DSS.

4.19. Exclude Animal Production/ Leave Land Fallow

In situations where the deposition is too high to continue agricultural food production and the external dose to humans has to be kept to a minimum, it may be appropriate to leave the land unmanaged for many years (IAEA, 1994a).

Performance and effectiveness

All land is left unmanaged, ceasing tillage, fertilisation and harvesting. In animal production systems it is necessary to destroy the animals. Arable crops can be abandoned though it is not advisable to leave bare soil due to the risk of erosion and resuspension. Loss of agricultural output will have to be compensated for by increased production in other parts of the country or through imports.

Side-effects

In environmental terms this countermeasure can be regarded as beneficial. Erosion and nutrient losses to water bodies will decrease and soil organic matter will gradually build up. Effects on biodiversity are difficult to predict. Gains in some species will be accompanied by losses of others. If large areas of agricultural land are left fallow, biodiversity in the long term may be negatively affected if habitats become more uniform and shrubs and trees colonise. Trends will depend on the presence of wild ranging herbivores such as red deer. Landscape change was given a slightly negative score assuming that most people will not like the unmanaged appearance. This was partly based on results from the Contingent valuation study, which showed a preference for improved (bright green) compared to rough (green/brown) grassland. Social effects on the farming community will be serious.

5. LIMITATIONS APPLIED TO COUNTERMEASURES

Limitations are environmental and agricultural factors, which may restrict the application of a countermeasure. This chapter explains the thresholds and conditions implemented in the CeserDSS, which determine whether a particular countermeasure is feasible and effective on a farm or piece of land.

5.1. Ploughing Countermeasures

Thresholds in the DSS are set to ensure that a sufficient depth of soil without a shallow field drainage system, rocks or too many stones. The maximum slope is set to ensure relative ease of execution. Use of a crawler tractor would extend the applicability to slopes of 25 degrees, but this would be very slow and increase the risk of erosion and loss of radionuclides. In Scotland, arable land is generally not found on slopes greater than 15 degrees and grassland would typically be permanent (Bibby *et al.*, 1991). Thresholds on soil wetness and drainage status ensure that wet soils are not treated. Also on arable land these soils are most likely to be less productive and thus have a lower priority for treatment.

Shallow ploughing

Parameter	**Threshold**
Slope	15 degrees
Soil depth	> 30 cm
Stoniness to 30 cm	< 35% stones by volume (moderately stony)
Depth to rock	> 30 cm
Depth of drains	> 30 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

Deep ploughing

Parameter	**Threshold**
Slope	15 degrees
Soil depth	> 60 cm
Stoniness to 60 cm	< 35% stones by volume (moderately stony)
Depth to rock	> 60 cm
Depth of drains	> 60cm
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

Skim and burial

Parameter	Threshold
Slope	15 degrees
Soil depth	> 60 cm
Stoniness to 60 cm	< 35% stones by volume (moderately stony)
Depth to rock	> 60 cm
Depth of drains	> 60 cm
Soil wetness	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	Excessive, free, imperfect - suitable Poor, very poor – not suitable

5.2. Potassium and Lime Application

Soil suitability for application of potassium and/or lime was determined according to PHREEQC modelling for different soil classes based on Scottish soil data. Thresholds for K application are set for pH and CEC on the basis that the Cs/K ratio in solution should be halved. If the user has no knowledge of the CEC a simpler set of thresholds using pH and exchangeable K can be used. Thresholds for liming are set for pH and CEC on the basis that the Sr/Ca ratio in solution should be halved.

For both potassium and lime application a slope limit is set to allow ease of mechanical spreading since applications have to be repeated annually or biannually. On steep slopes it may be possible to apply the chemicals from the air, however, there will be a high risk of rapid losses through runoff. Technical problems due to uneven topography have not been included.

Potassium application

Parameter	Threshold
Soil type	
Podsolic soils	pH < 4.4 and CEC < 30 meq/100g
Podsolic soils	pH < 5.2 and CEC < 15 meq/100g
Organic soils, not waterlogged	pH < 4.5 and CEC < 130 meq/100g
Sandy and loamy soils	pH < 6.2 and CEC < 15 meq/100g
Organic soils, waterlogged	Not suitable
Clay soils	Not suitable
Slope	15 degrees

If user does not know the CEC of the soil then use:

Parameter	Threshold
Sandy, loamy and podsolic soils	Exchangeable K < 120 mg/kg (= 0.3 meq /100g)
Organic soils, not waterlogged	pH < 4.5
Organic soils, waterlogged	Not suitable
Clay soils	Not suitable
Slope	15 degrees

Lime application

Parameter	Threshold
Soil Type	
Podsolic soils	pH < 4.4 and CEC < 20 meq/100g
Organic soils, not waterlogged	pH < 4.5 and CEC < 100 meq/100g
Organic soils, not waterlogged	Or pH < 5.4 and CEC < 70 meq/100g
Organic soils, waterlogged	Not suitable
Sandy, loamy and clay soils	Not suitable
Slope	15 degrees

Application of lime and potassium

Parameter	Threshold
Soil type	
Podsolic soils	pH < 4.4 and CEC < 20 meq/100g
Organic soils, not waterlogged	pH < 4.5 and CEC < 100 meq/100g
Organic soils, water logged	Not suitable
Sandy, loamy, and clay soils	Not suitable
Slope	15 degrees

5.3. Pasture Improvement

In addition to limitations already mentioned under ploughing countermeasures, suitable soils should not have a peaty surface layer more than 20 cm deep. This ensures that, as part of the improvement, organic and mineral horizons are mixed by ploughing to a depth of 25 cm. In addition, questions are asked to ensure that the land under assessment is not already improved.

Parameter	Threshold
Slope	15 degrees
Soil depth	> 30 cm
Soil drainage status	Excessive, free, imperfect – suitable; Poor, very poor – not suitable
Soil type	Soils with a peaty surface layer > 20 cm deep not suitable
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
Stoniness to 30 cm	< 35% stones by volume (moderately stony)
Depth to rock	> 30 cm

5.4. Pasture Intensification

This measure is limited to already improved grassland on hill and upland farms. Actual stocking density and annual application of nitrogen and phosphorus are compared to the maxima recommended by the Scottish Agricultural College (1990). These are 170 and 125 kg/ha of N and P (P_2O_5) for mowing grass and 110 and 100 kg/ha of N and P (P_2O_5) for grazing grass. Stocking density is limited to 2 livestock units per ha. Where the frequency of fertilisation is less than every 3-5 years the land is not classed as improved but the user has the option of choosing the countermeasure ‘Improve pasture’.

Parameter	**Threshold**
Current stocking density	1.5 livestock units
Current application of N to grazing grass	80 kg N /ha
Current application of P to grazing grass	70 kg P/ha
Current application of N to mowing grass	130 kg N/ha
Current application of P to mowing grass	100 kg P/ha
Frequency of fertiliser application	Annually, bi-annually, every 3-5 years – suitable Less frequently - unsuitable

5.5. Changes in the Diet of Animals

Countermeasures are generally restricted to farms with suitable feeding facilities and feeding regimes and where the uncontaminated feed is available either on the farm or for purchase. Where the level of concentrate in the diet of dairy cows is increased to 80% of the net energy intake, only farms currently feeding a maximum of 65 % qualify. Above this threshold the difference is deemed to be too small for the countermeasure to be sufficiently effective.

For dairy farms the option exists to provide increased feeding of concentrate by use of home-grown barley. In addition to limitations on ploughing, Land Capability Class is used to ensure that only suitable land is converted from grassland to barley:

Parameter	**Threshold**
Altitude	220 m
Slope	11 degrees
Soil depth	> 30 cm
Stoniness to 30 cm	< 35% stones by volume (moderately stony)
Depth to rock	> 30 cm
Depth of drains	> 30 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
Land Capability Class	4.1 or better

5.6. Afforestation

The minimum soil depth is set assuming the presence of shattered bedrock (Quine, pers. comm.), into which trees can root. Planting is restricted to fairly well drained soils to avoid the need for artificial drainage that could increase loss of radionuclides in runoff. A slope threshold is set to enable use of machines that will reduce human external exposure to radiation.

Parameter	**Threshold**
Soil depth	> 30 cm
Soil drainage status	Excessive, free, imperfect – suitable; -Poor, very poor – not suitable
Slope	25 degrees

Windthrow hazard has to be assessed separately (see Quine & White, 1993).

6. DEFINITIONS OF TERMS USED IN THE DSS

6.1. Soil Types and Properties

For the purposes of the CeserDSS a simple categorisation of soils was adopted to assess their suitability for application of lime and/or potassium:

Sandy soils

Soils with a topsoil of sandy or loamy sand texture.

Loamy soils

Soils with a topsoil of sandy loam, sandy silt loam, silt loam or sand clay loam texture.

Podsolic soils

Leached acid soils with light coloured eluvial horizons and illuvial horizons enriched in sesquioxides and/or organic matter (Avery, 1990).

Clay soils

Soils with a topsoil of clay loam, silty clay loam, sandy clay, silty clay or clay texture.

Organic soils, waterlogged

Soils, which contain a minimum of 30% organic matter in the top 10 cm and predominantly have anoxic conditions.

Organic Soils, not waterlogged

Soils, which contain a minimum of 30% organic matter in the top 10 cm and predominantly have oxic conditions.

Gley features

Mottles produced by reduction of iron and manganese oxides and hydroxides under wet conditions in soils.

Impermeable horizon

A soil layer which impedes percolation of water either due to a high silt/clay content or less commonly due to an iron pan which has formed through precipitation of iron transported in soil water, often associated with a fluctuating water table.

Soil Wetness Class

The Soil Wetness Class characterises the moisture status of a soil resulting from the interaction between soil properties (e.g. porosity, structure, texture) and relief and rainfall. Six classes are distinguished (Bibby *et al.*, 1991):

Class I

The profile normally lacks gley features (greyish soil colours with associated ochreous mottling resulting from reduction and mobilisation of iron compounds under anaerobic conditions) within 70 cm or an impermeable horizon within 80 cm depth. Many strongly gleyed, permeable soils, with efficient drainage systems also occur in this class.

Class II
The profile normally lacks gley features within 40cm or an impermeable horizon within 60 cm depth.

Class III
The profile normally lacks gley features or an impermeable horizon within 40 cm depth.

Class IV
The profile normally has gley features and an impermeable horizon within 40 cm depth, but lacks a humose or peaty topsoil greater than 20 cm thick.

Class V
The profile normally has prominent gley features within 40 cm depth and is usually wet within 70 cm depth. Commonly the topsoil is humose or peaty and the natural vegetation has numerous hydrophilous species.

Class VI
The profile normally has a peaty topsoil, a prominently gleyed mineral subsoil and is usually wet within 40 cm depth. The natural vegetation consists predominantly of hydrophilous species.

Soil Drainage Status

Refers to the drainage status of the soil based on the morphology of the soil profile. If a Scottish soil map is available this property can be taken from the legend. Information on major soil groups is also available in Memoirs of the Soil Survey of Great Britain. Scotland, Her Majesty's Stationary Office.
Where tile drains exist the drainage class of the improved soil should be entered.

Excessive = The soil horizons are much shallower than normal. The B horizons are bright and uniform in colour.

Free = The B horizons are bright and uniformly coloured, although those with a small degree of dullness and some mottles are permitted within this class.

Imperfect = The B horizons are not quite so bright as those of the freely drained soil and have appreciable mottling. They are designated B_2(g), B_3(g) etc to indicate a moderate amount of gleying.

Poor = The Bg horizons are dull and mottling is evident.

Very poor = The Bg horizons are dull and mottling is very evident

Cation Exchange Capacity (CEC)

The sum of cations held by electrostatic forces on soil particles to balance the surface negative charge. The major cations are typically calcium, magnesium, potassium, ammonium, with increasing amounts of sodium in saline soils, and hydrogen and aluminium in acid soils. To express CEC with a single numerical value the charges of cations differing in valency are expressed as <u>milliequivalents</u> or moles of charge. CEC is assumed to be measured by leaching with 1M ammonium acetate solution at pH 7. For further details see Rowell (1994).

meq/100g

Milliequivalents per 100 g of soil, a unit which measures moles of charge, also written as $cmol_c\ kg^{-1}$. One mol of charge is 6.02×10^{23} charges. For further details see Rowell (1994).

pH

The acidity of a soil measured in a suspension of soil and water or 0.01 M CaCl2 (enter into the DSS values for pH-CaCl2 if available). The pH of the suspension is defined as the negative logarithm of the hydrogen ion concentration (assuming a dilute solution). For further details see Rowell (1994).

Available Potassium (meq/100g or mg/kg)

The amount of exchangeable potassium held by electrostatic forces on soil particles to balance the surface negative charge, assumed to be measured by leaching with 1M ammonium acetate solution at pH 7. This parameter has to be entered in the DSS in mg/kg. To convert from meq/100g to mg/kg multiply by 400. To convert from mg/l the bulk density of the soil has to be estimated. Assuming a bulk density of 1.2 kg/l for sand/loamy soils, convert mg/l to mg/kg by multiplying by 0.83. For further details see Rowell (1994).

6.2. Land Use and Vegetation

Land Capability Class

The Land Capability Classification for Agriculture (Bibby *et al.*, 1991) was developed for Scotland to rank land on the basis of its potential productivity and cropping flexibility. It takes into account the restrictions imposed by soil, climate and relief. Class 1 is the best, 7 the worst.

During the assessment of limitations in the CeserDSS, the user may be asked which land suitability class their farm belongs to. They may select from two options: " Class 4.1 or Better" or " Worse than Class 4.1 ". The definition of Land Suitability Class 4.1 is: Land suited to rotations which, although primarily based on long ley grassland, include forage crops and cereals for stock feed. Yields of grass are high but difficulties of utilisation or conservation may be encountered. Other crop yields are very variable and usually below the national average.

Heather Moorland

Upland plant communities dominated by heather (*Calluna vulgaris*) and other dwarf shrubs (*Erica spp.*, *Vaccinium myrtillus*), typically on fairly well drained soils.

Rough Grassland

Grassland, which is not fertilised or otherwise managed; dominant grass species may include bents (*Agrostis spp.*), fescues (*Festuca spp*.), hair-grass (*Deschampsia spp.*), white bent (*Nardus stricta*) and purple moorgrass (*Molinia caerulaea*).

Blanket Bog

Waterlogged plant communities on acid peaty soils; with species such as deer grass (*Trichophorum caespitosum*), cotton grasses (*Eriophorum spp.)*, purple moorgrass (*Molinia caerulaea*) and bog myrtle (*Myrica gale).* Ericaceous warf shrubs such as *Calluna* and *Erica* may occur but will not dominate.

Improved Pasture

Grasslands used for grazing of livestock, which are dominated by grass and clover species of high grazing value and are generally established by reseeding and maintained by grazing control and use of lime and fertilisers.

Eutrophication

Increased primary production which leads to a deterioration in aesthetic and life-supporting qualities of water bodies caused by excessive fertilisation from effluents and runoff high in nitrogen. phosphorus and organic matter. Algae and higher aquatic plants grow excessively and their decomposition lowers oxygen levels. This causes changes in species diversity, favouring those with lower oxygen requirements (adapted from Parker & Corbitt, 1992).

6.3. Agriculture

Finish for Slaughter

Fatten animals on the farm and sell for slaughter.

Fatten Elsewhere

Sell store animals for fattening on other farms.

Dairy Farm

Farms producing milk from dairy cows. No distinction between farms in non-LFA and LFA areas is made. Soils are assumed to be predominantly mineral.

Lowland Sheep Farm

Sheep farms that breed and fatten lambs, and don’t receive payments for being in a ‘less-favoured area’ (LFA). Soils are assumed to be predominantly mineral.

Upland/Hill Sheep Farm

Sheep farms that breed lambs, and either fatten them or sell as store lambs, and receive payments for being in a ‘less-favoured area’ (LFA). It is assumed that a significant proportion of soils is organic or podsolic.

Lowland Beef Farm

Beef farms that breed and fatten calves, and don’t receive payments for being in a ‘less-favoured area’ (LFA). Soils are assumed to be predominantly mineral.

Upland/Hill Beef Farm

Beef farms that breed calves and either fatten them or sell as store cattle, and receive payments for being in a ‘less-favoured area’ (LFA). It is assumed that a significant proportion of soils is organic or podsolic.

Arable Farm

Farms growing wheat, barley, oilseed rape, potatoes, swedes or similar crops. Only mineral soils are assumed to occur.

Management for Deer

Land managed for the hunting of wild red deer. The number of red deer in Scotland is estimated at 300000 (Red Deer Commission 1989). Generally deer hunting takes place on large privately owned sporting estates in upland areas. Income is derived from the sale of venison and fees for hunting (mainly stags).

Less Favoured Areas (LFA’s)

LFA’s are defined under EEC Directive 75/268 (now integrated into Regulation 950/97) as areas where agricultural production may be limited by factors such as poor soils, altitude, slope, poor water supplies, risk of flooding etc. LFA’s receive special financial support in the form of compensatory allowances and investment aids. (for more details see http://europa.eu.int/comm/dg06/publi/cap2000/rd/rd_en/specmeas.htm#f2.

7. MERITS AND LIMITATIONS OF THE CESER-DSS

The CeserDSS represents a major step forward in the development of a decision support system for the evaluation of countermeasures at the farm level. It allows decision-makers to incorporate environmental and socio-economic criteria into the countermeasure selection process.

The CeserDSS software is designed to be user-friendly and intuitive to use, with extensive on-line help facilities. It allows the user to simultaneously evaluate a range of countermeasures in terms of their impacts on the environment and agricultural products as well as on-farm monetary costs and benefits. Although the actual criteria on which environmental impacts are judged, cannot be altered, the user has the option of weighting these and changing the default settings for the ideals according to their individual priorities. Furthermore, the impact scores for each criterion can be altered to reflect more accurately the potential impacts on the piece of land being assessed.

The user inputs required to run the software are a compromise between what is scientifically desirable and practically possible. Every effort has been made to limit the user-input variables to those which farmers and agricultural advisors would typically know or have access to. In the economic assessment all cost variables employed in the calculations can be manipulated. This ensures that prices can be updated and calculations can be made as farm-specific as possible. The environmental and agricultural conditions under which each countermeasure is feasible and effective, have been set to ensure that unsuitable areas are not treated. This cautious approach may be excessively restrictive in some areas.

Decision-aiding software cannot truly reflect the complexities of a decision making process and requires some abstraction. This is seen in the necessity to limit the number of farm types and define the agricultural and environmental conditions under which they operate. Many other features had to be pre-determined such as the deposition scenarios, the predicted level of food contamination, the countermeasures, the impact criteria and the limitations. In the future it may be possible, although technically challenging, to make these more flexible. 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 environmental impact scores accordingly.

The CeserDSS in it’s current form is intended for countermeasure assessments in Scottish agricultural systems. A UK-wide application is possible, but would be restricted to compatible farm types. However, the software also fulfils a general educational role in making decision makers aware of environmental and economic issues in the evaluation of countermeasures.

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