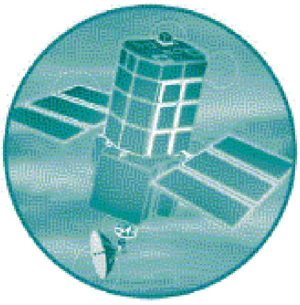
DEFRA/Environment Agency
Flood and Coastal Defence R&D Programme



Impact of agricultural soil conditions on floods - Autumn 2000

R&D Technical Report W5B-026/TR

DEFRA
Department for
Environment,
Food & Rural Affairs

ENVIRONMENT AGENCY

Impact of agricultural soil conditions on floods – Autumn 2000

R&D Technical Report W5B-026/TR

I P Holman, J M Hollis and T R E Thompson

Research Contractor:
National Soil Resources Institute, Cranfield University

Publishing Organisation

Environment Agency
Rio House
Waterside Drive
Aztec West
Almondsbury,
Bristol BS32 4UD

Tel: 01454-624400 Fax: 01454-624409
Website: www.environment-agency.gov.uk

 ISBN: 1857059336.

Dissemination status
Internal: Released Internally
External: Released to Public Domain

Statement of Use
This report describes a targeted survey to assess the spatial extent of agriculturally degraded soils and their contribution to high runoff and floods in 2000/2001. It provides basic understanding to assist in planning future R&D and also policy and management action.

Keywords
Soil, flooding, soil degradation, erosion, compaction, land management, agriculture, soil hydrology, catchment

Research Contractor
This report was produced under R&D Project W5B-026 by:
National Soil Resources Institute, Cranfield University, Silsoe, Bedford MK45 1ED

Authors: IP Holman, JM Hollis and TRE Thompson
Tel: 01525-863250 Fax: 01525-863253 Website: www.silsoe.cranfield.ac.uk/nsri

DEFRA / Environment Agency Project Manager
The Environment Agency's Project Manager for Project W5B-026 was;
Dr Mervyn Bramley, Flood Defence Development Manager

Further copies of this report are available from:
Environment Agency R&D Dissemination Centre, c/o
WRc, Frankland Road, Swindon, Wilts SN5 8YF

tel: 01793-865000 fax: 01793-514562 e-mail: publications@wrcplc.co.uk

CONTENTS

CONTENTS OF R&D PROJECT RECORD W5B-026/PR
FIELD OBSERVATION RECORDS FOR INVESTIGATED AREAS

INTRODUCTION

EXECUTIVE SUMMARY

The year 2000 was the wettest in Great Britain since records began in the eighteenth century. It has been repeatedly claimed in statements to the media that catchments such as the Severn, Yorkshire Ouse and Medway flooded because they were "saturated" by the first rain storms in October and were unable to absorb more rainfall. Some modern farming practices can lead to a reduction in soil water storage and infiltration capacity, particularly on certain types of soil. These "degraded" soil conditions can reduce the soil's inherent ability to absorb rain and thus lead to increased runoff to surface waters, particularly during storm events. However, there is little quantified data available to corroborate this possibility. As a consequence, the National Soil Resources Institute (formerly the Soil Survey and Land Research Centre) were commissioned to undertake a targeted survey to investigate the conditions of a range of soils under different cropping systems in selected areas of the large Severn and Yorkshire Ouse catchments and also the smaller catchments of the rivers Uck and Bourne in the south-east of England. The catchments of the Severn and the Yorkshire Ouse were too large to investigate in detail and field visits were therefore focussed on three selected representative 100 km^2 areas within each catchment.

During December 2000 and January 2001, experienced soil surveyors visited each of the selected areas. Each area was chosen to represent one or more of five cropping/management systems identified as having the potential to cause problems of soil degradation: *Autumn-sown crops*; *Late autumn harvested crops; Field vegetables*; *Orchards*; *Grassland - both permanent and ley grassland, but not including rough grazing*. The soil conditions under these cropping/management systems were investigated in a minimum number of 30 fields in each representative area. Fields were selected on a random basis, but chosen to reflect the approximate proportions of cropping systems representative of each area.

The field observations at each site were used to place the soils within a fourfold classification of Soil Degradation (*Low, Moderate, High* and *Severe*), according to the presence and frequency of the following features:

- The presence of erosion and deposition features;
- The presence of a slaked or capped topsoil;
- The presence of tractor wheeling or tramlines;
- The extent of poaching;
- The presence of structural change within, or at the base of, the topsoil;
- Unusual vertical wetness gradients within the soil profile.

The soil type within each field investigated was also classified according to a set of inherent soil characteristics that affect soil susceptibility to degradation. The percentage of each soil degradation class within each soil type, under each cropping system, in each representative study area was then calculated and the results used to extrapolate the data to catchment level, using MAFF, now DEFRA, agricultural census statistics, resolved to a 2 km x 2 km grid basis.

The results of the interpretation of the field observation data and the extrapolation of this data to the catchment scale show that:

- Enhanced soil degradation associated with a number of cropping systems/management practices is present in all four catchments studied. It occurs on approximately 22 and 30% of the land in the large Yorkshire Ouse and Severn catchments respectively and on approximately 18 and 33 % of land in the small headwater catchments of the Bourne and Uck respectively.
- Severe degradation is mainly associated with late harvested crops such as maize, sugar beet and, at least during the autumn of 2000, main crop potatoes.
- Extensive degradation occurred on 55 % of inspected sites on late harvested crops, 25 % of sites under grass, autumn sown crops and field vegetables and 10 % of sites under orchards.
- Simple calculations, using both a very conservative and an extreme estimate of the percentage increase in standard percentage runoff that may result from the observed enhanced soil degradation, suggest a potential increase of between about 0.5 and 12 % in the total volume of runoff entering each of the rivers from the whole catchment during storm events, although the increase for the Uck may have been greater.

These results thus provide strong evidence for enhanced soil degradation resulting when some current cropping and stock management practices have to be undertaken in less than ideal conditions. It also suggests that such enhanced soil degradation has the potential to give a significant increase in the amount of runoff entering rivers during storm events although whether such potential is realised is less certain. The data interpretation and extrapolation carried out here was a simple desk exercise. Monitoring experiments undertaken by the USDA Soil Conservation Service (Rallinson, 1980) have demonstrated that soil and crop management practices can have a significant effect on stream response to rainfall. Plot experiments under maize in this country (Martyn *et al*, 2000) have demonstrated impacts on run-off. However, no measured data exists for the UK to establish the connectivity between field-scale runoff and stream response during storm events. It is therefore recommended that the DEFRA and the Agency initiate research to investigate the following topics:

- Quantification of the hydrological impact of enhanced soil structural degradation on stream response to storm events, through linked field studies and modelling.
- Field studies to investigate the potential for developing on-farm ‘soft’ engineering solutions that will reduce the immediate impact of field-scale runoff.

It is also recommended that DEFRA and the Agency address the following in collaboration with the other bodies having responsibilities and interests:

- Detailed studies of the impact of selected cropping and management practices on soil structure for different soil types and climatic conditions.
- Field studies to investigate the potential for improved crop, pasture and stock management practices to reduce soil degradation and run-off.

1. INTRODUCTION

The year 2000 was the wettest in Great Britain since records began in the eighteenth century. As a result of the wet winter, many catchments, especially in England, suffered prolonged and frequent flooding.

It has been repeatedly claimed in statements to the media that catchments such as the Severn, Yorkshire Ouse and Medway have flooded because they were "saturated" by the first rain storms in October and were unable to absorb more rainfall. The impacts of the purported inability of the land to store additional precipitation has been exacerbated by development on the floodplains, which has restricted the storage areas into which water can safely overflow from the river channel.

Some modern farming practices can lead to a reduction in soil water storage and infiltration capacity, particularly on certain types of soil. These "degraded" soil conditions can reduce the soil's inherent ability to absorb rain and thus lead to increased runoff to surface waters, particularly during storm events. However, there is little quantified data available to corroborate this possibility. As a consequence, the National Soil Resources Institute (formerly the Soil Survey and Land Research Centre) were commissioned to undertake a targeted survey to investigate the conditions of a range of soils under different cropping systems in selected areas of the large Severn and Yorkshire Ouse catchments and also the smaller catchments of the rivers Uck and Bourne in the south-east of England. The following report describes the results of this investigation and interprets them in terms of their potential impact on runoff from storm events.

2. THE SOIL HYDROLOGICAL AND AGRONOMIC BACKGROUND

The vast majority of UK rain falls on vegetated or bare soil. The speed with which that water reaches the river network is strongly influenced by the nature and condition of the underlying soil. Work on the Hydrology of Soil Types (HOST) project (Boorman *et al*, 1995) has demonstrated a significant relationship between general soil properties, such as soil texture, inherent subsoil permeability and porosity, and the flood response of rivers. However what is poorly understood is the magnitude to which this relationship between soil and stream response is modified by land management, soil crusting and soil compaction (Figure 2.1).

A range of cropping and stock management systems in UK agriculture have the potential to impact upon soil structural conditions. These impacts mainly relate to the need for machinery or livestock to have access to the land at times when the soil hydrological cycle is at or approaching its wettest season. Five main agricultural management systems pose a problem:

1. Arable systems with an emphasis on **autumn-sown cereals, oilseed rape and field beans**. In such systems there is a need to cultivate the land and sow the crops during the autumn period when the soil is starting to 'wet up' after the period of summer moisture deficit. Following sowing and application of fertiliser and pesticide, the field remains bare or sparsely vegetated with a series of compacted tractor 'wheelings' over the winter period.

2. Arable systems that include **late-harvested crops such as maize, sugar beet and main crop potatoes**. In such systems heavy harvesting machinery needs access to the land during late Autumn and early Winter when the soils are likely to be at their 'field capacity' moisture state. Harvesting operations leave some, or all of the field surfaces bare, compacted and rutted for significant periods during this time.

3. Arable systems that include intensive crops of **field vegetables**. In such systems, access to the land is often required throughout the winter period when soils are likely to be at their wettest. Harvested areas usually remain bare and compacted over the winter period.

4. Farming systems with bush or 'top' fruit **orchards**. In such systems, a common management practice is to keep the rows in between trees or bushes with a minimum of vegetation, thus leaving the soil surface exposed to rainfall during the late autumn and winter periods when interception from the trees or bushes is likely to be minimal.

5. Sheep fattening and livestock rearing systems. Two problems exist here. Firstly a common practice in sheep fattening systems is to put stock out to feed on the green vegetation left after harvesting sugar beet or to feed on specially sown fodder beet. Both practices mean that stock are present on bare soil surfaces during the autumn and early winter periods. Secondly, in areas where grass growth starts early in the year or persists later in the year, stock are kept on the land at times when the soil surface is at its wettest point in the annual hydrological cycle and thus most susceptible to compaction.

These cropping and stock management systems have been practised for many years, but recent trends towards the use of larger harvesting and cultivation machinery, increased stocking densities and out-wintering of sheep are likely to have resulted in an increase in overall soil structural "degradation". Their interaction with inherent soil characteristics results in three specific problems:

1. The use of larger machinery to produce uniformly fine seedbeds for autumn sown crops and for late harvesting of crops such as maize, sugar beet and potatoes, compacts subsoils and weakens topsoil structural stability of slowly permeable soils with varying amounts of seasonal wetness, through smearing and compression (Photos 1 and 2). This significantly reduces the overall storage capacity of the soil and increases the magnitude of stream response to rainfall (in other words, the soil-Standard Percentage Runoff (SPR) coefficient becomes significantly greater than the "national average"). Whereas subsoiling will disrupt any plough pans that may be formed, allowing roots to adequately penetrate and exploit subsoil layers, it may not significantly increase soil water storage because subsoil aggregates remain compact. In fact subsoiling may increase rapid 'by-pass' flow through the soil by increasing the number of coarse fissures present.

Soil hydrology

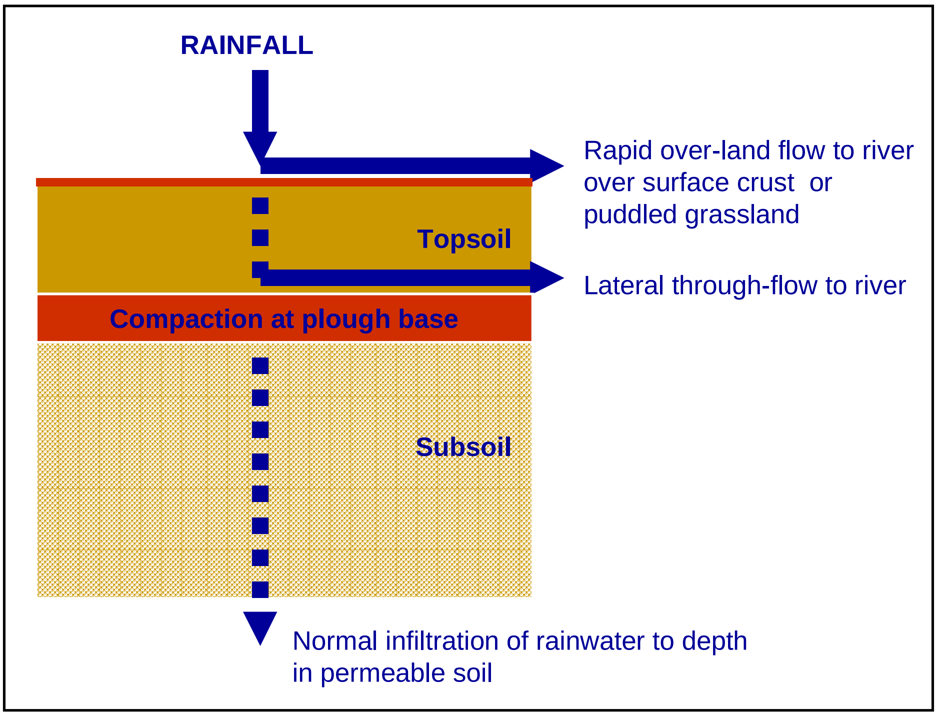


Figure 2.1 The relative proportions of over-land flow, lateral through-flow and vertical infiltration vary with fundamental soil physical properties but surface crusting, puddling by stock and deeper compaction divert more rain water into the over-land and lateral flow pathways that lead rapidly to the river.

2. On inherently weakly structured soils such as sands and light silts, the production of fine seedbeds in autumn, or the late harvesting of crops such as maize, sugar beet and potatoes, leads to rapid crusting and "capping" of the soil surface which in turn produces increased surface runoff (Photos 3 and 4). Although much of such runoff may be intercepted before it impacts on streams (the national average SPR values for such soils are only around 10%), it can still lead to a significantly greater soil-SPR than the national average of a given soil class.

3. The final problem relates to increased stocking densities and out-wintering of sheep flocks on grassland, particularly on recently sown leys. This results in compacted and smeared soil surfaces that significantly reduce infiltration and, again give increased surface runoff (Photos 5 and 6).

All three of these problems can exacerbate the “normal” response of streams to rainfall and are likely to have their greatest effect during extreme rainfall events at critical times of the year in late autumn, early winter and spring.

Photo 1 Soil structure under winter cereals showing surface compaction (upper 5 cm) and compaction at topsoil/subsoil junction (Severn Catchment SE 47)

Photo 2 Soil structure under sugar beet showing compaction at topsoil / subsoil junction (Severn Catchment SO 79/89)

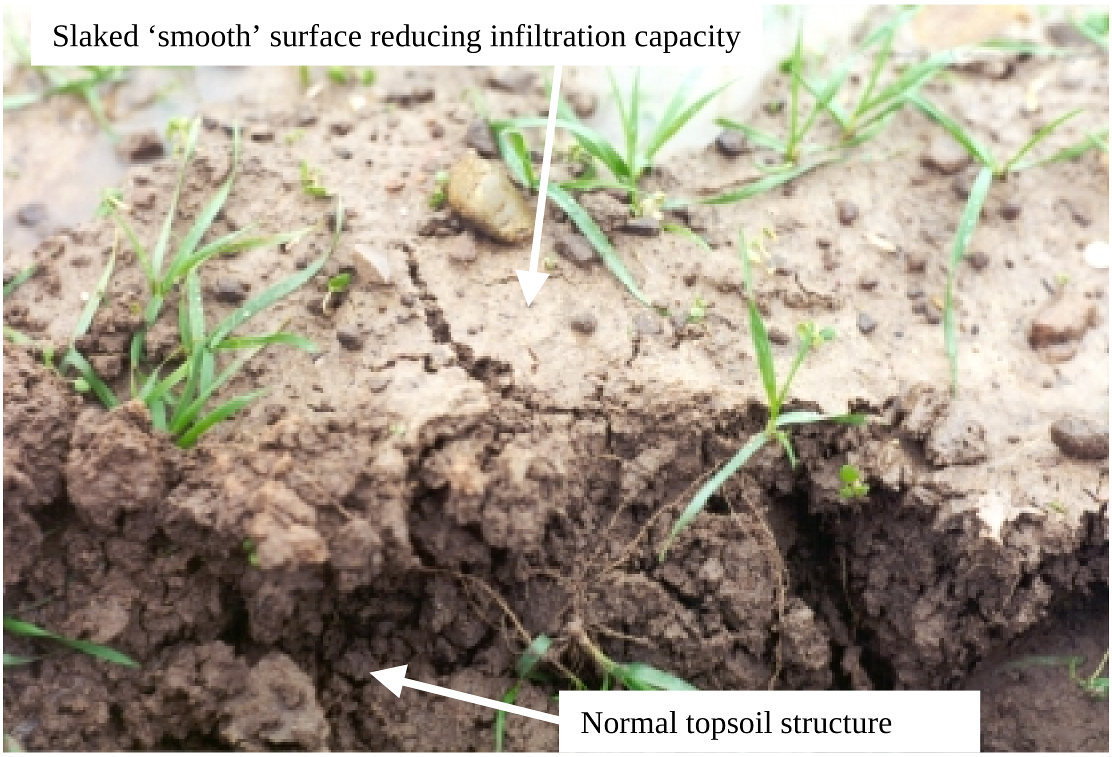


Photo 3 Slaked soil surface on winter cereal field (Severn Catchment SP05)

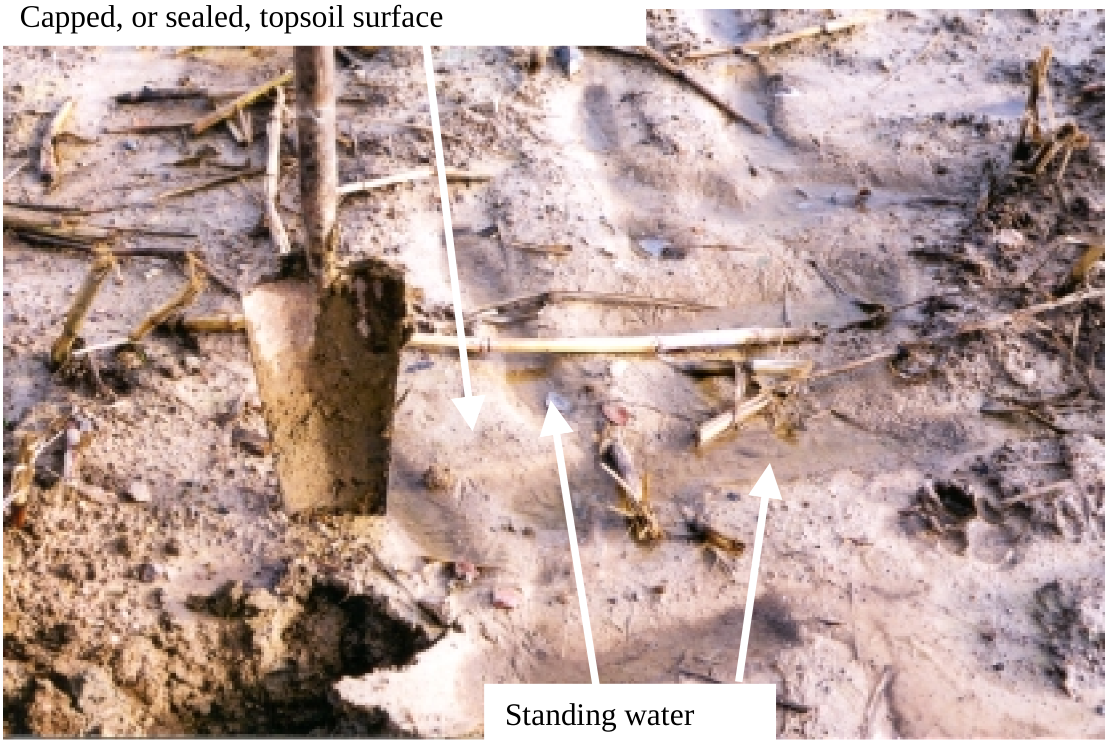


Photo 4 Badly capped soil surface under maize (Bourne Catchment)

Photo 5 Badly poached soil surface in sugar beet field grazed by sheep (Severn Catchment SO 79/89)

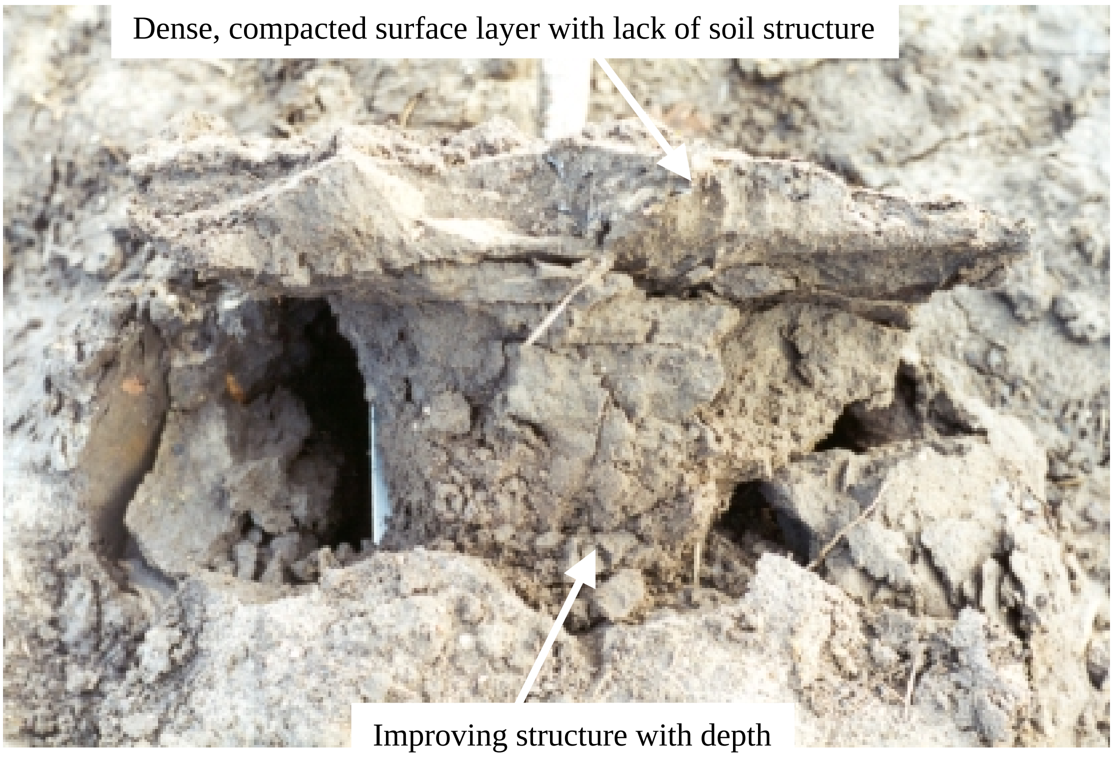


Photo 6 Topsoil compaction caused by poaching due to high stock density in cattle holding area (Yorkshire Ouse Catchment SE 47)

3. METHODOLOGY

3.1 Selection of study areas

The catchments of the river Severn, Yorkshire Ouse, Medway and Uck were highlighted by the Environment Agency as being of particular interest because of the flooding problems experienced during the late autumn and winter of 2000 / 2001. The whole of the small Uck catchment was investigated. Because of the scoping nature of this study, the major catchments of the Medway, Severn and the Yorkshire Ouse are too large to investigate in detail. It was therefore decided to focus field investigations on selected representative areas within each catchment. For the Medway, the small headwater catchment of the river Bourne was selected for study because it contains a representative range of soils and agriculture and it is often in headwater catchments that initial storm runoff is generated. For each of the much larger Severn and Yorkshire Ouse Catchments, fieldwork was focused in three representative blocks of land 10 km x 10 km in size. The criteria used to select these areas were as follows:

- They should represent the range of soil types under agriculture in each catchment.
- They should include a representative range of cropping and agricultural land uses.
- Wherever possible, there should be detailed 1:25,000 scale data on the soil pattern.

The location of each representative 10 km x 10 km blocks chosen to represent the Severn and Yorkshire Ouse catchments is shown in Figure 3.1 and the reasons for choosing each catchment summarised in Table 3.1.

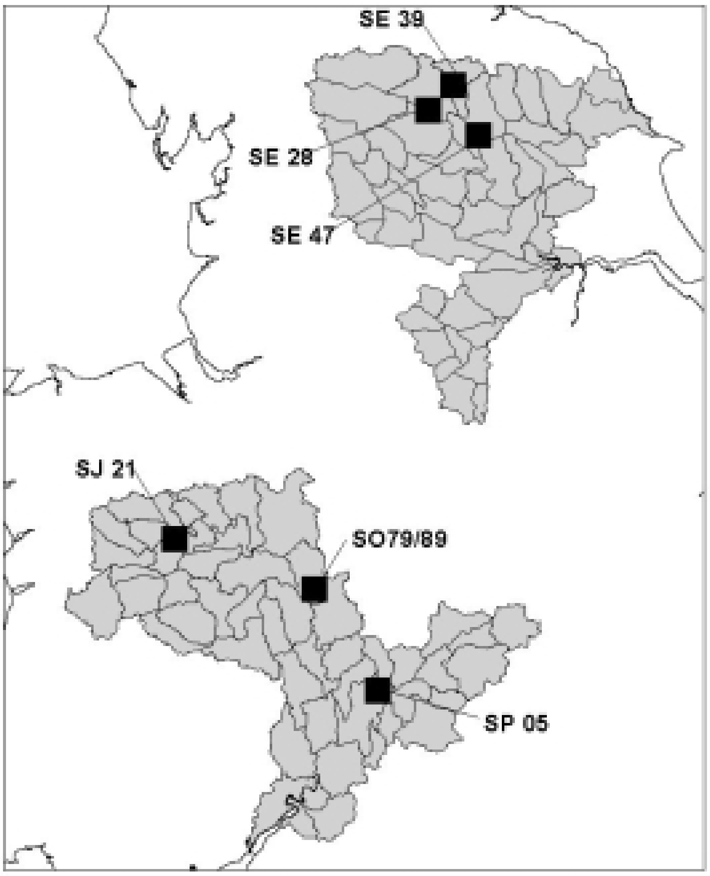


Figure 3.1 Location of the representative 10 km x 10 km blocks chosen to represent the Severn and Yorkshire Ouse Catchments

3.2 Field examination

During December 2000 and January 2001, experienced soil surveyors visited each of the selected areas. Each area was chosen to represent one or more of the five agricultural management systems identified in Section 2: *Autumn-sown crops (As)*; *Late autumn harvested crops (Lah)*; *Field vegetables (Vf)*; *Orchards (Or)*; *Grassland (Gr)*- both permanent and ley grassland, but not including rough grazing. The soil conditions under these cropping/management systems were investigated in a minimum number of 30 fields in each representative area. Fields were selected on a random basis, but chosen to reflect the approximate proportions of cropping systems representative of each area. In the Uck and the Bourne, where the whole of the catchment was investigated, field selection was guided by the use of specially commissioned aerial photography. Elsewhere, fields were identified on either side of a road network chosen to traverse the area via a representative cross section of local soils and cropping/management systems. The numbers of fields inspected under each cropping system in each study area are summarised in Table 3.2.

Table 3.1 Representative areas chosen as representative of soils and agricultural management systems in the Severn and Yorkshire Ouse Catchments

Catchment	100 km^2 area	Reason for choice
Severn	SP05	• A range of slowly permeable soils with slight or seasonal waterlogging, together with sandy loam soils on river terraces. • A range of winter-sown crops, vegetable crops, maize, short term and permanent grassland. • 1:25,000 scale soil map available.
	SO79E/89W	• Free draining sandy soils together with sandy loam soils with slowly permeable substrates and slight waterlogging. • A range of winter-sown crops, sugar beet, potatoes and maize. some short term grassland with sheep and cattle fattening. • 1:25,000 scale soil map available.
	SJ21	• Slowly permeable, seasonally waterlogged silty and clayey soils, often affected by groundwater. • Extensive permanent grassland with sheep and cattle fattening. Some winter sown cereals and fodder beet. • 1:25,000 scale soil map available.
Yorkshire Ouse	SE47	• Permeable sandy and loamy soils variably affected by groundwater. Some slowly permeable seasonally wet soils. • A range of winter cereals, potatoes, sugar beet and short term grassland for cattle and sheep fattening. • 1:25,000 scale soil map available.
	SE 39	• Slowly permeable seasonally waterlogged soils with some free draining sandy loams and loams on the terraces and alluvium. • Cereals with some potatoes on the lighter soils. Permanent and short-term grassland for dairying with some cattle fattening. • 1:25,000 scale soil map available.
	SE28	• Slowly permeable soil with slight seasonal waterlogging and free draining sandy loams and loams. Some slowly permeable, seasonally wet soils • Mainly cereals, permanent and short-term grassland for dairying cattle and sheep fattening. Some potatoes on free draining soils near the Ure • No detailed soil map available, chosen because of its representative soils and location on the Ure.

Table 3.2 Numbers of fields investigated under different management systems in each study area

Management system	Catchment							
	Ouse			Severn			Uck	Bourne
	Northallerton SE39	Bedale SE28	Dalton SE47	Claverley SO79/89	Arddleen SJ21	Alcester SP05		
Grass	14	16	9	3	20	11	31	18
Autumn sown	9	18	13	14	5	15	22	25
Late autumn harvested	14	5	10	21	5	2	11	1
Field vegetable	0	0	0	0	1	9	0	0
Orchards	0	0	0	0	0	0	14	50
Total	37	39	32	38	31	37	78	94

At each site, the surveyor recorded details concerning the cropping, soil surface condition, soil moisture state and the characteristics of the topsoil and upper subsoil horizons. The properties of the soil horizons were observed from small trial pits (approximately 30x30x40 cm) enabling a clearer interpretation of soil structure than can be gained from the use of an auger. Table 3.3 shows an example of the information recorded at each site. Full details of the field records are given in the accompanying Project Record W5B-026/PR.

Table 3.3 Example field observation record

Claverley SO79/89		
Locality: xxxxxxxxxxx Farm.		
Date: 14th Dec 2000	**Site:** 3	**Grid Ref:** SO7xx9xx
Elevation: 135m	**Crop:** Winter cereals	**Estimated cover:** 8%
Slope: Level 3.5^{o}	**Soil Series:** Salwick. Clay loam at 65cm, loamy sand at 80cm but stopped by stones.	
Erosion: Not excessive but some scouring along drill lines and tramlines. Depositional fans at the base of slope.		
Soil Surface: Mounded.	**Soil Condition:** Slaked.	
Topsoil Depth: 30cm.	**Texture:** Sandy loam.	**Colour:** 7.5YR3/2.
Structure: Moderate fine subangular blocky to 10cm then moderate fine and medium subangular blocky becoming medium below 20cm.		
Subsoil Texture: Sandy loam.	**Colour:** 7.5YR4/4.	
Structure: Moderate medium subangular and angular blocky structure.		
Comment: Drilling has changed the structure in the upper part of the topsoil. Soil wet and easily deformable below18cm. Less wet in the subsoil.		

4. INTERPRETATION OF THE RESULTS

4.1 Classification of the extent of soil degradation

There are several important soil characteristics recorded in the field observations that can be used to determine whether land management practices (or their timing) have altered the natural hydrological properties of a soil. These include:

- *Surface soil condition*- the presence of a slaked (Photo 3) or capped (Photo 4) topsoil indicates that the natural infiltration capacity of the soil surface has been reduced;
- *Presence of wheeling or tramlines*- the passage of vehicles over the soil surface deforms and compacts the upper parts of the topsoil, leading to a reduced infiltration capacity and the creation of preferential pathways for rapid water movement off the land (Photo 7 and 8);
- *The extent of poaching*- the overstocking of land, or the grazing of land when the soil is too wet, leads to poaching (Photo 5) and structural degradation of the upper parts of the topsoil (Photo 6);
- *The presence of structural change within, or at the base of, the topsoil*- the ill timed use of some cultivation practices, especially of ploughing, can result in the formation of compacted layers within (Photo 1), or at the base of (Photo 2), the topsoil. These layers reduce the overall permeability of the topsoil and/or the topsoil/subsoil junction and promote the lateral movement of water within the topsoil (see Fig. 2.1);
- *The presence of erosion and deposition features*- these indicate that runoff has been sufficiently great to cause the detachment and movement of soil particles (Photos 9 and 10);
- *Vertical wetness gradients within the soil profile*- In naturally well-drained, permeable soils it would be expected during the winter months that, except shortly after intense rainfall events, the soil profile will be of approximately similar wetness throughout. An indication of structural degradation is provided when such soils are significantly drier in the subsoil, compared to the topsoil and an adverse vertical wetness gradient is present.

A broad range of degradation features was identified in all catchments visited and these are described on the field record cards. However, for ease of comparison between sites to assist in interpretation of the data, a relatively simple classification of degradation was established. The classes are described in Table 4.1 and the main degradation features associated with each class, stratified for land use are given in Table 4.2.

Table 4.1 Soil degradation classes

Class	Name	Description
S	Severe	Soil degradation generates sufficient enhanced runoff to cause widespread erosion that is not confined to wheelings / tramlines.
H	High, extensive	Soil degradation generates enhanced runoff across whole field, where slopes allow
M	Moderate, local	Soil degradation generates localised areas of enhanced runoff, where slopes allow
L	Low	Insignificant enhanced run-off generation

Photo 7 The incomplete crop cover on this winter sown crop has led to slaking which, together with the deep wheelings, has lead to a reduced infiltration capacity and increased runoff (Severn Catchment SP 05)

Photo 8 The late harvesting of this maize crop when the soil was too moist has caused deep rutting and structural degradation, leading to enhanced runoff (Severn Catchment SP 05)


Photo 9 Enhanced runoff from the slaked soil and been channelled and concentrated by the landscape to scour out this gully (Uck)


Photo 10 Channelled runoff within rill (Uck)

Table 4.2 Soil degradation features associated with the Soil Degradation classification

Class	Management system	Soil degradation features
S	All (As, Lah, Vf, Or, Gr)[1]	Extensive rill erosion that is not confined to wheelings on slopes and depositional fans on footslopes and level ground + characteristics of Class H
H	Arable or Orchard (As, Lah, Vf, Or)	Slaked or capped topsoil + topsoil structural change / compaction or 'loose' surface / poor load bearing capacity + extensive areas of standing water (not confined to wheelings) + vertical wetness gradient ± erosion in wheelings
H	Grassland (Gr)	Extensively poached surface + extensive areas of standing water + topsoil compaction + vertical wetness gradient
M	Arable or Orchard (As, Lah, Vf, Or)	Slaked or partly slaked topsoil + standing water in wheelings ± topsoil structural change
M	Grassland (Gr)	Slight poaching (locally severe) + localised areas of standing water
L	All (As, Lah, Vf, Or, Gr)	Few signs of enhanced runoff mechanisms present, but can show signs of localised poaching and standing water as long as the whole profile maintains a good soil structure

[1]Autumn-sown crops (As); Late autumn harvested crops (Lah); Field vegetables (Vf); Orchards (Or); Grassland (Gr)

4.2 Classification of inherent soil characteristics

The Soil Degradation classification previously described does not directly incorporate the natural physical properties of the soil at each site. However, these properties, in particular texture and hydrology, play an important role in determining the susceptibility of the soil to degradation associated with land management practices. For example, soils with a large clay content have lower bearing strength when wet and are therefore more susceptible to compaction and damage during trafficking and cultivation than soils with a small clay content. Therefore, to aid the extrapolation of data from representative areas, the soils at each site have been classified according to their natural characteristics (Table 4.3).

4.3 Extent of degradation in the study areas

Having classified each site according to its cropping system, natural soil characteristics and level of soil degradation, a three dimensional matrix (Figure 4.1) was used to compile statistics on the percentage of land in each Soil type-Cropping system-Degradation group in each of the study areas.

Table 4.3 Characteristics of the Soil Classes

Soil class	Topsoil texture	Soil hydrology
1	Sand, loamy sand or sandy loam	Permeable soils, either freely drained, or experiencing seasonal subsoil waterlogging due to groundwater
2	Sand, loamy sand or sandy loam	Experience occasional seasonal waterlogging in upper layers due to slowly permeable subsoils
3	Sandy silt loam, silty clay loam, silt loam, clay loam or sandy clay loam	Permeable soils, either freely drained, or experiencing seasonal subsoil waterlogging due to groundwater
4	Sandy silt loam, silty clay loam, silt loam, clay loam or sandy clay loam	Experience occasional seasonal waterlogging in upper layers due to slowly permeable subsoils
5	Sandy silt loam, silty clay loam, silt loam, clay loam or sandy clay loam	Experience prolonged seasonal waterlogging due to slowly permeable subsoils or high groundwater levels
6	Heavy clay loam (>27% clay), sandy clay, silty clay or clay	Experience occasional seasonal waterlogging in upper layers due to slowly permeable subsoils
7	Heavy clay loam (>27% clay), sandy clay, silty clay or clay	Experience prolonged seasonal waterlogging due to slowly permeable subsoils or high groundwater levels
8	Organic	Experience prolonged seasonal waterlogging due to slowly permeable subsoils or high groundwater levels

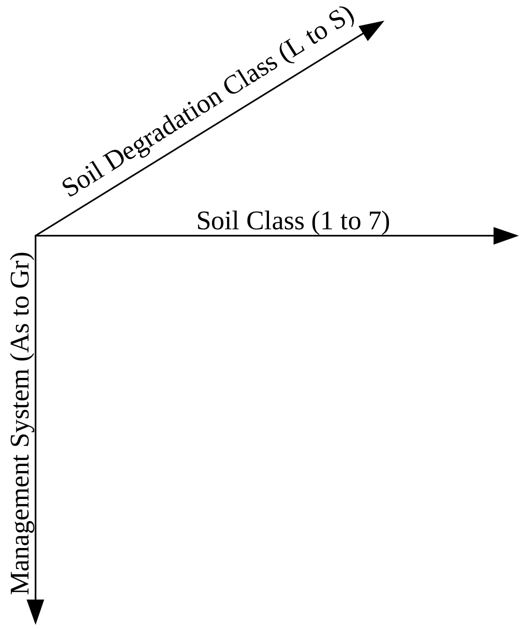


Figure 4.1 Schematic representation of the three dimensional matrix of Management System, Soil and Soil Degradation Classes used to spatially extrapolate the field observations

The statistics for each study area within each catchment were then amalgamated to give an overall estimate of the percentage of each degradation class in the studied management systems and soil types within the representative areas of each catchment. The results are presented in Tables 4.4 to 4.7, and Figures 4.2 to 4.7 and show how the pattern of soil degradation differs between the catchments, landuses and soil classes.

As a generalisation, the few cases of *severe* degradation identified are generally confined to sites on autumn sown or late autumn harvested crops, although some poorly established or heavily poached ley grassland sites have been included. The *high*, *moderate* and *low* degradation classes are roughly evenly divided on the grassland sites. In contrast, sites on autumn sown crops have a preponderance of *moderate* degradation, whereas late autumn harvested crops are characterised by *high* degradation.

Table 4.4 Breakdown of observations by Management System, Soil Degradation and Soil Class for the Severn Catchment (Figures in parentheses are percentage of management system-soil class)

Management System			Soil Degradation Class				
Symbol	System	Soil Class	S	H	M	L	Grand Total
Gr	Grass	1	0	1 (33)	1 (33)	1 (33)	3
	Grass	2	0	0	1 (25)	3 (75)	4
	Grass	3	0	1 (25)	2 (50)	1 (25)	4
	Grass	4	0	2 (33)	0	4 (67)	6
	Grass	5	0	5 (42)	5 (42)	2 (17)	12
	Grass	6	0	0	1 (100)	0	1
	Grass	7	0	1 (33)	1 (33)	1 (33)	3
As	Autumn sown	1	1 (9)	5 (45)	4 (36)	1 (9)	11
	Autumn sown	2	2 (29)	1 (14)	4 (57)	0	7
	Autumn sown	3	0	0	2 (100)	0	2
	Autumn sown	4	0	3 (50)	3 (50)	0	6
	Autumn sown	5	0	1 (25)	3 (75)	0	4
	Autumn sown	6	0	0	1 (33)	2 (67)	3
	Autumn sown	7	0	1 (100)	0	0	1
Lah	Late autumn	1	3 (21)	9 (64)	2 (14)	0	14
	Late autumn	2	0	5 (71)	2 (29)	0	7
	Late autumn	3	0	0	2 (100)	0	2
	Late autumn	4	0	1 (100)	0	0	1
	Late autumn	5	0	4 (100)	0	0	4
Vf	Field Veg.	1	1 (20)	1 (20)	3 (60)	0	5
	Field Veg.	2	0	1 (50)	1 (50)	0	2
	Field Veg.	4	0	1 (50)	1 (50)	0	2
	Field Veg.	5	0	0	0	1 (100)	1
	Grand Total		7	43	39	16	105

*Orchards did not occur within the areas investigated

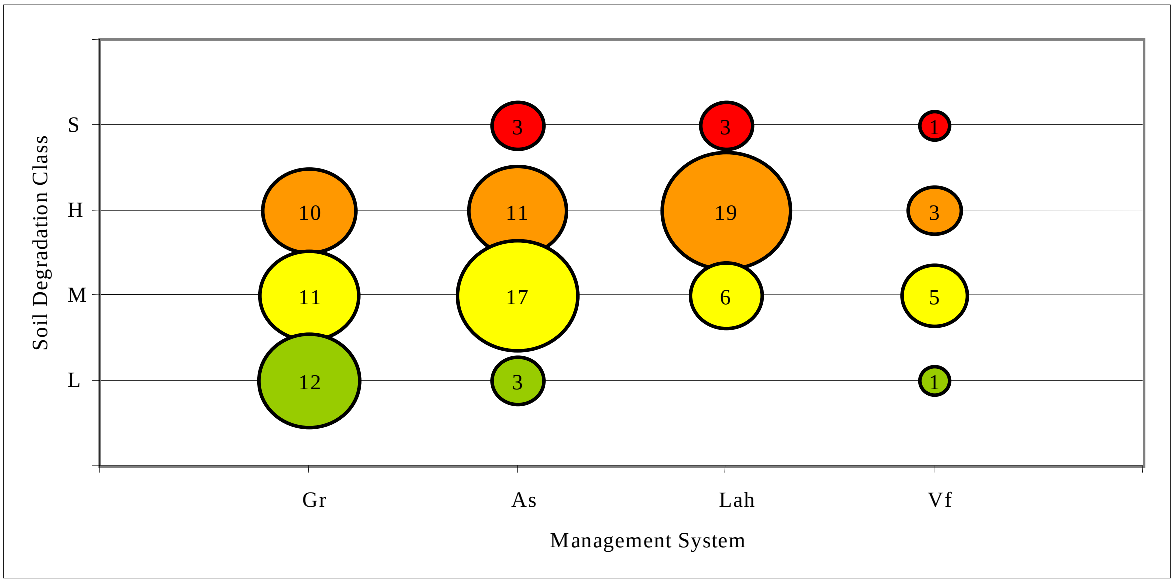


Figure 4.2 Distribution of observed Soil Degradation Classes by Management System in the Severn catchment (diameter of circle is proportional to the number of observations

Table 4.5 Breakdown of observations by Management System, Soil Degradation and Soil Class for the Ouse Catchment (Figures in parentheses are percentage of management system-soil class)

Management System			Soil Degradation Class				
Symbol	System	Soil Class	S	H	M	L	Grand Total
Gr	Grass	1	0	1 (17)	4 (67)	1 (17)	6
	Grass	2	0	0	1 (33)	2 (67)	3
	Grass	3	0	2 (50)	1 (25)	1 (25)	4
	Grass	4	0	3 (100)	0	0	3
	Grass	5	0	5 (28)	6 (33)	7 (39)	18
	Grass	7	0	2 (40)	0	3 (60)	5
As	Autumn sown	1	0	0	2 (67)	1 (33)	3
	Autumn sown	3	0	6 (30)	10 (50)	4 (20)	20
	Autumn sown	4	0	2 (100)	0	0	2
	Autumn sown	5	0	1 (9)	8 (73)	2 (18)	11
	Autumn sown	7	0	2 (40)	2 (40)	0	4
Lah	Late autumn	1	0	2 (33)	4 (67)	0	6
	Late autumn	2	0	3 (75)	1 (25)	0	4
	Late autumn	3	1 (14)	4 (57)	2 (29)	0	7
	Late autumn	4	1 (25)	3 (75)	0	0	4
	Late autumn	5	2 (29)	3 (43)	2 (29)	0	7
	Late autumn	7	1 (100)	0	0	0	1
	Grand Total		5	39	43	21	108

*Orchards did not occur within the areas investigated

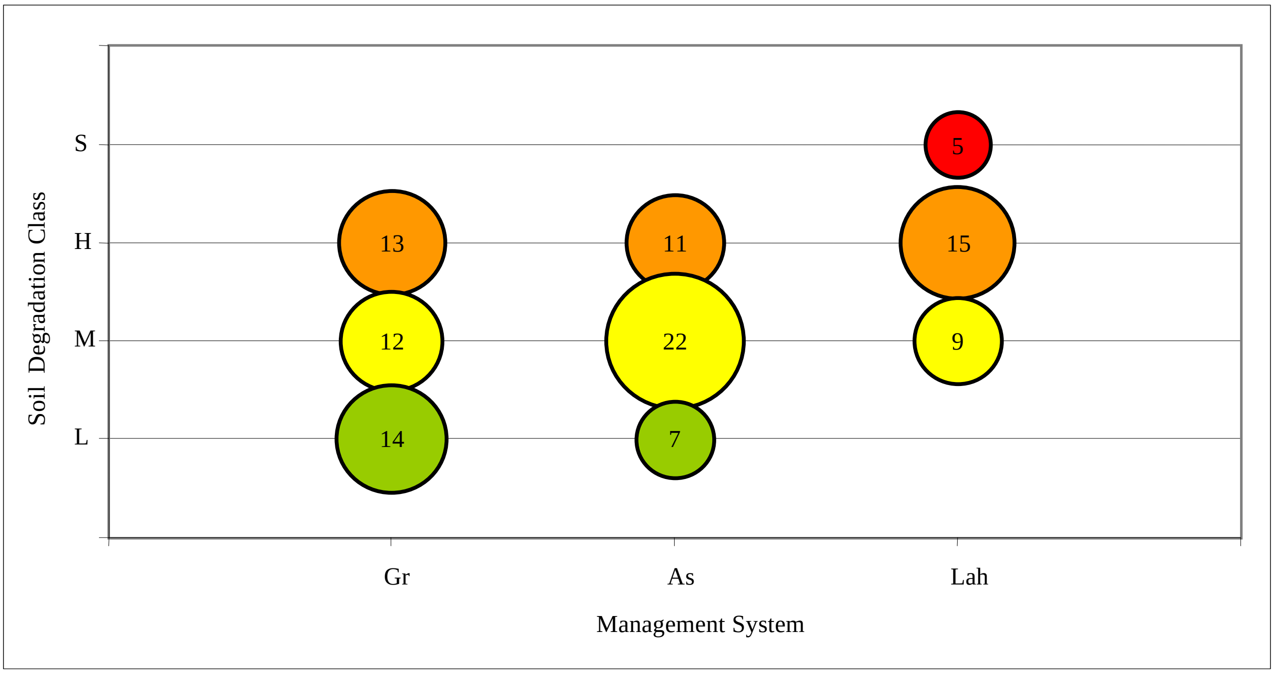


Figure 4.3 Distribution of observed Soil Degradation Classes by Management System in the Yorkshire Ouse Catchment (diameter of circle is proportional to the number of observations)

Table 4.6 Breakdown of observations by Management System, Soil Degradation and Soil Class for the Bourne Catchment (Figures in parentheses are percentage of management system-soil class)

Management System			Soil Degradation Class				
Symbol	System	Soil Class	S	H	M	L	Grand Total
Gr	Grass	3	0	3 (30)	0	7 (70)	10
	Grass	4	0	0	0	1 (100)	1
	Grass	5	0	0	2 (100)	0	2
	Grass	7	0	1 (20)	2 (40)	2 (40)	5
As	Autumn sown	1	0	1 (100)	0	0	1
	Autumn sown	3	0	0	7 (70)	3 (30)	10
	Autumn sown	4	1 (50)	0	1 (50)	0	2
	Autumn sown	5	0	4 (50)	4 (50)	0	8
	Autumn sown	7	0	1 (25)	2 (50)	1 (25)	4
Lah	Late autumn	5	1 (100)	0	0	0	1
Or	Orchard	1	0	0	1 (50)	1 (50)	2
	Orchard	3	0	2 (4)	34 (74)	10 (22)	46
	Orchard	4	0	0	1 (50)	1 (50)	2
	Grand Total		2	12	54	26	94

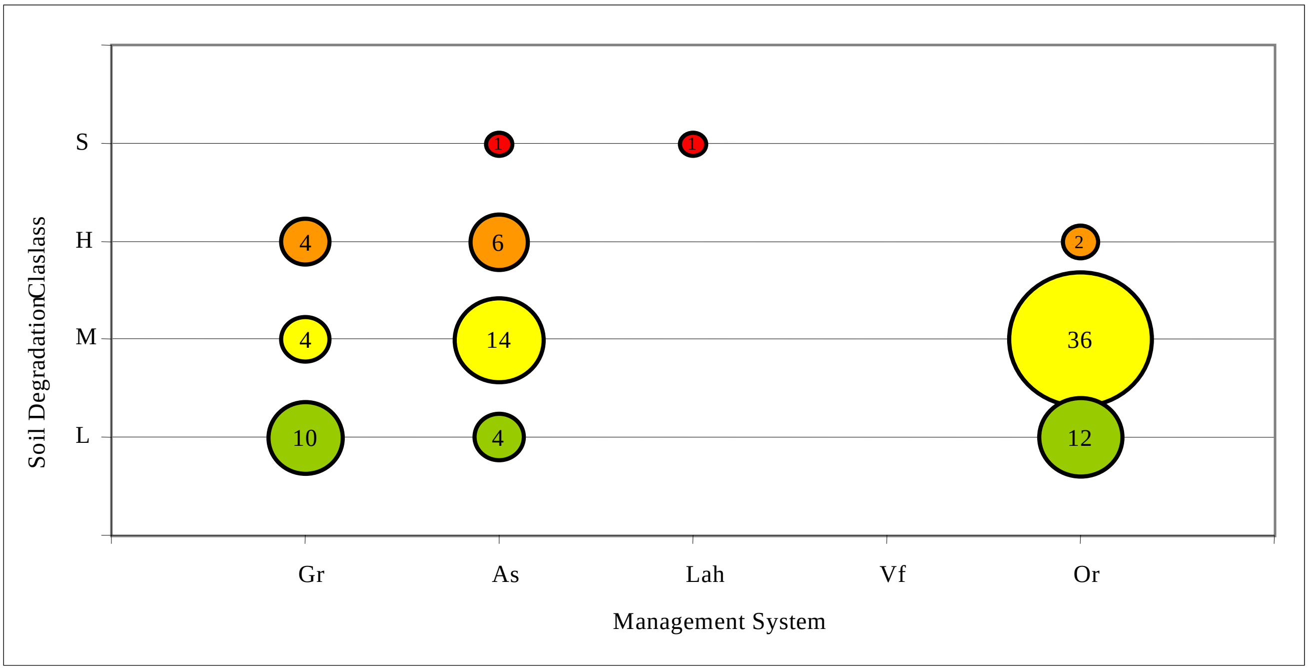


Figure 4.4 Distribution of observed Soil Degradation Classes by Management System in the Bourne Catchment (diameter of circle is proportional to the number of observations)

Table 4.7 Breakdown of observations by Management System, Soil Degradation and Soil Class for the Uck Catchment (Figures in parentheses are percentage of management system-soil class)

Management System			Soil degradation class				
Symbol	System	Soil Class	S	H	M	L	Grand Total
Gr	Grass	1	0	0	0	1 (100)	1
	Grass	3	0	0	1 (100)	0	1
	Grass	4	1 (13)	3 (38)	3 (38)	1 (13)	8
	Grass	5	1 (5)	9 (47)	7 (37)	2 (11)	19
	Grass	7	0	2 (100)	0	0	2
As	Autumn sown	4	4 (40)	5 (50)	1 (10)	0	10
	Autumn sown	5	3 (33)	4 (44)	2 (22)	0	9
	Autumn sown	7	0	2 (67)	1 (33)	0	3
Lah	Late autumn	1	0	1 (100)	0	0	1
	Late autumn	2	0	1 (100)	0	0	1
	Late autumn	3	1 (100)	0	0	0	1
	Late autumn	4	1 (100)	0	0	0	1
	Late autumn	5	5 (71)	2 (29)	0	0	7
Or	Orchard	3	0	2 (25)	3 (38)	3 (38)	8
	Orchard	4	0	2 (33)	2 (33)	2 (33)	6
	Grand Total		16	33	20	9	78

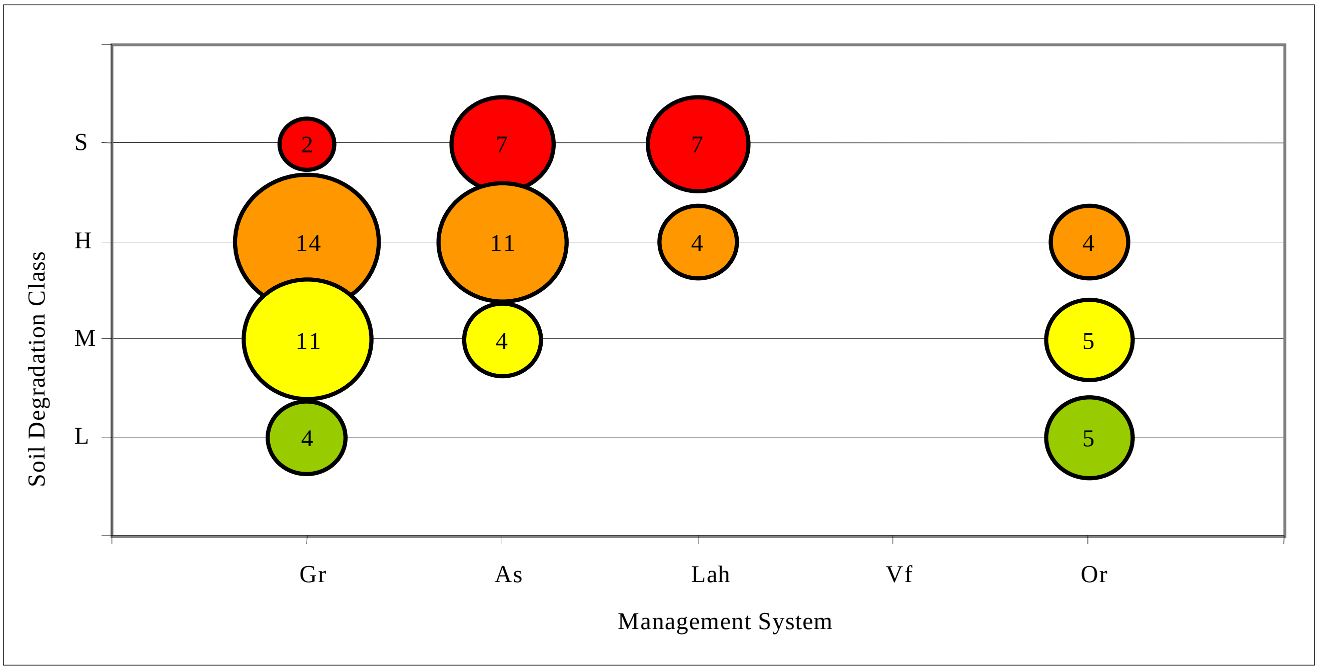


Figure 4.5 Distribution of observed Soil Degradation Classes by Management System in the Uck Catchment (diameter of circle is proportional to the number of observations)

4.4 Extrapolation of data to whole catchments

The results from the sites examined have been extrapolated to the catchment scale using the MAFF (now DEFRA) 2 km x 2 km agricultural land use statistics and the National Soil Map of England and Wales. Land use statistics from 1995 were used, except for orchards where data from 1988 was used. For the larger catchments, the extrapolation has been carried out at the sub-catchment scale, of which there are 47 each forming the Yorkshire Ouse and Severn catchments, and subsequently spatially summed. The extrapolation has been carried out as follows:

1. The MAFF agricultural crop categories which correspond to the agricultural management systems studied in this project have been identified and their extents in each of the 2 km x 2 km grid squares within the sub-catchment areas determined;

2. Due to errors and uncertainties implicit in the data, where the summed areas of the correlated management systems in a grid square exceeds the total area of the grid square, the areas of all the classes present have been proportionately reduced to equal the total area. In most grid squares the summed areas of the classes present will be *less than 400 ha (or 100 %)* due to the presence of other land uses such as rough grazing or urban area;

3. Based on the data compiled in 1 and 2, the total area of each of the correlated management systems in each sub-catchment has been determined;

4. All soil series occurring within the National Soil Map of England and Wales have been assigned to one of the soil classes used in this project;

5. Using data from the National 1:250 000 scale soil map of England and Wales, the area of each soil class in each 1 km x 1 km grid square has been determined, based upon the expected soil series composition of each soil association present within the grid square;

6. The total area of each of the soil classes in each sub-catchment has been determined;

7. An initial estimation of the fraction of each management system within each soil class within each sub-catchment is made by combining the fraction of the management system with the fraction of the soil class. For example:

Fraction of management system Gr in sub-catchment	= 0.35
Fraction of soil class 1	= 0.50
Fraction of Gr on soil class 1 in sub-catchment	= 0.35 x 0.5
	= 0.175

8. The fraction of each soil degradation class within each management system-soil class combination in each sub-catchment is then calculated by combining the percentages of degradation classes given in Tables 4.4 to 4.7 with the areal fraction of the corresponding management system-soil class. For example:

Fraction of degradation class H on Gr on soil class 1 in Ouse study areas	=	0.50
Fraction of Gr on soil class 1 in Ouse sub-catchment	=	0.175
Fraction of degradation class H on Gr on soil class 1 in Ouse sub-catchment	=	0.5 x 0.175
	=	0.0875

9. Where there are no observations for a given management system-soil class combination, which tend to relate to combinations that do not occur (such as late harvested crops on wet and heavy soils) the area of that combination is assigned in equal amounts to each of the other management system – soil class combinations. The exception to this is in areas of soil class 8 (soils with organic topsoils) in which degradation, of the types observed and classified within this study (e.g. compaction, slaking etc.) do not occur.

10. Finally, the calculated fractions of each degradation class for each management system-soil class combination are combined at the sub-catchment level to give the predicted area of the catchment in each soil degradation class.

The results of this extrapolation exercise are shown in Table 4.8 for the four catchments and in Figures 4.6 and 4.7 for sub-catchments of the Ouse and Severn. The results are expressed as the percentage of each Soil Degradation Class within the total areas of the four catchments. Because each of the catchments contains both non-agricultural areas and areas of cropping systems not considered in this study, the percentages shown do not sum to 100 %.

Table 4.8 Percentage of each Soil Degradation Class within the four catchments studied

	Soil Degradation Class				
	S	H	M	L	Total
Ouse	1.0	12.7	16.3	9.9	39.9
Severn	0.6	18.6	24.8	12.9	56.8
Bourne	1.6	10.0	14.7	12.1	38.4
Uck	6.4	24.3	12.9	5.0	48.6

The above table, however, does not allow for the tendency of some soils to suffer limited degradation when under intensive agricultural management even when a high standard of land management is practised. It is considered that moderate (local) degradation (Class M) is the typical state for clay-rich soils (Soil Classes 4 to 7) i.e. some localised degradation of these soils is inevitable, even under optimum land management. However, any areas of these soil classes where degradation is Severe or High (Class S and H) represent locations where enhanced runoff has probably occurred in autumn 2000.

After taking into account the background degradation that will occur in these heavier-textured soils, Table 4.9 shows the area of land in each catchment within which land management practices are predicted to have caused enhanced run-off.

Table 4.9 Area (sq km) of each catchment in which land management practices are predicted to have caused enhanced runoff, as given by Soil Degradation Class (percentages of total area in parentheses)

	Severe	High	Moderate	Total
Ouse	94 (1.0)	1 256 (12.7)	873 (8.9)	2 223 (22.6)
Severn	62 (0.6)	2 070 (18.6)	1 258 (11.3)	3 391 (30.5)
Bourne	0.9 (1.6)	5.3 (10.0)	3.7 (7.0)	9.8 (18.6)
Uck	6.6 (6.4)	25.1 (24.3)	3.2 (3.1)	34.9 (33.8)

4.5 Potential impact of enhanced degradation

The soil investigations indicate that some current agricultural management practices are significantly impacting on the structural characteristics of a range of soils. Locally the ability of the soil to absorb rainfall has been adversely affected. When these site-specific results are extrapolated to the sub-catchment or catchment scale, it is clear that significant proportions of the land are potentially at risk. However, the potential impact of this enhanced soil degradation on river flow response is less clear.
In the absence of measured data, as a first estimate of whether such enhanced soil degradation could significantly change stream response, the changes in the runoff volume associated with 1 mm of rainfall have been determined, based on the following two sets of very differing assumptions. It must be noted, however, that there are no quantitative data available linking soil degradation with stream response, in order to demonstrate the degree to which the assumptions below are conservative or extreme:

Conservative assumptions:

- Calculation of an initial Standard Percentage Runoff (SPR) value for each of the soil classes studied, based upon a spatially weighted mean of the HOST class SPR value for each soil series occurring within the river basin (Ouse and Severn) or catchment (Uck and Bourne);
- Soil Degradation Class E equates to a 10 % increase of the initial SPR for the relevant Soil Class. For example an SPR of 10% would increase to 11%;
- Soil Degradation Class H equates to a 5 % increase of the initial SPR for the relevant Soil Class;
- Soil Degradation Class M equates to a 5% increase of the initial SPR over 10 % of the area for the relevant Soil Class.

Extreme assumptions

- Calculation of an initial Standard Percentage Runoff value for each of the soil classes studied, as described above;
- Soil Degradation Class E equates to a 100 % increase of the initial SPR for the relevant Soil Class. For example and SPR of 10% would increase to 20%;
- Soil Degradation Class H equates to a 100 % increase of the initial SPR for 25 % of the area and a 50 % increase in the remaining 75 %;

- Soil Degradation Class M equates to a 10 % increase of the initial SPR over the area for the relevant Soil Class.

Using these assumptions for a rainfall event for which the Percentage Runoff equals the Standard Percentage Runoff, Table 4.10 shows the extra runoff that the soil degradation generates in the catchments for each 1 mm of rainfall. The volumes equate to an increase of between about 1.5 and 25 % in the volume of runoff entering each of the rivers from the affected areas, and an increase of between about 0.5 and 12 % in the total volume of runoff entering each of the rivers from the whole catchment, although the values for the Uck catchment are larger.

Table 4.10 Predicted extra run-off (m^3) for a 1 mm rainfall event caused by soil structural degradation

	Predicted extra runoff (m^3)	
	Assumption 1	Assumption 2
Ouse	25 900 (2.1) [**0.8**]	322 100 (26.3) [**9.4**]
Severn	37 400 (1.7) [**0.9**]	475 300 (21.6) [**12.0**]
Bourne	100 (1.6) [**0.6**]	1 200 (19.7) [**7.4**]
Uck	870 (4.1) [**2.0**]	10 200 (47.5) [**23.0**]

Percentage Runoff equals the Standard Percentage Runoff, using two different set of assumptions regarding the effect of soil structural degradation on SPR (percentages of predicted normal runoff from affected areas in parentheses) [percentages of predicted normal runoff from total catchment in bold]

Whilst the lower figure may not appear at first glance to be highly significant, it is worth bearing in mind that:

- The extra runoff caused by the soil degradation will impact upon the river, following a rainfall event, more rapidly than runoff associated with ‘normal’ soil conditions, due to the preferential flow routes associated with wheeling/tramlines and badly capped or poached soil surfaces;
- The assumptions made in the first calculation are highly conservative- the soil structural degradation observed at many of the worst sites will have reduced the capacity of the soil to absorb rainfall to a negligible rate, so that it is not infeasible that the Standard Percentage Runoff will have increased by upwards of 100 %.

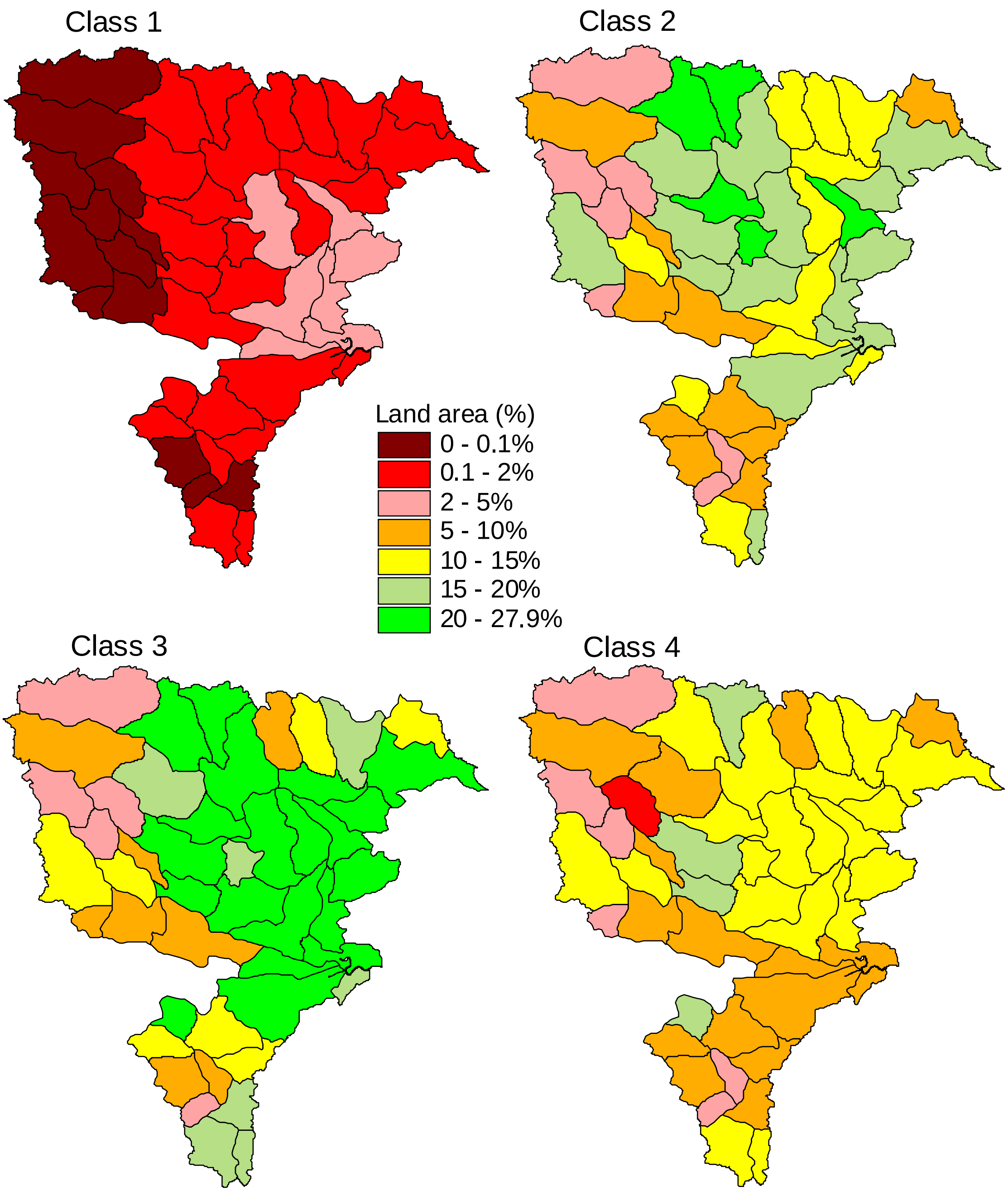


Figure 4.6 Percentage of each Soil Degradation Class within the total area of each sub-catchment of the River Ouse

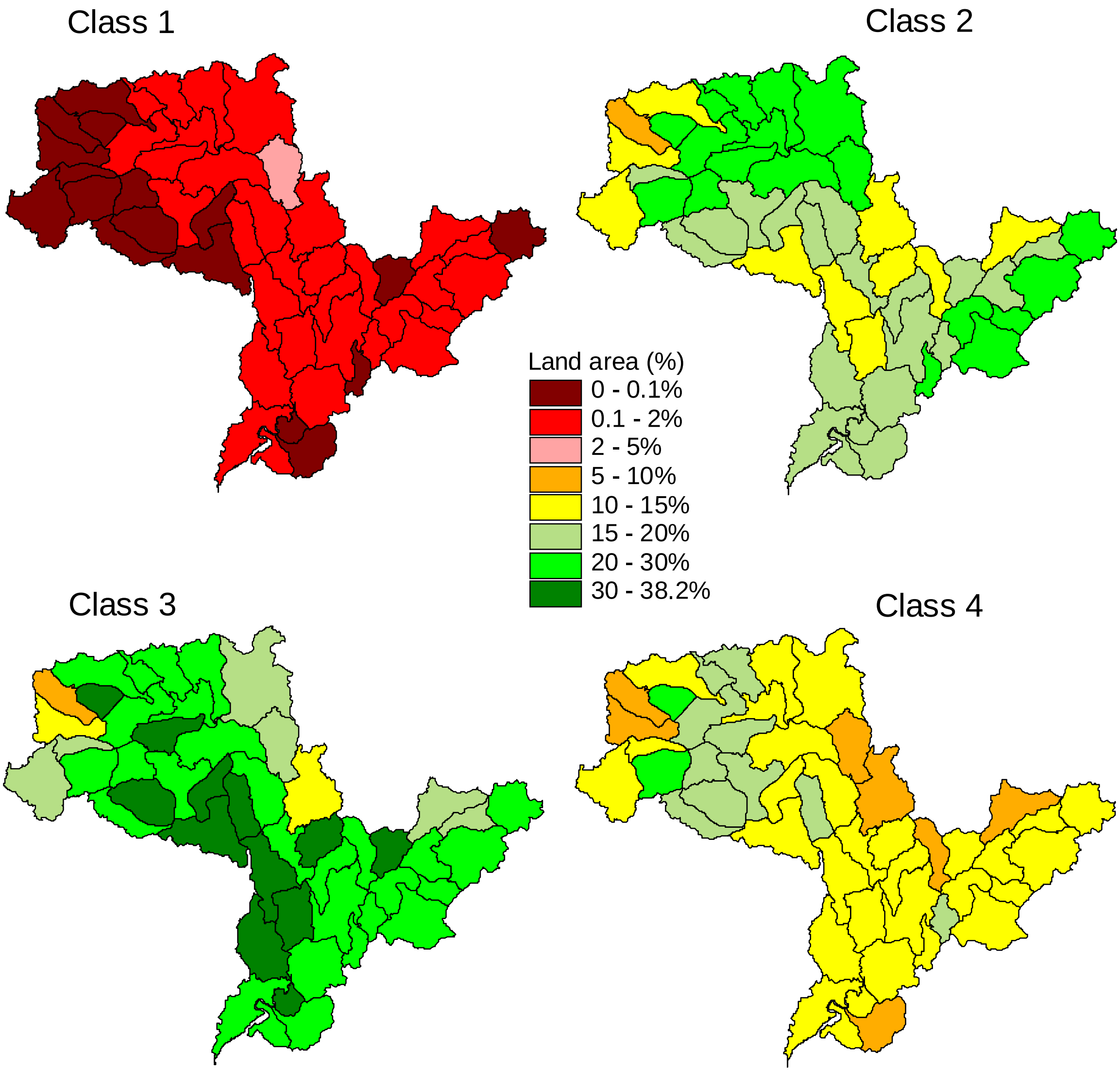


Figure 4.7 Percentage of each Soil Degradation Class within the total area of each sub-catchment of the River Severn

5. CONCLUSIONS AND RECOMMENDATIONS

The field observations undertaken during the months of December 2000 and January 2001, together with the data interpretation and extrapolation exercise described in Section 4 of this report, show the following:

- Enhanced soil degradation associated with a number of agricultural management practices has been identified in all four catchments studied. It occurs on approximately 22 and 30 % of the land in the large Yorkshire Ouse and Severn catchments, respectively, and on approximately 18 and 33 % of land in the small headwater catchments of the Bourne and Uck respectively.
- Severe degradation is mainly associated with late harvested crops such as maize, sugar beet and in the case of autumn 2000, main crop potatoes. In a normal year, maincrop potatoes would be harvested earlier than occurred in 2000, such that the soil degradation observed after harvesting under the wet conditions of 2000 is less likely.
- Extensive degradation occurred on 55 % of inspected sites on late harvested crops, 25 % of sites under grass, autumn sown crops and field vegetables and 10 % of sites under orchards.
- Simple calculations using both a very conservative and less conservative estimate of the percentage increase in HOST-derived standard percentage runoff that may result from the observed enhanced soil degradation, suggest a potential increase of between about 0.5 and 12 % in the total volume of runoff entering each of the rivers from the whole catchment during storm events, although the increase for the Uck may have been greater.

The conclusions from this targeted survey thus suggest that enhanced soil degradation resulting from a number of current cropping and stock management practices could have a significant impact on runoff entering rivers during storm events.

The evidence for enhanced soil degradation that occurs when some current cropping and stock management practices have to be undertaken in less than ideal conditions has been well-demonstrated by this study. However, the linkage of such soil degradation to enhanced runoff to rivers during storm events is less certain. The data interpretation and extrapolation carried out here was a simple desk exercise. Work undertaken by the USDA Soil Conservation Service in developing their Runoff Curve Number approach to field and catchment scale modelling (Rallinson, 1980) has demonstrated that soil and crop management practices can have a significant effect on stream response to rainfall. In this country, plot experiments have indicated the impact on run-off of a range of soil management practices under maize (Martyn *et al*, 2000). However, no measured data exists to establish the connectivity between field-scale runoff and stream response during storm events. It is therefore recommended that DEFRA and the Agency initiate research to investigate the following topics:

- Quantification of the hydrological impact of enhanced soil structural degradation on stream response to storm events, through linked field studies and modelling;
- Field studies to investigate the potential for developing on-farm ‘soft’ engineering solutions that will reduce the immediate impact of field-scale runoff.

It is also recommended that DEFRA and the Agency address the following in collaboration with the other bodies having responsibilities and interests:

- Detailed studies of the impact of selected cropping and management practices on soil structure for different soil types and climatic conditions.
- Field studies to investigate the potential for developing improved cropping and stock management practices that reduce soil degradation.

REFERENCES

Boorman D M, Hollis J M & Lilly A. 1995 *Hydrology of Soil Types: A hydrologically-based classification of the soils or the United Kingdom*. Institute of Hydrology Report No. 126, Wallingford, UK. 137 pp.

Martyn T M., Donaldson G, Clements R O and Lindsay J 2000 *Soil erosion control in maize stubbles.* In Proceedings of Sixth Research Conference, British Grassland Society, 29-30. C2.

Rallinson R E 1980 Origin and evolution of the SCS Runoff Equation. Symposium on Watershed Management. ASCE, New York, N.Y. 912-924.