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ACCELERATED EROSION OF ARABLE SOILS
WITH SPECIAL REFERENCE TO THE WEST MIDLANDS

Thesis submitted for the Degree of Ph.D.
in the University of Keele, 1979
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VOLUME 1

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ABSTRACT

Whilst acknowledging the growing concern about the environmental impact of modern farming on the soil system, there has been little discussion about the natural extension of these problems where cropping takes place on sloping terrain - soil erosion. The widely held belief that accelerated erosion of arable soils rarely occurs in the United Kingdom outside of parts of eastern England affected by wind erosion, is challenged here. Evidence to substantiate the view that soil erosion (splash erosion, sheet, rill and gully erosion) is widespread in lowland Britain and is a cause for concern and action is derived in general from a number of areas in the United Kingdom and in particular from parts of the West Midlands.

On more than six hundred sites in the West Midlands where water erosion was recorded by the writer during 1967-1976, soil compaction and down -slope cultivation lines were identified as major contributory factors in over 95% of cases.

Three 'arable' parishes in east Shropshire are used as a case study where erosion episodes have been monitored by the writer (1967-1976). Of the total arable hectareage of each parish, 17%, 27% and 38% respectively was affected by a combination of wind and water erosion over the stated period. The principal causal factors, notably rainfall, wind, slope, soil

compaction and management practices are examined.

A detailed analysis of daily and hourly rainfall data for key stations provides background information for a special study of soil erosion events during 1967-1969 and 1976.

The principal factors which affect the development of concentrated and unconcentrated surface run-off on arable soils are examined and a tentative classification of erosional forms is proposed.

In the summary a case is made for the introduction of a national organisation to monitor soil erosion and provide guidance on soil conservation measures.

CONTENTS

	<u>Page</u>
<u>Introduction:</u> Outline of the aims and objectives of the study.	1- 4
<u>Chapter 1:</u> Evaluation of research work on soil erosion in the U.S.A., Canada. Application of research findings to the U.K. situation.	5- 33
<u>Chapter 2:</u> Accelerated erosion of arable soils in the U.K.1 Historical and pedological evidence.	34- 56
<u>Chapter 3:</u> Accelerated erosion of arable soils in the U.K.2 The present day pattern of erosion by water and wind.	57- 80
<u>Chapter 4:</u> Analysis of the principal factors affecting the erosion of arable soils by rainfall and raindrop splash in the U.K.	81-118
<u>Chapter 5:</u> A study of the principal factors which influence the development of concentrated and un-concentrated surface run-off on arable soils in the United Kingdom.	119-155
<u>Chapter 6:</u> Analysis of the principal factors affecting the erosion of arable soils by wind in the U.K.	156-182
<u>Chapter 7:</u> Soil erosion in the West Midlands: a qualitative assessment of the distribution and an analysis of the main causal factors.	183-219
<u>Chapter 8:</u> Soil erosion monitoring: a ten-year survey of soil erosion in the east Shropshire parishes of Claverley, Rudge and Worfield.	220-265
<u>Chapter 9:</u> Evaluation of selected field methods used in measuring soil erosion on arable soils.	266-287
<u>Chapter 10:</u> Impact of modern agriculture on the soil system and the increasing hazard of soil erosion. Summary of field evidence: conclusions and recommendations towards a policy of soil conservation in the U.K.	288-311
<u>References:</u>	312-333

LIST OF FIGURES

(Located in Volume 2)

	<u>Page</u>
1. Hedge acting as a trap for drifting sand	1
2. Talud or step along hedgerow running transverse to slope	2
3. Talud in the process of development	3
4. Unconcentrated soil wash and incipient rill erosion	4
5. Base of slope deposition	5
6. Layered hedgerow partially buried by eroded soil	6
7. Deep truncation in sandy loam by confined gully erosion	7
8. Distribution of sandy arable and earthy peat soils liable to erosion	8
9. The relation between kinetic energy of rainfall and intensity	9
10. Transport of soil particles in snow drift (Pattingham 1963)	10
11. Contact areas between tyre and soil for different soil conditions (after Soehne 1958)	11
12. Slope-effect chart (topographic factor LS)	12
13. Loss of structure - severe puddled soil surface	13
14. 'Flash' flooding causing erosion and damage to sugar beet	14
15. Confined rill erosion affecting ground prepared for sugar beet	15
16. Unconfined rill erosion, incipient gully and gully development	16
17. Pattern of gullies, Hilton, east Shropshire	17
18. Confined and unconfined rill erosion affecting winter barley	18
19. Confined rill erosion	19
20. Raindrop splash, splash transport and unconcentrated surface wash along seed-drill furrows	20
21. Confined and unconfined rill erosion	21
22. Confined rill erosion on soils of Newport series	22
23. Detail of tractor wheeling with beet seed-drill roller	23

LIST OF FIGURES continued

	<u>Page</u>
24. Lug pattern on tractor wheel	24
25. Sequence of stages in the erosion of tractor wheeling	25
26. Detail of erosion pattern in tractor wheeling	26
27. Tractor and implement wheelings	27
28. Confined rills and gullies, Hallow	28
29. Unconfined rill erosion affecting Bridgnorth and Wick soils	29
30. Unconfined rill erosion on an experimental plot, Hilton	30
31. Confined and unconfined rill erosion (Salwick and Newport series)	31
32 and	
33. Confined gully erosion (Newport series) Hilton	32
34. Cross sections of confined gully (A) in tractor wheeling	33
35 and	
36. Unconfined gully erosion (Newport series)	34
37. Confined rill, incipient gully and gully erosion (Hallow)	35
38. Confined gully erosion in tractor wheelings (Hallow)	36
39. Confined and unconfined gully erosion (Hilton)	37
40. Incipient rill erosion and concentrated overland flow (Hilton)	38
41. Unconfined rills and incipient gullies in Bridgnorth series	39
42. Unconfined gully erosion, Bridgnorth series (Bonningale)	40
43. Unconfined incipient gullying and gully erosion (Quatford)	41
44. Unconfined trough-like incipient gullies (Rudge series)	42
45. Large overlapping fans of eroded soil (Hilton)	43
46. Accelerated concentrated run-off during the passage of a storm (1)	44

LIST OF FIGURES continued

	<u>Page</u>
47. Accelerated concentrated run-off during the passage of a storm (2)	44
48. Accelerated concentrated run-off during the passage of a storm (3)	44
49. Unconcentrated surface wash	45
50. Deltaic growth of eroded soil in temporary ponded run-off	46
51. Deltaic growth of eroded soil into flooded stream	47
52 and	
53. Large single fan	48
54. Deltaic growth of eroded soil into small pond	49
55. Confined rill erosion on land prepared for sugar beet	50
56. Incipient confined rilling and sedimentation in potato furrows	51
57. Compaction lines in potato furrows	51
58. Erosion of ridge crests running at right angles to wind direction	52
59. Commencement of soil blowing, Worfield	53
60. Wind eroded ridges and infilled furrows	54
61. Cross section of eroding ridge	55
62. Detail of eroded ridge crests	56
63. Detail of ridge crests and furrows	57
64. Ripples in wind blown soil	58
65. Surface creep affecting large exposed field	59
66. Drifted soil against hedgerow	60
67. Gully erosion in the Clee Hills	61
68. Soil association map of the West Midlands	Pocket a
69. Rainfall map of the West Midlands	62
70. Distribution of thunderstorm activity in the U.K.	63, 63a
71. East Shropshire: Location of parishes	64
72. East Shropshire: Parish boundaries	65
73. East Shropshire: Relief and drainage	66

LIST OF FIGURES continued

	<u>Page</u>
74. Rainfall stations, east Shropshire	67
75. Frequency of all falls of 10 mm and greater for Newport	68
76. Agricultural land classification for the three parishes	69
77. Land use capability classification for the three parishes	70
78. Field boundary changes in the three parishes 1967-1976	71
79. Vertical airphoto showing gully erosion	72
80. Oblique airphoto showing gully erosion	73
81. Soil erosion damage by run-off and ponding	74
82. Location of eroded fields in the three parishes	75
83. Frequency of erosion on a field to field basis (three parishes)	76
84. Distribution of eroded fields in relation to relief	77
85. Plot design and layout, Hilton	78
86. Site preparation for calibration plots, Hilton 1978	79
87. 'Badland' topography. Severe active erosion near Nimes, Languedoc	80
88. Confined rill erosion in vineyard near Sommieres, Languedoc	81

LIST OF TABLES

	<u>Page</u>
1. Survey figures of soil deterioration in the U.S.A. (1948)	10
2. Analysis of data on effects of different vegetative cover on erosion	18
3. Present and potential land use (Kentucky soil and water conservation needs)	27
4. Soil loss and corn yields from conventional and no-tillage (Ohio 1964-66)	27
5. Soil loss totals as affected by management systems (Dixon Springs 1969-71)	28
6. Surveyed acreages and their ability to erode (East Midlands)	68
7. Soil series which are liable to blow	72
8. Soil series which occasionally blow	73
9. Number of raindrops of various sizes in nine rainshowers	86
10. Effect of particle size on transport by drop impact	90
11. Estimate of the percentage retention of ⁵⁹ Fe on soil trays	92
12. Major rainfall events of 1968	101
13. Classification of erosion forms	151
14. Sediment model flow chart	152
15. Wind speed in knots, 15-20th March 1968 Eastern England	161
16. Rate of soil flow in a silt loam at different moisture conditions	164
17. Soil particle movement by wind	165
18. The effect of surface roughness on rate of erosion by wind	167
19. Mean values of soil characteristics for eroded and non-eroded sites	172
20. Soil associations with series liable to structural and erosional damage	189-192
21. Soil series in the West Midlands susceptible to erosion	193a
22. Soil series susceptible to loss of structure and capping	193b

LIST OF TABLES (continued)

	<u>Page</u>
23. Analytical data for the Bridgnorth series	195
24. Analytical data for the Bromsgrove series	198
25. Analytical data for the Bromyard series	198
26. Analytical data for the Eardiston series	199
27. Analytical data for the Munslow series	200
28. Analytical data for the Newport series	202
29. Analytical data for the Ross series	204
30. Summary by months of falls of 10 mm or more, Hatton Grange	211
31. Summary by months of falls of 10 mm or more, Newport	213
32. Size of holdings in the parishes of Claverley, Rudge and Worfield	222
33. Total hectarage affected by accelerated erosion (1967-1976)	230
34. Soil series susceptible to erosion in the three parishes	234
35. Distribution of the wettest and driest months 1967-1976 (Newport)	238
36. Soil erosion susceptibility related to crop calendar	240
37. Summary of hourly rainfall for Shawbury 1967	243
38. Calendar of erosion events in the three parishes (1967)	244- 246
39. Summary of hourly rainfall for Shawbury 1968	248
40. Calendar of erosion events in the three parishes (1968)	249- 253
41. Summary of hourly rainfall for Shawbury 1969	256
42. Calendar of erosion events in the three parishes (1969)	257- 260
43. Hourly rainfall for Pershore and Shawbury September 1976	262
44. Provisional classification of soils for continuous cereal direct drilling	
45. Flow diagram of data sources for National Soil Conservation Committee	

Introduction

Research into accelerated erosion* of arable soils by the writer has revealed that the incidence of both wind and water erosion is much more widespread in the West Midlands than is generally accepted. Reference to other parts of the United Kingdom with similar relief, soils and land utilisation to east Shropshire provides further corroborative evidence of erosion. However, although wind erosion is acknowledged as a problem in eastern England there are few references in the literature to the occurrence of soil erosion by water as it is not considered to be a problem on arable soils in lowland Britain. This assumption is challenged by the evidence presented in Chapters 5, 8 and 10 of this study.

The main aim of this thesis has been to monitor and describe erosive events in a selected area over a period of time in order to assess the frequency, distribution, causal effects and impact of erosive events on arable soils. The east Shropshire parishes of Claverley, Rudge and Worfield were chosen for a soil erosion monitoring survey. Each parish has over 60% of its hectareage of crops and grass in arable and a soil and land use survey had been carried out by the writer (M.Sc. Thesis) 1968-1972. The findings of the ten-year monitoring survey 1967-1976 are reported in Chapter 8. The survey shows that out of a total arable hectareage of

* The term accelerated soil erosion is used here to mean erosion which is man induced or accelerated by man through agriculture, in contrast to natural erosion or geologic erosion, which is an important and integral part of the process of soil development.

4097 for the three parishes approximately 32% (1324 ha) has been affected by erosion during the survey period. These data are essentially qualitative and as such do not provide information of soil loss per unit area. They do show, however, that a more accurate assessment can be made of soil erosion hazard in an area and the fact that monitoring surveys of this type have not been reported elsewhere in the United Kingdom helps to explain the continued under-estimation of soil erosion by water in the arable areas of lowland Britain.

In order to obtain a better understanding of the causal factors and effects of soil erosion reference has been made to a wide array of papers, most of which have been published in the U.S.A., and this review forms the subject matter of Chapters 1 and 4.

A field programme of monitoring needs the backing of detailed analysis of daily rainfall records for all available stations within the study area, together with the establishment of a number of automatic rainfall recorders, to provide information on rainfall intensity. This has been effected for a number of key stations in east Shropshire, many of which have over 50 years of daily rainfall records, and computer analysis has been run on this data. The frequency of rainfall events during the station year (a rainfall event = 10 mm or more in a 24 hr. period) has been analysed and this data matched with hourly rainfall values for a number of key stations so that the erosivity of rainfall in this area can be

assessed. It has been observed that rainfalls of 10 mm or more are erosive on fallow or partially covered sandy soils when the rate reaches or exceeds 1 mm per hour. This data is presented in part in Chapters 7 and 8 and is used in a number of case studies for the years 1967-1969 and for September 1976. The selection of the years 1967-1969 has been made to emphasise that soil erosion hazard is not restricted to the occasional 'abnormal' season, which may have a long return period. September 1976 was selected as an example of an abnormal month which was characterised by more than three times the monthly rainfall and by six closely spaced erosive events, each with higher than average rainfall rates per hour which caused widespread and serious erosion.

Despite the large number of eroded sites which have been recorded very little quantitative data on sediment yield is available. In 1976 work commenced on the establishment of fractional-hectare plots on a permanent site within the study area. Reference is made to this in Chapter 9, though the experimentation is not regarded as an integral part of this thesis as it was not envisaged that either the finance or labour would be available to install and manage permanent plots. However the problems encountered in monitoring of this type (i.e. fixed plot studies) are discussed and the advantages and disadvantages of different designs of plots which have been operated by the writer are considered.

Reference has been made by a number of writers to accumulations of 'hill-wash' against hedgerows and walls in lowland Britain

and the time scale for this depositional sequence is considered to be in the order of hundreds of years. This is, perhaps, more accurately described as cultural erosion than the more accelerated forms which have been described here. Toy (1977) considers the rate of erosion normal to an area under a specific set of environmental conditions can be greatly increased should those conditions be altered and modification of these conditions can be a consequence of natural events or man-induced. In either case the term 'accelerated erosion' denotes a positive departure from the norm. Such a departure from the norm in British agriculture is considered to have taken place during the period 1939-1945 when over 2.7 million hectares (6.5 million acres) of new arable land came into existence, a programme which was made possible by a great increase in mechanisation. Since then profound and lasting changes have been effected in the agriculture of lowland Britain, which have had a marked impact on arable soils and on the agricultural landscape.

It is against this background that the case for soil conservation is presented in Chapter 10. Soil conservation measures should be applied before soil erosion manifests itself as a major problem. The present official approach to the problem (vested in the Ministry of Agriculture) is too complacent and stands in marked contrast to the official policy of State and Federal Agencies in the United States of America.

CHAPTER I

1.1 Soil erosion and soil conservation in North America.

1.2 Evaluation of research work in soil erosion in
North America.

1.3 Application of research findings in the U.S.A. to
the United Kingdom situation.

1.1 Soil erosion and soil conservation in North America

'Accelerated soil erosion has posed a latent if not chronic environmental problem ever since agriculture became the dominant mode of subsistence in parts of the old world, almost 10 millennia ago', (Butzer 1974) yet it was to reach its most spectacular proportions in the prairie provinces of the U.S.A. and Canada within a relatively short period of 150 years culminating in the disastrous years of the early 1930's.

It is difficult to comprehend the vast scale of the problem in North America. A nationwide survey made by the Soil Erosion Service in 1934^{*} recorded 20 million hectares (50 million acres) which were ruined for crop production, a figure which is more than twice the total acreage of crops and grass in England and Wales (1958) and 298 million hectares (775 million acres) which had become so severely eroded as to require erosion control measures to ensure continued productivity. According to Butzer (1974) the agricultural soil resources of the United States have been cut by perhaps a half in 150 years, and in some areas such as Oklahoma, a single generation sufficed to destroy almost 30% of the soil mantle.

In the Upper Georgia Piedmont settlement of the bottom lands began between 1780 and 1805 but erosion first became apparent when sloping lands were cleared and was locally accentuated by the impact of plantation agriculture after the 1840's and 1850's. In contrast to the older cotton

* Quoted by Beasley 1972

plantation areas, major erosion was delayed until the 1880's when forest acreage was significantly decreased and row crops, especially cotton, became dominant. By the 1930's, when efforts of the U.S. Soil Conservation Service began to take effect, the impact of man on the soil mantle, hydrography and sedimentation had exceeded that of any natural climatically-induced ruptures of equilibrium experienced in the south-eastern U.S.A., during all Pleistocene times (Butzer 1974).

Stallings (1957) cites extracts from a number of writers in the 1850's, in particular Hardwick, Lee, Sorsby and Ruffin, who recognised rainfall run-off as a menace and who realised that the up-down hill method of cultivation then in general use was leading to the destruction of farm land. They strongly recommended conservation measures of terracing, contour cultivation and deep ploughing in an attempt to stabilize soils on sloping sites and the planting of hedges and shelter belts where wind erosion was a problem.

Other writers like Pendleton realised that soils stood up against the forces of erosion better when crop rotation was used than when fields were cropped continuously and Agricole and Kefauver* noticed that the use of straw mulches encouraged the germination rate and establishment of newly seeded wheat and clover. It was acknowledged that terracing was only a partial remedy as soil wash continued even after the field was terraced. However, a clearly defined national policy had been outlined by the Department of Agriculture in

* Quoted by Stallings 1957

a report (1907) which stated that 'erosion is due directly to the run-off of water of which the ratio is dependent partly on slope, but chiefly on the nature of the soil and its produce; indeed, with any reasonable slope, a full cover of forest or grass with an abundant mulch, or close crop on deeply broken soil, or a friable furrow slice kept loose by suitable cultivation, will so fully absorb precipitation as to curtail run-off or even to reduce it to slow seepage through the surface soil . . . the ideal, and the one toward which modern agriculture should be bent . . .'

The Reconnaissance Erosion Survey which was carried out by the United States Department of Agriculture's Soil Erosion Service in 1934 recorded all occurrences of erosion on 1:62,500 maps and published State maps at the scale of 1:500,000. A vast card file of historical references to soil erosion was collated and deposited in the National Archives Washington. The Soil Conservation Service, as it is now called, recorded all eroded land or land currently eroding or subject to erosion and this amounted to an impressive 82.9% of the total land in farms. In 1936 the Great Plains Committee concluded that 'there is no evidence that in historical times there was ever a severe drought to destroy the grass roots and cause erosion comparable to that which took place in 1934 and 1936; that phenomenon is chargeable to the ploughing and overcropping of comparatively recent years'. An estimated 40,469,444 hectares (100,000,000 acres) are affected by wind erosion in the U.S.A., of which

approximately 10% are seriously affected. In the Great Plains there were thirteen periods between 1854 and 1964 when major dust storms occurred, with the worst periods in 1936-1937 when 120 storms were reported at Dodge City, Kansas and again in 1955-1956 when there were 40 storms reported at this location. Since 1956 no major storms have occurred, though on average 2.7 million acres (1.1 million hectares) per year have been damaged by wind erosion during this period (Beasley 1972).

For some states, for example Arkansas, Oklahoma, Louisiana and Texas, a detailed erosion survey published by the Soil Conservation Service in 1948 ranked erosion into five classes of increasing severity; 1 - medium to slight, 2 - medium, 3 - medium to severe, 4 - severe, 5 - very severe. One class, for example, medium to slight erosion, was defined as resulting from the removal of less than 25% of topsoil or soil accumulations 0 - 15 cm high (0 - 6"). The medium erosion class was defined as the removal of less than 25% of topsoil with occasional crossable gullies more than 30 metres apart, or removal of 25 - 75% of topsoil with no gully erosion, or removal of 25 - 50% of topsoil by wind, or soil accumulations 15 - 30 cm high caused by wind. Their findings indicated that some 49% of cultivated land, 38% pasture and 20% of woodland fell into erosion rankings 2 - 5.

In the same year 1948, the Soil Conservation Service published survey figures of soil deterioration on 183 million hectares (451 million acres) of cropland and ley grass. This data

is summarised in Table 1. below.

Table 1. Survey figures of soil deterioration on 183 million hectares of agricultural land in the U.S.A. (1948)

Degree of deterioration	Number of years at current rate (1948) in which the land would be degraded one capability class if no remedial measures taken	Millions of hectares
Critical	10 - 15	46
Serious	15 - 30	48
Slight to none	30 and over	88

Stallings (1957) emphasises the fact that it should not be inferred from these estimates that during the base period (1942-51) soil deterioration was occurring on the entire hectarage of cropland, as millions of hectares in the slight to none category were being maintained and even improved through the application of sound soil management, including soil conservation. During the period 1945-1951 the Corn Belt suffered the greatest annual soil loss largely because of the adoption of the monocultural practice of continuous corn growing on long unbroken slopes. For the United States at large, recent Soil Conservation Service estimates indicate that about 80% of soil erosion losses have occurred in the area east of the 100°W meridian (Stallings 1957).

Although great strides have been made in combating erosion by the adoption of soil conservation measures, many of which

were pioneered in North America, the problem still remains a serious one. In 1965 the United States Department of Agriculture's inventory of soil and water conservation needs indicated that conservation measures were required on more than 60% of the cropland (112 million hectares - 267.9 million acres) to reduce erosion losses to an acceptable minimum. This publication also shows that susceptibility to soil erosion is the most widespread conservation problem limiting the land capability. Beasley (1972) concluded that the results of national surveys indicate that there has been slight progress in soil erosion control on land used for crop production during the past thirty years, though soil erosion on sloping land is still a major problem.

Comparable problems are found in Canada but not to the same degree for the ground remains frozen* during the winter and rainfall totals are generally lower during the spring and summer than those in southern and eastern U.S.A. Wind erosion occurred on the prairies of western Canada soon after the land was brought under cultivation and frequent outbreaks led to the adoption of strip cropping in southern Alberta around 1918. Severe and widespread drifting occurred during the period from 1931 to 1938 and was widespread in the provinces of Alberta, Saskatchewan and Manitoba. Despite the adoption of conservation measures, soil drifting has occurred intermittently since that time and the drought

* However, conservation measures are necessary to protect exposed soils against wind erosion even when the ground is frozen.

during the late 1950's and early sixties was accompanied by many isolated outbreaks in the prairies with severe erosion on some farms. Research in western Canada has revealed that the sorting action of the drifting process removed up to one half of the silt and one third of the clay from some sandy soils. Losses of about one fifth of the silt and smaller quantities of clay particles were recorded on severely eroded medium textured soils whereas heavy clay soils were least affected by sorting action. Reduced moisture-holding capacity of the cultivated layer resulted from the loss of the silt and clay particles, and the soil was more easily eroded (Canada Department of Agriculture 1966).

In western Canada Albright (1939) reported that 'though the black cloud of soil drifting has reappeared this year in the Peace River country (Alberta), water erosion has been much the more general evil to date and may still in the long run prove the more difficult to control'. He was convinced that an unrecognised degree of damage occurred in many other parts of the west and quotes Neatby and McCalla's statement that 'soil losses due to wind and water erosion are becoming increasingly apparent and will continue to do so unless a carefully planned system of cropping is adopted'. According to Albright the menace of water erosion in the Peace River District first came prominently to the settlers' attention in 1917 when a foot of slushy snow fell in the middle of May and disappeared during a rapid thaw. Gashes a foot deep were cut down many a sloping field.

'Gutters were filled in by subsequent tillage operations but washes occurring in subsequent years rescoured and deepened these, besides forming many new ditches, until thousands of fields have been lined with rock-strewn, grey depressions where crops grow poorly, where implements are passed across with difficulty, and where in some cases neither teams nor tractors can cross at all'. It can be surmised from Albright's account that the grey depressions referred to represent areas of soil truncation with the Ea horizon of the podzolised soils being exposed as the average depth of top soil is quoted as no more than 5-6 inches (12.5 - 15 cm). He also states that the soils 'puddle into a soupy condition when wet and bake hard when dry' - the symptoms of severe loss of structure usually associated with soils with high silt and fine sand content (though no mention is made of soil texture in the paper). Albright considered that it would not be surprising to find that some of the older fields of the Peace River country (74 million acre drainage basin) have already, in less than a generation, lost 30% of their topsoil by erosion.

'In Canada there has been water erosion with flooding in every province within the memory of the present generation' (Ripley et al 1961)*. Clark (1942) refers to evidence which points to considerable erosion of soils on Prince Edward Island during the period 1871 and 1928. A survey in 1871 referred to the ordinary soil of the island being a bright red loam passing into a stiff clay on the one hand and a sandy loam on the other, whereas another survey in 1928

* See Canada Department of Agriculture, Soil Erosion by Water (1961)

classified all the soils as sandy or fine sandy loams with only two or three containing sufficient silt or clay to class them as loams. A survey in 1910 at the Charlottetown Experimental Station was made for drainage purposes and resurveyed in 1939. On checking back from the bench marks the loss from areas with 10% slope was about 6 inches (15 cm) while on the lower areas a gain of 4 inches (10 cm) of soil was recorded.

There are many points of similarity between the soils and land use of Prince Edward Island and those of east Shropshire. Both areas have soils derived from the drift of Triassic Sandstones and marls. The landscape rarely exceeds 400 ft. above sea level (122 metres) (ridges of harder beds of sandstone) with gently undulating hills with broad valleys. Precipitation is higher in Prince Edward Island (1092 mm) than in parts of east Shropshire (700 mm) but no data are available for high intensity rainfall. It is interesting to note that sandy loam soils (Oka sandy loam) are considered to be the least susceptible to erosion when compared with high risk and clay loam soils (Rideau Clay and Chateauguay clay loam).

Severe erosion has taken place in the Aroostook potato growing district of Maine, U.S.A. where Bennett (1941) refers to 89,033 hectares (220,000 acres) of ideal potato soil known as the Caribou loam. He quotes an example of a field which 32 years ago had a combined soil and sub-soil depth of at least 2 feet (61 cm) which during that period

had lost all the topsoil - 'more than a foot of soil and subsoil amounting to 32,000,000 lb. per acre had been unnecessarily wasted in this field by 'vertical farming' (the use of up-down slope cultivation techniques for growing potatoes).

1.2 Evaluation of research work in soil erosion in North America

At the time that America experienced the worst effects of the Dust Bowl, the influence of climate, topography, soil and vegetation on run-off and erosion had been well established. Research since then has concentrated on measuring the influence of rainfall intensity, wind velocity and a number of other important parameters on run-off and erosion. The importance of soil cover by vegetation or crop residues in reducing or eliminating erosion by rainfall and run-off was first demonstrated by S. Wollny in Germany in the 1880's, who used microplots (80 cm² x 5 cm) to study the relationship of erosion to density of crop cover, soil type, steepness and aspect of slope under natural and simulated rainfall. Lowdermilk (1930) emphasised the importance of forest litter in protecting the soil surface and preventing excessive run-off and erosion, but the ways in which these processes were effected were not fully understood for many years. Early experiments by Wollny, Lowdermilk, Miller and Hendrickson are reviewed by Stallings (1957). This work in turn highlighted the importance of raindrop impact and splash erosion on exposed soils. Ellison (1944) was the first to demonstrate that a falling raindrop was an erosive agent

in its own right and his work, together with Yoshiaki Mihara (1952) was confirmed by Free (1952) and Ekern (1953).

Erosion research in the United States began in 1917 with the establishment of plots for study of the effect of soils, slope and crops on run-off and erosion by Professor M.F. Miller of the University of Missouri. Similar work was started between 1929 and 1933 by H.H. Bennett and L.A. Jones of the U.S. Department of Agriculture and resulted in the establishment of ten Federal State experimental stations in the more critical erosion areas of the United States (Smith and Wischmeier 1962). Apart from these stations work was carried out on eighteen additional soils during the next decade and plots were used to measure run-off and sediment yield from natural and simulated rainfall under a range of management practices.

In 1940 Zingg's paper on the degree and length of land slope as it affects soil loss in run-off broke new ground in that it contained the first rational equation to give a relationship between total soil loss, degree of slope and horizontal length of slope which was applicable to field conditions. He concluded that soil loss varies as the 1.4 power of the degree of slope, as the 1.6 power of slope length, and the loss per unit area as the 0.6 power. This method of calculating field soil loss was referred to as the factor system with an empirical rather than a theoretical approach. This was applied by Smith (1941) who defined the concept of a permissible soil loss, and made the first evaluation of a crop factor and a factor allowing for different degrees

of mechanical protection. Browning et al (1947) described a method for determining the use and limitation of rotation and conservation practices in the control of soil erosion in Iowa.

The Corn Belt factor values, as they were known, were reappraised in 1946 by a nationwide committee on soil loss prediction and a new formula was designed which became known as the Musgrave equation or the slope practice equation. A first approximation of this equation was published in 1947 (Musgrave) in which the relationships between major causal factors and the resulting rate of erosion were examined. The four primary factors which influenced the rate of erosion were considered to be: 1, rainfall, characterised particularly by intensity and amount in their determination of the energy of impact; 2, flow characteristics of surface run-off particularly as affected by (a) slope gradient and (b) slope length; 3, soil characteristics, particularly those physical properties which affect erodibility; and 4, vegetal cover, characterised by comparative densities and protective effects. 'The quantitative evaluation of these major causal factors has been attempted with the clear recognition that in the present state of our knowledge only a first approximation of precise values is feasible' (Musgrave p.134).

A quantitative evaluation of rainfall had been advanced by Hays et al (1936) who showed that erosion at the La Crosse, Wisconsin Station, was correlated with the maximum amount of rainfall occurring within any 30 minute period. Accordingly, as a

first approximation the relationship of rainfall to erosion, E was found to be $E \propto P_{30}^{1.75}$. The most common relationship between degree of slope and amount of erosion per unit area was found to be $E \propto S^{1.35}$, where E is erosion in tons per acre of dry soil and S is the slope in feet per hundred. The best relationship for length of slope (L) with data then available was found to be $E \propto L^{1.37}$ which when equated to a basis of Unit area (tons per acre) became $E \propto L^{0.37}$, and subsequently $L^{0.35}$. These values were later modified when adapted to a new soil loss equation. An analysis of data on the effects of different vegetative cover upon erosion was given as follows in Table 2.

Table 2 Analysis of data on the effects of different vegetative cover upon erosion

Crop	Relative Erosion
Continuous row crops (principally cotton, corn, tobacco <u>UNCONTOURED</u>)	100
Small grains (wheat, oats, barley, rye)	15-40
Hay, pasture, woodland and forests less than	1

Continuous row crops which are contoured would have a relative erosion effect between 50 and 100% of that of the corresponding non-contoured row crop. Numerical values for the relative erodibility of soils presented a problem since this factor could not be readily expressed by a single numeral so recourse was made to the measured rates of erosion on different soils using data from all places where experiments had been conducted for 5 or more years. This data was

used to derive the equation:

$$E \text{ (erosion)} = T \text{ (soil type)} \times S \text{ (slope)} \times L \text{ (length of slope)} \times P \text{ (management practice)} \times M \text{ (mechanical protection)} \times R \text{ (rainfall)}.$$

Smith and Wischmeier (1962) reviewed the progress of work on soil loss prediction which culminated in the universal soil loss equation. A run-off and soil loss data laboratory was established at Lafayette, Indiana in 1953 by the Soil and Water Conservation Research Division (Agricultural Research Service U.S. Dept. of Agriculture) in co-operation with Purdue University. Approximately 8,000 plot years of basic run-off, soil loss and associated precipitation and related data from 37 widely scattered Federal-State research projects in 21 states was assembled at Lafayette. These data were obtained from standard field plots selected for uniformity of soil and slope. These plots have been used as a basic tool in erosion research and have varied in size from fractional acre plots up to 2 acre plots. In the United States the 'standard' plots measured 6 feet x 72.5 feet (approx. 2 x 22 metres) covering 0.01 acre (0.004 hectares). Further consideration of plot design, function and reliability will be given in Chapter 9.

Van Doren and Bartelli (1956) developed a method for determining soil loss from various soils in Illinois under different management and conservation programmes. Soil losses could be estimated by using the following erosion equation,

$$A = F(T, S, L, P, K, I, E, R, M)$$

where A = annual estimated soil loss in tons per acre.

T = tons per acre of measured soil loss from soil

type (considered unity) of given slope, with known conservation practices and cropping pattern.

S = steepness of slope.

L = length of slope.

P = practice effectiveness (appropriate factor expressing effectiveness of the particular supporting practice or practices under consideration in solving for A above).

K = soil erodibility (may include some adjustment for rainfall).

I = intensity and frequency of 30 mm rainfall.

(It was combined with the soil factor K in assigning erodibility factors for the various soil groups within Illinois).

E = previous erosion (expresses effect of influence on current erosion or influence on yields or physical condition of rooting zone).

R = rotation effectiveness.

M = management.

Values for (T, S, L, P) and (K, I, E, R, M) were combined in separate tables.

Wischmeier and Smith (1961) published an improved soil loss prediction equation which overcame many of the limitations of former equations. It was designed to be geographically universal in applicability and to provide major improvements in localised soil loss prediction with minimum changes in basic concepts and the application procedures which had been developed in the 1950's. Two significant improvements introduced by Wischmeier were the rainfall-erosion index (1959)

and the method of evaluating the cropping-management factor on the basis of local climatic and crop cultural conditions (1960). In the first paper investigations to determine which characteristics of rainstorms significantly influence erosion losses were described and this was approached through multiple regression analyses. The rainstorm characteristic found to be outstanding as such an indicator is the variable whose value is the product of the rainfall energy and maximum 30-minute intensity of the storm (designated as EI). It was found that this variable explained from 72-97% of the variation in individual storm erosion from tilled continuous fallow on 6 soils. Seasonal rainfall erosion index values computed by adding the EI values of storms 0.5 inch (12.7 mm) explained as high as 94% of the yearly deviation in total soil loss from fallow during the summer season.

The Universal Soil Loss Equation as it is now known differed from its predecessors in the manner and precision with which locational differences in rainfall are brought into the soil-loss computations (Wischmeier and Smith 1965). For example the Musgrave equation assumed that the erosivity of annual rainfall varied as the 1.75 power of the 2-year maximum 30 minute rainfall which was based on limited data taken in Wisconsin in the 1930's. Subsequent research did not support the accuracy of this term and its use as a rainfall factor allowed no consideration of effects of locational differences in the number of erosive rainstorms and in their expected distribution within the year (Wischmeier 1962). In the second paper (1960) Wischmeier

compared the results from experimental stations on different soils and this extended the range of soil erodibility values which were now remodelled on a new scale. Further, the single value for the crop factor which was used in the Musgrave equation to give an average effect over the whole season was broadened to allow for inter-relations between crop management practices and climate throughout the growing season and harvest period. These refinements allowed each of the six major variables which influence soil erosion to be isolated and defined numerically so that when these values are multiplied together they give the total amount of eroded soil in tons per acre. The soil loss equation is presented in the form:

$$A = R.K.L.S.C.P.$$

where A is the computed soil loss per unit area (tons per acre) from a specific field under a specific rainfall pattern, cropping management plan and applied conservation practice.

R, the rainfall factor or rainfall erosivity index, a number which indicates the erosivity of the rain on a scale based on the EI_{30} index. The erosion index is a measure of the erosive force of a specific rain.

K, the soil erodibility factor - a number which reflects the liability of a soil type to erosion in cultivated continuous fallow on a 9% slope 72.6 feet long (22.6 metres).

L, the slope length factor, is the ratio of soil loss from the field slope length, to that from a 72.6 foot (22.6 metres) on the same soil type and gradient.

S, the slope-gradient factor, is the ratio of soil loss from the field gradient to that from a 9% slope.

C, the cropping-management factor, is the ratio of soil loss from a field with specified cropping and management to that from the fallow condition on which the factor K is evaluated.

P, the erosion control practice factor, is the ratio of soil loss with contouring, strip cropping, or terracing to that with straight-row farming, up and down slope.

Discussion of each of the six primary factors R, K, S, L, C, P will be dealt with in Chapter 4.

The main purpose of the universal soil-loss equation is to provide specific and reliable guidance to help select suitable soil and water practices for cultivated land. It can also be used to compute the total annual soil loss from sheet and rill erosion within a particular watershed where agricultural land is a major sediment source. Wischmeier (1976) enumerates the following designed uses of the equation:

1. Prediction of average annual soil movement from a given site under specified land use and management conditions and
2. Guiding the selection of conservation practices for specific sites. The product of factors R, K, L and S for a given site determines the basic soil loss index for that site.
3. Estimating the reduction in soil loss attainable from various changes that a farmer might make in his cropping system or cultural practices.
4. Determining how much more intensively a given field could be safely cropped if contoured, terraced or strip cropped.

5. Determining the maximum slope length on which a given cropping and management system can be tolerated in a field.
6. Providing local soil loss data for soil conservation service technicians and others to use when discussing erosion control needs and conservation plans with farmers or contractors. This enables the farmer to know how much soil he is losing by erosion and how much he could reduce the loss using other practices.
7. Estimating soil losses from construction, rangeland, woodland and recreational areas.

The equation was designed primarily to predict soil loss from sheet and rill erosion on agricultural land. The soil loss predicted by the equation is that soil moved off the particular slope segment represented by the selected topographic factor and this must be distinguished from field sediment yield, some of which may be re-deposited within the field as this deposition is not accounted for in the equation (Wischmeier 1976). It must be recognised, however, that the soil losses computed by the equation are the best available estimates rather than absolute data. The prediction accuracy of the equation was checked against 2,300 plot-years of soil loss data from 189 field plots at widely scattered locations. When its factors are evaluated from the tables and charts the equation predicts the average annual loss for a 22-year rainfall cycle (Wischmeier 1976).

In 1971 Wischmeier, Johnson and Cross introduced a soil erodibility nomograph which greatly improved the applicability

of the universal soil loss equation. They introduced a new soil particle size parameter, M (product of silt % and sand-silt %), which was used to derive a convenient erodibility equation that is valid for exposed sub-soils as well as farmland. The five soil parameters (silt %, sand %, organic matter content, structure and permeability) needed to read numerical soil-erodibility values directly from the nomograph can be obtained from routine laboratory determinations and standard soil profile descriptions and obviate the necessity for actual soil-loss measurements from plots. The factor interrelations graphically combined in the soil-erodibility nomograph were derived by statistical analyses of the 55 K values obtained with simulated rainfall. Similar soil property data were subsequently obtained for 13 bench-mark soils for which K values had been established in long-term natural rain plot studies and these were used to check the accuracy and validity of the nomograph (Wischmeier et al 1971). This new technique for computing soil erodibility has greatly facilitated evaluation of the erodibility factor for hundreds of agricultural soils throughout the U.S.A. and can be of great value in planning sediment control measures for construction sites and open cast mining.

The importance of sediment control measures for construction sites was emphasised by Thompson 1970, who found that in the Detroit Metropolitan area in 1968, 2.1% of an arbitrarily delineated urban zone was under development and this zone produced approximately the same amount of eroded material as the remaining 97.9% of the area. Erosion from the developing areas averaged 69 tons per acre per year (28 tons

per hectare) and an overall/average erosion rate for south-east Michigan of 2.6 tons per acre per year (1 ton per hectare).

One of the most promising soil conservation developments in the last decade has been the no-tillage method of crop production which Young (1973) estimates is now used to produce some 2 million hectares*of crops (mostly grains) in the United States. Young lists the physical advantages of no-tillage as including reduction of wind and water erosion; conservation of soil moisture, especially in times of inadequate rainfall, or in drier areas; and maintenance and improvement of soil structure. He considers the economic advantages of the system include increases in grain yields, lower equipment investment and farm production costs, increased farming profits, more intensive land use, adoption and use of certain crops over wider areas, new cropping combinations made possible on many farms previously limited to less diversity of cropping because of erosion risks, and reduction of certain weather risks. The most significant factor pertinent to the theme of this chapter is the new and profitable opportunity to grow high value row crops on land previously considered as usable only for pasture or hay, because of wind or water erosion hazards. McClure, Phillips and Heron (1968) quote data from a study of no-tillage cropping practices in Kentucky (see Table 3).

* Estimate for 1978 is 3.2 million ha (Lessiter 1978).

Table 3 Present and potential land use, based on Kentucky soil and water conservation needs

Land Class	Crop Type	Present use with conventional tillage '000 ha ('000 acres)	Potential use with no-tillage '000 ha ('000 acres)
I and II	Row crops	697 (1,723)	1,763 (4,357)
III	Small grains	97 (240)	585 (1,446)
IV	Hay and pasture in crop rotations	376 (929)	2,250 (5,559)
V and VI	Permanent non-rotational hay and pasture	2,171 (5,365)	1,986 (4,909)

Another example of the erosion-reducing effects of no-tillage quoted by Young (1973) was derived from the work of Harrold, Triplett and Youker (1967) in Ohio, which is summarised in Table 4.

Table 4 Soil loss and corn yields from conventional tillage and no-tillage watersheds with 5% slopes 1964-1966

Year	Soil loss (Kg/ha) Conventional Tillage	No Tillage	Corn Yield Conventional Tillage q/ha (bu/acre)	No Tillage q/ha (bu/acre)
1964	6 382	132	60 (95)	85 (136)
1965	145	0	66 (106)	66 (106)
1966	0	0	61 (97)	73 (117)

Gard and McKibbin (1973) report the results of three year soil loss from no-till and conventionally managed plots on Grantsburg silt loam at Dixon Springs Agricultural Centre, Illinois (Table 5). These figures clearly illustrate the value of the no-till system in soil conservation.

Table 5 Three year soil loss totals as affected by three management systems Dixon Springs 1969-1971

Management	Soil loss (t/ha) Three-year total		Approx. number of years to erode to plough depth (17 cm)	
	(9% slope)	(5% slope)	9% slope	
			5% slope	3% slope
Conventional double-cropped wheat and maize	64.5	22.8	100	300
No-till double cropped wheat and maize	3.8	2.6	1,700	2,600
No-till continuous maize	2.8	1.9	2,400	3,300

It is hoped that this system will help to improve the large areas of dense fragipan soils as attempts to produce fertile drought resistant soils from this material have proved slow and expensive by conventional tillage methods and have only been partially successful.

1.3 Application of research findings in the U.S.A. to the United Kingdom situation

A major question which arises concerns the applicability of American research data on soil erosion and soil conserva-

tion practices to the United Kingdom situation. How far is it valid to extrapolate this data, even allowing for the dangers inherent in such an exercise, in an attempt to solve erosion problems in the United Kingdom? In a general sense a range of well-tried American conservation measures can be immediately applied. For example, the practice of up and down ploughing and cultivation is considered to be the worst erosion situation that can occur and data for continuous row crops planted and cultivated in this manner show the greatest potential and actual erosion risk. Likewise, clean cultivated fallow exposed on sloping terrain is very prone to erosion by water and is liable to damage by wind on both sloping and flat sites. Although not emphasised to such an extent in American work, the presence of tractor and implement wheelings which run parallel to field slope is another potential erosion situation which can and should be avoided. Other obvious data applications relate to slope factors of degree, length and shape. Zingg's work (1940) demonstrated that doubling the degree of slope increased the total soil loss 2.61 times whereas doubling the horizontal length of slope increased the total loss 3.03 times. Despite all the data available even from the early slope practice equation there has been a widespread tendency to increase slope length in many of our arable areas by field amalgamation - a practice which has been encouraged and even subsidised by the Ministry of Agriculture. Much research effort has been expended in the U.S.A. on emphasising the importance of crop cover and mulches in combating the erosive impact of falling raindrops yet in

many parts of the United Kingdom susceptible soils, notably sands and silts, are left exposed for longer periods than necessary, particularly during winter months and this results in the widespread incidence of loss of structure, particularly in arable soils which are continuously cropped and have low levels of organic matter.

Research into the role of soil organic matter in the maintenance of soil structure and soil fertility has proceeded on both sides of the Atlantic and although there is a broad measure of agreement on the importance of its role, economic factors have tended to override the principles of sound farming practice with monocultural practices and continuous arable cropping becoming more important in recent decades. The ever increasing dependence in the western agricultural world on mechanisation has exerted its own pressures on the land literally through the increased trafficking of machinery which in turn has caused widespread problems of soil compaction, and through the need to produce larger field units. The increased weight and power of tractor units, together with the growing importance of contract farming has led to the temptation of untimely cultivations and the forcing of tilths, particularly during adverse weather conditions. Many of these factors act to influence soil erosion both individually and together and further consideration will be given to them in Chapters 5, 7 and 10.

The American soil loss equation is considered to have a number of disadvantages which make its applicability to problem

solving in other areas difficult. Firstly, the factors used in the equation are derived directly from soil loss measurements based on field plots for a number of benchmark soils. No such plot experiments have been carried out in the United Kingdom and apart from the expense of running them they need to function for a minimum period of ten years and preferably 30 years before a reasonable estimate of mean soil loss can be obtained. Even so, such an expensive and time consuming operation could eventually be rendered obsolete by the widespread adoption of new practices such as direct drilling (no-tillage) which has proved to be the most important single soil conservation measure.

One possible approach might be the selection of an area in the United States where the soils and rainfall are broadly similar to a region in the United Kingdom and attempts to extrapolate data for each of the six main factors used in computing the soil loss equation (R.K.S.L.C.P.). In conjunction with this a number of bench mark soils would be selected for plot studies which would initially record runoff and sediment yield under continuous fallow on slopes of variable degree, length and aspect. These experiments would provide tentative values for bench mark soils for R.K.S.L.C.P. The wealth of rainfall data available in the United Kingdom would enable the rainfall erosivity factor R to be calculated for areas selected for bench mark soil plot studies. Wischmeier (1962) selects two sets of data which can be derived from rainfall records; the one involves geographical differences in the ability of the average annual

rainfall to cause erosion, and the other involves locational differences in the distribution of erosive rainstorms within the year. Both of these greatly influence the selection of optimum erosion control measures on a particular field and specific data on both are needed for widespread use of the universal soil loss equation. Further consideration is given to deriving the factor R in Chapter 4.

A first approximation for K, the soil erodibility factor, could be obtained from plot studies. The soils selected should be representative of soil series which are widespread in lowland Britain and which are classed as good arable soils. For many such soils there is available Soil Survey data which provides detailed information on profile characteristics and general soil capability for agriculture. Although the United States Department of Agriculture publishes K values for hundreds of soil types these stem from actual measurements on some twenty-three soils. The extrapolation of this data to other soils is done largely through the judgement of experienced field workers. Data for two other factors, Slope S, and Slope length L, can be derived initially from prepared tables used in the United States and then tested against data derived from pilot plot studies. In the United Kingdom although there is a wealth of data on crop management it is essentially qualitative when considered in the light of its effects on soil loss. In the U.S.A. about 10,000 plot years of run-off and soil loss data from 47 research stations in 24 states were analysed to obtain empirical measurements of the effects of cropping system and management on soil loss within each crop stage period

(Wischmeier and Smith 1965). The writer has attempted to relate periods of erosion susceptibility in east Shropshire to those periods when crop or management practice provides the least protection (see Chapter 8). Again, with the conservation practice factor P, there is no quantitative data available in the United Kingdom though qualitative statements can be made to support the adoption of a number of practices which heighten or reduce erosion risk and these will be referred to subsequently in Chapters 8 and 10.

In the United States the tolerable soil loss A, has a range of values of 2 - 11 tons per hectare. Adopting a tolerable soil loss for arable soils in lowland Britain a value of 2 - 3 tons per hectare for unstable sandy/silty soils with shallow profiles and 5 - 6 tons/hectare for 'stable' soils - loam clay loam, clay with deeper profiles could be proposed as a first approximation for water erosion.

Chapter 2

2 Accelerated erosion of arable soils in the United Kingdom 1:
Historical and Pedological evidence

2.1 Introduction: Evidence in the agricultural landscape
of accelerated soil erosion.

2.2 Historical evidence.

2.3 Pedological evidence.

2.1 Introduction: Evidence in the agricultural landscape of accelerated erosion

'The History of Agriculture is not only to be found in books, it is written for all to see over much of our countryside.' Franklin (1948).

In this section field evidence is examined which points to accelerated erosion of soils in areas of rolling or gently sloping terrain characterised by a tradition of arable agriculture. In some cases the fields which are being investigated are over 900 years old whereas others only date from the early 19th century. The dominant process involved is soil wash (or hill wash) which is brought about by exposure of fallow soil to splash erosion, which in turn leads to soil detachment and soil entrainment when rainfall exceeds the infiltration rate of the soil. These processes result in soil being eroded from the steeper sections of slopes and this in turn leads to changes in soil depth and type. Material which is transported down slope is usually deposited as an overwash which is trapped against hedges, fences and walls, or where the slope decreases.

Both of these processes can bring about significant soil changes and can result in a shift of a soil from one series to another either by truncation on shedding sites or by the deposition of overwash on receiving sites.

If the rate of erosion is slow, pedogenic processes may keep pace so that no apparent modification can be detected in the soil profile particularly in soils lacking clear horizon

differentiation. In some areas with a long tradition of arable agriculture the presence of taluds may be the only visible sign of the occurrence of soil erosion (the term talud is explained in Section 2.2 below).

Although water erosion has the dominant role there is evidence that wind erosion can play a part in accentuating field boundaries in some areas depending upon the orientation of the hedge to dominant and prevailing winds (see Figure 1 Page 1)*.

These changes in the agricultural landscape can be conveniently examined under the broad headings of historical and pedological evidence, though in reality they are inseparable.

2.2 Historical evidence

Recourse is made to historical evidence wherever this is available in an attempt to obtain broad age groupings for enclosed land. In approaching this problem it has been necessary to restrict attention to the area of east Shropshire where detailed field work has been carried out. This section is not intended to be a comprehensive survey of historical evidence as this would constitute a thesis in its own right, rather it aims to highlight the importance of analysing historical data which is of value in tabulating the types of crops grown, crop rotations and periods of

* The page numbers refer to Volume 2 which contains all of the figures.

expansion and contraction in agriculture, all of which can be of significance in evaluating the impact of agriculture on the soil system through time. Using historical evidence it is possible to identify two broad groups of fields namely those which were enclosed at an early date and those which were enclosed by Acts of Parliament in the early part of the 19th century. Field evidence points to another category which is characterised by fields which have undergone modification particularly in the post-war period as a result of field and farm amalgamation. These changes invariably involve fields in both of the groups referred to above but most of the changes have affected old enclosed fields which are usually smaller and irregular in shape and thus present the most problems to mechanised agriculture.

A distinctive feature of some old arable land in east Shropshire is the well defined steps or breaks in slope which are often present where hedge boundaries are located transverse to slopes. These steps vary in height from 1 metre to approximately 3 metres with the larger values being more common on moderate to strongly sloping land ($4 - 11^{\circ}$). Such features are referred to in the American Soil Survey Manual (1951) as special short steep escarpments, called taluds (from old French) which are gradually formed at down-slope field margins against hedges or stone walls (see Figure 2. Page 2). As the talud forms with the slow accumulation of soil wash from above, the soil slope decreases. It is considered that in areas of fairly erodible soils, with a pattern of small fields, erosion may now be reasonably well stabilized with taluds that act

as terraces to reduce the slope gradient and hence run-off and accelerated erosion. Although the term is not in general use in literature the description of the talud fits exactly the features seen in Shropshire and other parts of England which are referred to by a number of writers, including Avery (1964), Hodgson (1967) and Ragg (1973) and which are considered to be a product of cultivation and accelerated soil erosion (see Figure 3 Page 3). Further consideration will be given to the processes involved in the formation of taluds in Section B below.

The key question which arises here is concerned with the relative age and significance of such features. It is usually assumed that areas which are known to have a long tradition of agriculture and characterised by fields with well developed taluds, that these features represent significant though gradual erosion over a long period of time. However, this assumption can be very misleading for inherent in it is the belief that such fields formed part of an arable system for a long period of time. Agricultural history documents marked changes over the centuries between arable and pasture, open fields and piecemeal enclosure, so that the greater the time span being considered the more difficult it becomes to construct a reliable land use history for a given area. In lowland Britain marked anomalies exist between areas which have been in continuous cultivation for over 1000 years and others as exemplified by parts of the Downs, where a cultivation gap of some 2000 years existed between the Celtic

fields and the major ploughing up campaign of Downland in 1940.

The task of compiling a land-use history, however broad, to assess the impact of man's agricultural activities on the soil system is further complicated, as Stamp (1955) observes, by significant differences of interpretation between experts in agricultural history. Stamp refers to the evidence of two writers, Meyers and Bindoff. Meyers considers that by the end of the 13th century there was more land under the plough than ever before or possibly since - which would mean more than 7,284,500 hectares (13 million acres) in England alone. Bindoff, however, claims that as late as 1485, 'we have to picture the countryside as a sort of agrarian archipelago, with innumerable islands of cultivation set in a sea of 'waste'.' How far recent discoveries of many more sites of lost villages in lowland Britain supports Meyers' view is still unresolved. A more realistic appraisal can be made of changes in agricultural land-use during the 19th century for where new field boundaries were established during the enclosure of wastes a qualitative estimate can be made of rates of sedimentation during the period of time which has elapsed. Further discussion of this approach is dealt with later in this chapter.

Historical evidence from east Shropshire

In east Shropshire some fields date back to the 11th century as a number of settlements like Claverley and Worfield were

already important in 1086. Yates (1965) refers to these settlements and others that margined the ancient Forest of Morfe in east Shropshire. He chronicles the extension of arable farming into the forest and considers that much of the settlement was made up of individual farmsteads. Many of the small fields that formed part of this ancient landscape he considers were individually held. Lee Farm near Claverley (S.O.778943) which is now amalgamated with Dalicot Farm was associated with Robert atte Lee (S.R.O.* 958/1,9,11) and like Sytch Farm (S.O.781.903 2 miles due south) associated with Hereward de la Sytch, contained crofts that were not part of an open-field system. All of Lee Farm is developed on sloping terrain and contains some good examples of taluds.

Although it is conceivable that some of these features are approximately 1000 years old, and others of the order of 700 years, considerable doubt remains concerning the relative age of the accumulated sediment. Lee Farm has today a marked erosion problem with several fields eroding every year during the ten year erosion survey period (1967-1976). The question concerning the extent to which recent erosion has contributed to the total accumulation of sediment will be dealt with in subsequent chapters.

Sylvester (1969) considers that the Anglo-Saxon settlements of Claverley, Alveley and Worfield formed part of a group of comparatively large nucleated villages of which each must originally have been isolated in deep woodland.

* S.R.O. Shropshire Records Office

Numerous small hamlets were formed in some parts of the forest, notably around Worfield, where, as H.L. Gray (1915) recalled, there was a marked development of open field, much of it three field. According to Rowley (1972) by the end of the 16th century the county must already have been largely enclosed, for Shropshire was excluded from the last Act (1597) relating to depopulation because it was best treated as a pastoral county. Shropshire, Rowley contends, differs from most Midland counties in that even where open fields had survived until the end of the 18th century, they tended to be enclosed by agreement, often in a piecemeal manner, rather than by Act of Parliament as only seven acts were brought forward for the enclosure of open fields in Shropshire.

Roque (1752) produced a map in his 'Actual Survey of the County of Salop', which showed that the large tracts of woodland around the Alveley, Claverley, Shifnal and Worfield areas had largely disappeared since Domesday times.

Bazeley (1921) considered that large districts in Shropshire were deforested in 1204.

Howell (1941) summarises much of the evidence of enclosure available for Shropshire. The distribution of enclosure is mapped for the county 1492-1516 and 1763-1891. He considers that by the end of the 18th century land remaining to be later enclosed was of sub-marginal quality as either it was inherently infertile, or it required extensive drainage

operations, or it lay in accessible areas.

In Shropshire the period of parliamentary enclosure began in 1763 but much of the heathland remained unenclosed until around 1800. Much of this land coincided with outcrops of Bunter Pebble Beds and stony glaciofluvial deposits and was characterised by very acid soils - podzolised Brown Earths, Podzols and Gley Podzols. One of these areas, Lizard Hill (SJ 775095) near Shifnal, was enclosed in 1786 and was followed by the enclosure of five open common fields in Shifnal itself in 1794. There followed a series of awards, as follows:-

1806 (Parish of Worfield) for the enclosing of Cross Heath and Rudge Heath.

Enclosure at Oldington, Newton, Winscott, Hallon, Catstree and Stableford, Sowdley Common and Cranmere Heath.

1812 Parishes of Worfield, Claverley, St. Mary Magdalene, Bridgnorth and Quatford.

This latter award covered an area of 3,600 acres (1457 hectares) known as the Forest of Morfe (Shropshire County Records).

Apart from the useful plans contained in some of the awards there are occasionally references made to cultivation practices. For example on the Lizard Hill award the Commissioners gave directions for improving the land. They stated, 'We do direct and appoint that the said Lessees shall cultivate their respective allotments for and during the terms in their respective leases by taking only one crop of any sort of grain before a fallow and two crops afterwards and that they shall cause the fallow

so to be ploughed at least four times over and to be harrowed well between each time of ploughing, three of such ploughings and harrowings to be performed in the months of May, June and July, and that they shall manure the same with well reduced rotten muck or dung at or after the rate of twelve cartloads each to contain one cubical yard or, with well-burnt clod lime at or after the rate of sixty bushels to each and every acre. And shall with the said second crop lay the same down with good clover seed at or after the rate of twelve pounds, and with rye grass seeds at or after the rate of two pecks to each and every acre.' These instructions are considered by Howell to indicate a presumed norm for light soil husbandry at that time (Howell 1941).

Even allowing for the fact that soil organic levels at that time would have been higher and soil structure more stable, the practice of fallowing ground would expose sloping fields to the risk of accelerated erosion particularly in the months of May, June and July when thunderstorms are fairly common. The presence of small fields and shorter slopes would, however, reduce the effects of run-off during high intensity storms and it is considered likely that splash erosion and sheet wash* would be the principal processes at work. To what extent the practice of shallow ploughing influenced these processes is difficult to assess.

* The use of this term is considered in Chapter 5.

Young (1785) in his Tour of Shropshire refers to a ploughing depth of 3-4 inches on land near Shrewsbury. Shallow ploughed land would have a reduced infiltration capacity, particularly if compacted by sheep folded on roots and hence there would be a considerable risk of run-off during periods of heavy rainfall. Today, even with deeper ploughing, loss of structure and capping are particular problems where sheep are folded on beet tops or roots. During adverse seasons severe sheet erosion is common on such fields, notably where soils are of sandy or silty texture (see Figure 4 Page 4).

The data contained in the Enclosure Award and Tythe Redemption maps make it possible to obtain approximate dates for some fields which today already show signs of talud development as for example, parts of the former Forest of Morfe, which was enclosed in 1812. The whole of this area is characterised by loamy sands and sandy loams and is prone to wind and water erosion. During the last war and subsequently, many of the fields in this area have been in arable agriculture and recently have tended to be in continuous arable use. During the ten year erosion survey (1967-76) a number of fields have been observed to erode each year when in arable cropping. Sheet and rill erosion are the most common forms and give rise to extensive base of slope deposits, an example of which is shown in Figure 5 (Page 5).

Although it is possible to make a crude estimate of the total

sediment accumulation along the down slope margin of these newly enclosed fields within the 166 year period, it is difficult to know whether it has resulted from a gradual accumulation over the entire period or whether deposition has been accelerated during the post war period. There have been occasions during the 10-year erosion surveys (1967-1976) which is referred to in Chapter 8, when the amount of down slope accumulation of washed-off sediment has been equivalent to 100 tons per hectare of soil loss. Allowing for the fact that there have been no apparent significant shifts in rainfall during this later period, the increased tendency to run-off and erosion stems from increasing compaction from heavier machinery and declining levels of soil organic matter which in turn result from continuous arable cropping. These problems will be referred to in Chapters 4 and 5.

One valuable source of both historical and pedological data can be found in the Rothamsted Reports on the soils of Woburn Experimental Farm. Catt et al (1976) describe the soils and land use history of Lansome, White Horse and School fields in Woburn farm. The authors refer to a thin layer of colluvial material which overlies part of the lacustrine deposits in the north-eastern corner of Lansome field which were associated with a former lake. This colluvial material must have been deposited after the lake was drained in the mid-19th century and this testifies to the extremely recent origin of much of the colluvium as a result of erosion. In an earlier report which deals with another part of Woburn Experimental Farm, Great Hill,

Road Piece and Butt Close, Catt et al (1974) include

a photograph which shows marked talud formations where a former hedge runs transverse to slope. Today only the steepest sections of the talud remains and this may well represent part of the hedge which contained large trees which have acted both as a buttress and a trap for sediment.

One other useful method of dating hedgerows can be mentioned here though it does not appear to be readily applicable to the agricultural landscape of Shropshire. Hooper (1970) describes a method of dating hedges by counting the numbers of shrub species in one or more short lengths of the hedge. Hooper considers that it appears possible that one more species colonizes a hedge every hundred years, and on the Huntingdon/Northamptonshire border he found evidence to confirm this general theory. Here the correlation coefficient came to +0.92 and the regression equation for predicting the age of a hedge from the number of species in a 30 yard length was calculated thus:-

the age in years = 99 x the number of species - 16.

That is a 4 species hedge is 380 years old (= Tudor) and a 10 species hedge is 974 years old (= Saxon) according to this formula, but there is still variation not accounted for by the age factor and it would be improper to say that every 10 species hedge is 974 years old. It suffices to say that 95% of ten species hedges are between 800 and 1150 years old and that their mean age is 974 years.

Clearly a seven species hedge could be the same age as a 10 species hedge but it is extremely improbable that a

hedge with five species or less in a 30 yard length is Saxon in origin.

Hooper, however, finds no correlation of a magnitude sufficient for even this level of approximation in Shropshire, for in the area south of Shrewsbury nearly all the hedges seem at first sight to have three, four or five species in them irrespective of their age. Although there is a tendency for older hedges to be richer it is not sufficiently marked to be able to date any one hedge even in a very approximate way by the shrub content. He considers this to be the result of a tradition of planting mixed hedges. The rate of colonization may well be the same as elsewhere, one species per 100 years, but of two hedges planted in 1600 one might have been of pure hawthorn and now be a three or four species hedge while the other might have been a two or three species hedge to begin with and now be a five or six species hedge. This latter hedge would be indistinguishable botanically from a hedge planted as pure hawthorn, late in the 14th century.

Occasionally rapid run-off from up-slope has eroded cuttings through hedgerows to reveal the presence of layered sections (a practice which is used to make stock-proof hedges) which have been buried subsequently by sediment trapped against the base of the hedgerow. In one example (see Figure 6 Page 6) a burst water main sprayed a jet of water against the down slope face of a hedge line which formed a talud feature of 1.3 metres in height. Excavation of this revealed a former layered section which had been covered

by 70 cm of soil. Hedge layering or laying has been practised since the time of enclosure and it is not yet clear how layered sections of different species of hedging react to partial or complete burial. Obviously if they are prone to rapid decay when buried this would not provide any means of approximate dating. However, in the case of the quoted example historical data points to a hedgerow age of approximately 140 years. The lower sections of layered hawthorn had decayed and this might be accounted for either by fairly rapid burial which inhibited growth or by biological factors such as the onset of disease. Some twenty metres along the hedge was further evidence of sediment accumulation where an iron sheep fold was found in an upright position with only the top 30 cm showing. It appeared that the sheep fold had been used to fill up a hole in the hedge and this had been later partially buried by 73 cm of soil.

Whilst none of this evidence is conclusive in terms of rate of sedimentation it does provide a number of levels of enquiry which, if pursued more objectively, might lead to a clearer understanding of the processes of erosion and deposition at work on the agricultural landscape. Reference will be made below to more recent examples where rates of sedimentation along hedgerows have been particularly rapid with evidence from one area of an estimated 1.5 metres (5 feet) of material in 38 years (1940-1978).

2.3 Pedological evidence

The evidence which is examined here relates to elutriated

and truncated soils and the down slope deposits of over-wash associated with the latter through rainfall erosion and run-off. Apart from the pedological and agricultural significance of these changes they do impart information of sedimentation yield through which some estimate can be made of rates of erosion.

Avery (1964) considers that many of the agricultural soils in the Chilterns have come to differ markedly from their semi-natural counterpart on similar sites as a result of accelerated erosion. The clay-with-flints which mantles the chalk on upper slopes and spurs is normally covered by a layer of flinty loam which supports ancient woodland, whereas in adjoining long cultivated fields the profile has commonly been truncated by erosion, so exposing the clay subsoils, or where this is thin, the chalk below. Further evidence of this process he considers is afforded by the occurrence of marked declivities in association with field boundaries following the contour (taluds). On the lower side of such boundaries is eroded soil consisting virtually of bare chalk or raw clay, whilst on the upper side, there is an accumulation of top soil material derived from further up slope.

Hodgson (1967) considers that much of the hill-wash in the dry valleys of the chalk in West Sussex has resulted from the accelerated erosion that follows deforestation and cultivation, as evidenced by the deep burial of Roman and Mediaeval artifacts and the accumulation of similar material on the upper side of field boundaries. He contends that the

higher chalk content commonly found in arable profiles of the Wollop Series is due to ploughing and other disturbance and many such soils may result from erosion of thin Winchester Soil Series. In the Reading district, Jarvis (1968) describes recent colluvial deposits and sandy materials such as the Barton, Bagshot and Reading Beds sands which contain little clay and show no clearly defined B horizon of any kind, which are appropriately classed as rankers (non-calcareous soils with A, C profiles). They occur mainly on agricultural land and sometimes may be former podzols, in which the characteristic sub-surface horizons have been lost by long agricultural use or by accelerated erosion.

Deposits in a temporary pipe line trench in a dry valley near Hawkesbury Upton (S.T. 797868) Southern Cotswolds, are described by Findlay (1976). He refers to a brown clayey deposit of two kinds which overlies a weakly bedded limestone gravel on the lower slopes of one side of the valley. The upper deposit was very stony, containing limestone fragments of various sizes and below this was a more or less stoneless layer. The latter presumably represents rainwash under grassland conditions, whereas the upper layer is recent material moved off nearby fields by erosion while under intensive arable cropping.

Further reference can be made to evidence from the soils of Woburn Experimental Farm (Catt et al 1976) where a combination of natural and man induced erosion of weathered

boulder clay on Lansome Hill has exposed the Lower Greensand around the summit so that Cottenham Soils (Brown Sand on Lower Green Sand) are developed on Greensand in situ. The authors consider that further recent erosion on this part of Lansome field has resulted in the formation of sandy rather than loamy colluvial tongues on the surrounding slopes which have been mapped in Cottenham series. There is, however, an absence of similar colluvial tongues on White Horse field and this, together with the persistence of loamy colluvium, almost to the highest point of the field, suggest that much of the erosion into the Greensand on the summit has occurred since the hedge between Lansome and White Horse fields was established during the enclosures about A.D. 1800. The hedge and the long period during which White Horse field was maintained in pasture prior to 1961 have together prevented the most recent soil erosion from affecting the field. Now that the field is in arable the authors consider that removal of this hedge would most certainly result in increased erosion and could ultimately change the mapped distribution of the two soil series. Elsewhere in the area under consideration colluvium of slightly stony sandy loam or sandy clay loam at least 80 cm thick mantles all the lower slopes and partly fills the dry valleys reaching 2 - 4 metres thick in parts of the central sections of the valleys.

In the West Midlands, Mackney and Burnham (1966), Hodgson and Palmer (1971) and Hodgson (1972) refer to talud-like features which are present in areas with a long tradition of arable agriculture. The authors consider these features

to be the product of cultivation and exposure of soils to the impact of rainfall erosion and run-off over a period of time.

In east Shropshire the writer (1972) has made reference to eroded soils of the Bridgnorth and Newport series in the Worfe basin and in this area examples of both truncated soils and buried soils can be found. Some of the best examples of truncated soils can be seen on strongly sloping land (8-11°) where ploughing reveals a marked colour difference between the eroded knolls (shallow phase of the Bridgnorth series) and the deeper soils of the lower slopes and minor re-entrants. Along convex facets of slopes the Ap horizon rests directly on the weathered mottled sandstone of the C horizon or is separated from it by a remnant of the B horizon. Water erosion is not the only process at work here for sandy loams and loamy sands of the Bridgnorth, Bromsgrove and Newport series are prone to severe wind erosion, particularly on exposed banks.

While it is evident that soil characteristics in this area have been altered through time by man's interference by ploughing and such practices as marling and stone picking, there is clear evidence to suggest that accelerated erosion has brought about the greatest changes on sloping land which has been in arable cultivation for a long period of time. In a number of cases there is evidence to suggest that the erosion rate has increased significantly since 1940 when a number of 'banky fields' were ploughed, some

possibly for the first time in the parish of Claverley. This has resulted in remarkable rates of sedimentation down slope with soil losses exceeding 150 tonnes per hectare in one storm. One field which has been in continuous arable cultivation since 1940 has been observed to erode each year during a ten-year erosion monitoring survey. Splash, sheet and rill erosion have been the most common forms with severe gully erosion in 1975 and 1976. Continued erosion has resulted in parts of the upper slopes of one field (slope 7-8°) losing much of the former sandy Ap horizon so that recent ploughing has brought to the surface in places a silty clay loam derived from underlying beds of rythmites. These areas of the field now have a silt loam texture, whereas the texture up slope and down slope of these areas is sandy loam. Down slope deposition has taken place here at such a rate since 1940 that the hedgerow at the bottom of the field has been buried to a depth of approximately 1.5 m. This represents the sediment which has been retained by the hedge rather than the total amount of material lost from the slopes above. Large quantities of material moved through the hedge into the field below during two big storms and much of the run-off entered Hilton Brook (see Figure 7 Page 7). Other examples can be quoted of datable fences and hedges where the rate of sediment accumulation has been notable. In other cases erosion has partially exhumed the base of electricity pylons and exposed the roots of trees. In places along tributary valleys quantities of material from adjoining arable fields have been deposited as an overwash on ground water gley soils, thus significantly

altering the upper soil horizons of the latter.

A number of causal factors interact in this part of east Shropshire to effect the significant rates of erosion referred to above. Much of the Worfe basin is characterised by undulating land with steep convex-concave slopes of varying length and aspect which are commonly found along the sides of the main valley and its tributaries. A high proportion of these slopes are today in arable and in recent years some have been in continuous arable cropping. The soils are predominantly sandy, low in organic matter and weakly structured. Continuous arable cropping on some farms has further exacerbated this situation. Row crops predominate and the practice of up and down slope cultivation is very common. Although these soils are well drained and of easy access for cultivations there is a tendency to plough and cultivate when the soil is too moist and this results in compaction and smearing and the formation of strong pans. Weak surface structure together with extensive compaction results in reduced infiltration capacity and hence greater run-off potential on slopes during heavy periods of rainfall.

The effects of run-off have been heightened by the practice of amalgamating fields and consequently increasing the length of slope. Field amalgamation in areas of sloping terrain often creates one large field with slopes of varying steepness and direction which minimise the chances of successful 'contour' cultivation. Further it is important to note that the practice of continuous arable cropping on sandy

soils can lead to accelerated changes in situ even on flat sites through the process of splash erosion and elutriation. Soils which are weakly structured and have organic matter levels of less than 3% are adversely affected by rain falling at the rate of 1 mm/hr. or more when the surface is fallow or partially covered by a growing crop or crop residues. Splash erosion pulverises weak soil aggregates and causes the concentration of coarse sand on the soil surface with the silt and clay sized particles being translocated down the profile until the interstices and voids become blocked. The number of large voids in a soil are reduced when the surface is compacted by vehicles and implements and this has a profound effect on the rate of water acceptance into the Ap horizon, particularly during periods of high intensity rainfall. Following a rainfall event, a field surface which has been harrowed often shows an accumulation of coarse washed sand on the ridges and thin coatings of silt and clay in the furrows.

Once a sandy soil has been exposed to processes which break down soil aggregates and result in the sorting of soil particles the surface is very susceptible to further modification by wind erosion. Large quantities of coarse and medium sand are moved by saltation and surface creep until checked by hedgerows or other obstructions. The removal of material in this way leads to the concentration of stones on the soil surface in quantities which vary in amounts depending upon the stone content of the affected soil. Removal of fines and coarse/medium sand in this way and by water erosion might account for the anomalous presence of

thin spreads of stones on the soil surface (Ap horizon) which are not present in similar concentrations or are absent in the sub-surface horizons. It is acknowledged that in an area such as this one with a complex drift geology many reasons can be advanced to explain the presence of surface spreads of gravels. In some cases, however, one simple explanation can be advanced by considering the combined effects of wind and water erosion.

Chapter 3

Accelerated erosion of arable soils in the United Kingdom: 2

The present day pattern of erosion by water and wind

3.1 Introduction.

3.2 Water erosion.

3.2.1 Water erosion of arable soils in Scotland.

3.2.2 Water erosion of arable soils elsewhere in the
United Kingdom.

3.3 Wind erosion of arable soils in the United Kingdom.

3.3.1 Distribution of wind erosion in the United Kingdom.

3.4 Summary.

Chapter 3

The present day pattern of erosion by rainfall run-off and wind in the United Kingdom

3.1. Introduction

Research on soil erosion in the United Kingdom has been concerned largely with the impact of man in upland areas where natural events such as moorland fires, overstocking or tourist pressure has accelerated erosion rates. Evans (1971) reviews the work of a number of authors who report erosion of deep peat in the northern and southern Pennines. Thomas (1956) describes examples of gully erosion in the Brecon Beacons, South Wales and also draws attention to sheep-induced erosion in the Plynlimon area of central Wales (1965).

Despite the incidence of steeper slopes and greater annual rainfall totals the impact of soil erosion on upland agricultural land is small in comparison to that of lowland areas as the proportion of arable land in the upland farming systems is small. It is in the intensively cultivated areas of lowland Britain that the risk of soil erosion by both wind and water is greatest. As any exposed soil surface is potentially vulnerable to wind and water erosion

the period of greatest risk occurs during early spring through to early summer and to a lesser extent during the autumn and early winter during the periods of ground preparation, sowing and crop emergence until sufficient cover is afforded to the soil surface. The occurrence of adverse weather during spring and autumn will have an important bearing on the incidence and type of erosion likely to occur. While wind erosion in eastern England is an acknowledged hazard during dry windy spells in spring and early summer and has been widely reported, the effects of water erosion on arable land by comparison have received little attention.

3.2 Water erosion

Evidence from a number of areas in the United Kingdom seems to suggest that soil erosion by rainfall and run-off is a more widespread and frequent event than is generally accepted and this is certainly borne out by a decade of soil erosion monitoring in the West Midlands by the writer. Although much of the data here relate to sandy soils they demonstrate that significant amounts of soil erosion can be effected by rain falling at much lower intensities and for shorter durations than is experienced in many parts of the U.S.A. where soil erosion is a serious problem. By analogy with the West Midlands there are many areas of the United Kingdom with similar soils, terrain and land use to warrant a closer inspection of the problem. Apart from sandy soils there are extensive areas in lowland Britain that are characterised

by silty soils which suffer from varying degrees of instability under continued arable use and these problems can be exacerbated during periods of adverse weather. Soil Survey Memoirs and Records report surface structural problems (loss of structure) affecting a wide array of soils which in some cases have led to sheet and rill erosion. The circumstances which give rise to loss of structure in soils are examined in Chapter 4. Of the four types of water erosion namely, splash, sheet, rill and gully, the first three types are the most widespread. However, in the United Kingdom few writers refer specifically to splash erosion but rather to soil structural instability under heavy rainfall.

3.2.1 Water erosion in Scotland

Instances of water erosion of arable soils in Scotland are reported by Glentworth (1954), Glentworth and Muir (1963) and Ragg (1960 and 1973). Ragg (1973) describes the occurrence of sheet and rill erosion in Scotland in the Merse of Berwick and the Central Lowlands. He refers to the turbidity of streams and rivers after heavy rain and the quantities of soil deposited on roads and neighbouring fields which provide ample evidence of sheet and sometimes rill erosion. He considers that less obvious erosion probably occurs whenever appreciable rain falls on ploughed land with slopes exceeding 7° . As evidence of these processes he cites the presence of talud-like features or breaks of slope (1-2 metres) where soil has accumulated against hedge or fence boundaries. More specifically he refers (1960) to water erosion of the

Whitsome series (loam to clay loam) around Kelso and Lauder which covers some 118.5 sq. miles and occupies all that part of the Merse below 350 ft. and contains the main arable soils of any extent on the Borders. This series is developed on a till with well developed elongated drumlins 25-30 ft. high and up to one mile in length. Up and down slope cultivation on these drumlins has resulted in sheet and rill erosion developing during periods of heavy rain.

Glentworth (1954) describes the soils of the country around Banff, Huntley and Turriff. Although he does not consider soil erosion to be a problem in the north-east of Scotland, he has noted occasional gullies developing in arable fields with up and down slope cultivation. 'Where this has occurred an attempt is commonly made to re-transport the eroded soils to the top or to the thinner parts of the field.' (a practice which is written in to some tenant farmers' agreements in the south-west peninsular - notably Devon). Reference is also made to deep gullies cut out on the hillsides by phenomenal 'cloudbursts'. Although such events Glentworth considers to be extremely rare, other examples of gullying have been reported elsewhere in the north-east.

In the country around Aberdeen, Inverurie and Fraserburgh, Glentworth and Muir (1963) consider that the extensive felling of trees during the first and second world wars has increased the risk of soil erosion and evidence of this is provided by the infilling of many drainage ditches on the lower ground with material eroded from the felled areas. Grove (1977 personal communication) examined gully erosion

of arable land in Speyside. He described deep long gullies which formed after a week of heavy rainfall producing large fans of deposited material along lower slopes and field boundaries.

The hazard of soil erosion on cultivated slopes was acknowledged by 19th century writers in Scotland. Bennett (1939) quotes the work of Sinclair who was writing in the early 19th century on the problems of ridging on sloping lands. Sinclair condemned the practice of up and down slope ridging and favoured diagonally sloping ridges which provided the necessary drainage but inhibited rapid run-off and soil loss.

Jacks and Whyte (1939) believed that sheet erosion was taking place, particularly on light soils and in the more hilly cultivated lands in the higher rainfall areas of Wales and Scotland. They refer to various indicative signs of erosion and in particular to eroded patches in sloping arable fields which could be clearly seen in emergent cereal crops. They emphasise the need to cultivate along the contour and avoid the practice of up and down slope cultivation. Other methods were recommended which suited better the topography and field pattern, and these included ditching and banking which could act as sediment traps and slow down run-off. 'Contour cultivation' cannot be easily and safely applied to a landscape characterised by steep slopes and small fields as it presents serious problems of tractor stability and poses a serious risk to tractor drivers.

Another problem cited by Bennett (1939) concerned the rapid

erosion of upland acid peat and its subsequent deposition down slope, thus reducing the fertility of any arable soils affected by this process. There is evidence to suggest that erosion of upland soils has increased locally under the combined impact of over-grazing and burning.

3.2.2 Water erosion of arable soils elsewhere in the United Kingdom

Other parts of the United Kingdom affected by water erosion are referred to by Evans and Morgan (1974). They describe spectacular erosion near Balsham in south Cambridgeshire on shallow loamy soils of the Swaffham Prior association on slopes $4 - 5^{\circ}$ planted with beans and sugar beet. An estimated 3.3 tonnes/hectare of soil was deposited during a thunderstorm which yielded 7.4 mm of rain over Cambridge 13 km to the north-west. Further erosion was noted near Abington, Cambridgeshire on slopes of less than 2° on compacted ground sown to turnips. Morgan (1974) refers to sheet and rill erosion in the Silsoe area of mid-Bedfordshire on sandy loams derived from the Lower Green Sand (Cottenham Flitwick and Oak series) when 17.7 mm of rain fell in 30 minutes causing some minor roads to be partially blocked with sediment. Catt et al (1974) describe soil erosion affecting soils of the Cottenham series (Brown sand on Lower Green sand) and the Stackyard series (Brown earth on sandy colluvium) at Woburn Farm, when exposed to heavy rain. One example quoted occurred during a storm in May 1973 when over 50 mm rain fell in an hour causing severe sheet erosion in a field of potatoes (slope $1 - 3^{\circ}$)

with several centimetres of surface soil and many young potato plants being washed out. The inherent erodibility of the soils on the Lower Greensand when exposed to heavy rain and the influence of surface and sub-surface compaction by heavy machinery are considered to be causal factors by the authors.

Douglas (1970) cites a number of examples of soil erosion by water ranging from small gullies 0.35 mm deep in winter wheat on chalk near Horncastle, Lincolnshire (April 1939) to 4 m deep gullies which developed in a crop of young turnips growing on the slope of a drumlin near Blaydon, Co. Durham following a thunderstorm on 22nd June, 1941, when almost 80 mm of rain fell in 2 hours. Rogers and Greenham (1948) described erosion caused by a heavy storm in a young plantation on sandy soil at East Malling and also at Larkfield, Kent. They comment on the tendency of siting fruit plantations on hillsides, in order to lessen risk of frost damage, has made soil erosion a more serious problem. Low (1963) reports erosion of silty loam soils on a newly planted apple orchard at Jealotts Hill Research Station when the first winter's rain produced many tons of washed soil down slope (concentrated along cultivation lines paralleling the slope) which necessitated the use of a bulldozer to return the material back up slope. He also refers to rill erosion in sandy loams of the Berkhamsted and sheet erosion in the Hildenborough series at Fernhurst, Sussex, (Low 1972).

In a survey of poor soil and crop conditions in Lincolnshire

and Nottinghamshire, Archer and Wilkinson 1969 refer to sheet and gully erosion on undulating ground, causing damage to small seedlings, particularly sugar beet. In the Ollerton district of Nottinghamshire sandy soils of the Newport series cover an area of 3990 hectares (9859 acres) and some 40% of the survey area (Robson and George 1971). The soils are prone to wind erosion with severe blows resulting in the loss of fine earth and abrasive damage to seedlings being expected once every five years. However, Robson and George consider that the cumulative effect of annual rainwash (mean annual rainfall 640 mm, 25 inches) on arable land may reduce the productivity of Newport soils more than the dramatic but rarer blows.

South of Derby in the Melbourne area, Reeve (1975) records erosion affecting the Worcester series (clay loam) after heavy spring rain, and also on strongly sloping land which carries the shallow phase of the Rivington series (coarse loamy) which is prone to erosion when intense rain follows compaction resulting from spring harvesting of horticultural crops.

Clayden (1964, 1971) refers to soils in Devon around the middle Teign valley and the Exeter districts where arable cultivation on moderate to strongly sloping ground with a long tradition of barley growing has led to a moderate degree of soil erosion. He also considers sheet and gully erosion to be a hazard on virtually all the cultivated land around Exeter and that erosion is likely to be more

serious where steep slopes are cultivated. In another part of Devon, near Honiton, erosion is considered to be a hazard on sloping sites used for intensive arable cropping on soils of the Bridgnorth series (Harrod 1971).

3.3 Wind erosion of arable soils in the United Kingdom

3.3.0 Introduction

Wind erosion of arable soils may occur in the British Isles wherever soil, crop and climatic conditions are conducive and contrary to some reports (Agricultural Advisory Council 1970) and Davies & Harrod 1970) the problem of 'blowing soils' is not solely confined to flat exposed sites on the eastern side of England. Certain arable soils, notably fine sands, sands, loamy fine sands, loamy sands, sandy loams, light, loamy and sandy peats are particularly prone to damage by wind when in a fallow or partial fallow - a condition which is common during seed bed preparation, seed emergence and in the early stages of crop growth before sufficient cover is afforded. It can be seen from Figure 8 that the distribution of these soils in England is widespread.

In a survey of the agriculture of the sand lands in districts of low rainfall (<30 inches per annum) (1954)* wind erosion constituted a problem in 3 out of 5 of the National Agricultural Advisory Service provinces, namely Yorkshire, East Midland and the Eastern Province, though no estimate is given of the extent of the problem either locally or regionally. This report emphasises the profound changes which have taken

place in the post-war period in the farming of light soils through the introduction or extension of root crops like sugar beet and carrots, by the lowering of costs by mechanisation and by increased yields of cereals through the use of new varieties and heavier applications of nitrogenous fertilizers. These changes in agricultural practices necessitated the enlargement of fields with a consequent increase in exposure to erosive winds and the increase in continuous arable cultivation at the expense of ley farming has resulted in a decline of organic matter in soils which are already inherently poor in humus. Other management practices such as continuous barley cropping, burning of straw and stubble, deeper ploughing and the forcing of tilths with rotovators have tended to increase the risk of soil erosion, particularly during adverse seasons. Certain crops like sugar beet occupy the ground for a longer period, require more seed bed preparation and the crop takes longer to provide adequate protective ground cover.

3.3.1 Distribution of wind erosion in the United Kingdom

A combination of suitable soils, landforms and farming practices, together with a drier climate, make parts of the arable areas of eastern England particularly susceptible to wind erosion. Reference is made to 'soil blowing' in a number of reports and papers. In the Ministry of Agriculture survey (1954) referred to above wind erosion constituted a problem in the Vale of Pickering, on the Nottingham and Lincolnshire sands, the lower Greensand of mid-Bedfordshire and the Breckland area of Norfolk. In a survey of wind

erosion on sandy soils in the east Midlands, Wilkinson et al (1968) investigated erosion hazard in Lincolnshire (Lindsey) and Nottinghamshire during the winter of 1965-1966. Five districts in Lindsey and Kesteven are recognised and two in Nottinghamshire as having an erosion problem and these are identified in Figure 8.* The soils are predominantly sandy and are derived from glacial sands, cover sands, loess, fen peat and alluvium as well as Triassic sandstone. A total of 60 farms were surveyed amounting to 2,383 hectares (5,889 acres) and the percentage area subject to erosion is recorded in Table 6.

Table 6

Surveyed acreages and their liability to erode (East Midlands)

County	Total acreage surveyed	Percentage of acreage liable to erosion	Percentage of acreage where whole field stated as liable to erode
Lincs	4,790 (1,938 ha)	35	13
Notts	1,099 (445 ha)	42	16
Total	5,889 (2,383 ha)	36	14

Source: Wilkinson et al 1968 Page 55.

The survey revealed that organic matter levels were very low in general (<2%) and significantly lower in the eroded areas. Mechanical analysis of soil samples (in situ and eroded) showed a higher fine sand content (0.2 - 0.02 mm) in

Lincolnshire soils and this is considered to be one of the reasons to explain the higher percentage of arable land liable to wind erosion. Robinson (1968) described the distribution of wind erosion in Lincolnshire following the exceptional conditions of March 1968 and considered the problem to be more widespread than ever before affecting an estimated 2024-2428 hectares (5000-6000 acres) in Lindsey and 6070 hectares (15,000 acres) in Kesteven. This figure of 8498 hectares (20,998 acres) represents an over 12-fold increase on Wilkinson's 1965-1966 survey, which in part can be accounted for by the greater severity of the blow which was sustained over a period of six days and resulted in wind erosion affecting a variety of soils which hitherto are thought to have been unaffected. The particular climatic circumstances which gave rise to these events are examined in Chapter 6.

Robson et al (1974) however, describing the soils in the Till valley near Woodhall Spa, considers erosion to be slight in this area and constitutes only very minor limitations on certain sandy and peaty soils. Reference is made to wind erosion in Kesteven during dry springs which may result in sugar beet having to be re-drilled.

In the Ollerton area of Nottingham, soils of the Newport series (sands, loamy sands and sandy loams) cover 3990 hectares (9859 acres) which amounts to 40% of the 100 km² surveyed by Robson and George (1971). The authors consider that severe local erosion with resulting loss of fine earth and

abrasive damage to seedlings can be expected once in five years.

To the north-west the Bunter sands which dominate the Nottinghamshire parishes around Worksop give rise to light soils prone to both drought and wind erosion (Reeve 1976). Newport soils form the largest mapping unit covering 1510 hectares (3730 acres) or 15.1% of the area. Although some erosion occurs in most years, severe damage can be expected on average once every five years. Other soils affected are the Bridgnorth series (350 ha, 865 acres 3.5%) and the Crannymoor series (60 ha 150 acres 0.6%) with crops of beet and carrots at most risk. Reeves cites the changes which have taken place in the farming of these 'Bunter' parishes which have shifted from a very mixed system to one of total arable farming. Herein may be the reason for the extent of present erosion and the potential for increased erosion hazard in the future.

In the Trent valley around Newark wind erosion is not considered to be a major limitation to land capability on soils other than the Newport series which are prone to blowing in spring when strong winds coincide with insufficient ground cover' (Johnson 1975).

Wind erosion in parts of east Yorkshire reached serious proportions in February and March 1967 with the principal area affected being the glacial and lacustine sands and areas of cover sand on the east side of the Vale of York where patches of erosion affected a corridor some 50 miles long and 3-11 miles wide stretching from the Humber to the

vicinity of Northallerton (Radley and Simms 1967). Damage to soil, seed beds and crops was widespread and in places dunes 3-4 feet high (0.9 m-1.2 m) formed in the lee of hedges with one example near Moxby Moor (SE 590 670) of a dune 275 yards (252 m) in length and of more than 15 yards (13.7 m) in width - an estimated 50,000 cubic feet (1415 m³) of material. The authors contend that erosion has been accentuated as a result of the combined effects of modern farming practices, particularly field amalgamation which has increased wind fetch, and the onset of a dry spring with above average frequency of gale force winds.

In the Soil Survey of York East, Matthews (1971) describes soils representative of the glacial and post-glacial (Flandrian) deposits in the Vale of York. The soil series which are liable to blow together with those which occasionally blow are listed in Tables 7 and 8. Some 19 series and 4 complexes have been mapped in the York East area and of these, 6 series amounting to 1530 hectares (3770 acres) or 20.4% of the area surveyed are liable to blow. In two series, Holme Moor and Kelfield, blowing is considered a limiting factor and a potentially serious one. Blowing occurs in four other series and one complex and affects some 2385 hectares (5880 acres) - a further 32% of the surveyed area. To the south of York the Escrick (SE 64) and Barmby Moor (SE 74) districts form a 20-mile transect of the Vale of York covering some 200 km² and include soils representative of the whole Vale (Bullock 1974). Most of the soil series described by Matthews (1971) as being liable to wind erosion are represented here. Soils liable to blow amount to some

Table 7

Soil series which are liable to blow

Mapping Unit Series	Texture	Parent Material	Area hectares (acres)	% of area surveyed
Claxton Ground water gley (non-calc.)	Loamy fine sand or fine sandy loam	Aeolian fine sand over reddish brown clayey till mainly from Keuper marl	230 h (570)	3.1
Everingham Ground water gley (non-calc.)	Loamy fine sand	Aeolian fine sand (Late Glacial/ Flandrian)	480 h. (1190)	6.4
Holme Moor	Loamy fine sand	Aeolian fine sand (Late Glacial/ Flandrian)	200 h (480)	2.6
Kelfield Acid brown earth	Stony loamy sand	Stony sandy drift (morainic)	340 h (840)	4.5
Kexby Gleyed brown earth	Loamy fine sand	Aeolian fine sand Late Glacial/ Flandrian	260 (640)	3.5
Naburn Acid brown earth	Loamy fine sand	Aeolian fine sand Late Glacial/ Flandrian	20 (50)	0.3

Total

1530
(3770)

20.4

Source: Adapted from Matthews (1971)
Pages 21 - 27

61% of the area surveyed (6135 hectares - 15,159 acres). On the land capability classification map large areas of both sheets are shown as 3 se (land with moderate soil and erosion limitations).

In the Doncaster area Jarvis (1973) describes soils representative of the sands of the 'Doncaster delta' (glacial/post glacial lake) which are mapped as Newport series amounting to 27% of the surveyed area (2090 hectares 5170 acres). As in other districts, Newport soils are very susceptible to wind erosion, though the author considers that it is less of a problem here than in the fine sand areas of the eastern Vale of York. To the west of York and Selby Crompton and Matthews (1969) describe soils of the western part of the Vale of York. Although a number of sandy textured series are described the authors consider that wind erosion is only a minor problem on the Stockbridge series which cover less than 1% of the area surveyed (445 hectares 1100 acres).

Some of the most serious wind erosion has taken place in the Fens where some soil blowing takes place nearly every year. Reports of wind erosion on arable land in the Fens begin in the early 1930's and these events register a change in farming practice rather than a significant change in weather. In certain seasons, 1943, 1950, 1955, 1956, 1967 and 1968, wind erosion was more severe. Dry springs which are preceded by winters with above normal frequency of frost to break down soil aggregates provide ideal prerequisite conditions for erosion when damaging winds occur. Spence (1955) describes a severe 'blow' in the Fens around Manea (an area

with virtually no hedges) when winds gusted to 56 knots on May 4 - 5, 1955. Fields which suffered most erosion were those prepared for seed but still bare and those recently sown with sugar beet, carrots and other root crops. Abrasion damage was done to young crops of barley and established winter wheat. Spence (1957) considered that in 1956 soil blowing was less severe and more localised and records wind erosion on 10 May affecting 800 acres (324 hectares) of black fen 8-10 miles north-east of Cambridge. Damage was caused in the same area on resown crops of carrots and sugar beet during July (5 and again on 29-30 July) when the hourly wind speed reached or exceeded 25 kt.

In Huntingdonshire Pollard and Millar (1968) reported severe blowing on 18 March 1968 which affected virtually every field in fine tilth in the area around Holme and Ramsey St. Mary's. Severe blowing continued during the period March 16-20 and again on 1 April when the hourly wind speed was never less than 20 kt with gusts up to 40 kt on the 18th and 20th.

Approximately 86% (480 km²) of the soils around Ely are derived from fen deposits - fen islands, skirtland, silt fenland and peat fenland. Of this area 25% is mapped as Adventurers' series (Seale 1975.1) which covers 14095 hectares (34828 acres). These soils are most susceptible to wind erosion when the surface is bare and dry. Seale considers that serious blows occur once every 4 or 5 years. Adventurers' series forms the largest mapping unit (11.1%, 6,200 hectares 15,320 acres) to the north-east of Cambridge and here Hodge

and Seale (1966) report occasional wind erosion damage. Small areas of Isleham series (sand to loamy sand) have been mapped around Ely and Cambridge and these soils are known to blow. Between Cambridge and Peterborough, Seale (1975.2) has mapped soils of the Adventurers' series in the district around Chatteris. Here, in addition, small areas of soils of the Prickwillow, Ireton and Isleham series are reported as being susceptible to wind erosion.

In East Anglia, apart from in the Fenland, wind erosion adversely affects soils on the Breckland sands around Thetford and Brandon, and the sandy skirtland of west Suffolk. Corbett (1973) refers to 2 fairly extensive areas of blown sand to the north-east and east of Mildenhall and a small area to the south-west of Brandon and considers that wind erosion occurs to a limited extent in most years and seed beds occasionally need re-drilling. Sneesby (1953) refers to the records of 16 dust storms sighted at the weather station at Mildenhall in west Suffolk between 1935 and 1953. All but one of these 'blows' took place in late March and in April though blows have been recorded as early as February 27 and as late as June. Corbett and Tatler (1970) have mapped soils of the Adventurers', Prickwillow, Isleham and Freckenham series to the north of Beccles, east Norfolk. Wind erosion occurs on the Freckenham series but is not considered to be of importance.

Localised damaging wind erosion has been reported from the West Midlands - notably in east Shropshire by the writer (1972) and in Worcestershire, around Kidderminster by Hollis

and Hodgson (1974). The principal soils affected are Newport, Bridgnorth, Bromsgrove and Wick series and the distribution and frequency of erosion is considered in Chapter 7, which deals specifically with the West Midlands.

On the Wirral peninsular in Cheshire occasional crop failures result from wind erosion on very fine loamy sands and fine sandy loams of the Dee series and blowing is known to affect soils of the Crannymoor series (Furness and King 1973) and sandy loams and loamy sands of the Stockbridge series near Crewe, Cheshire (Furness 1971). Other instances of wind erosion are reported in Lancashire on Shirdley Hill sand and organic soils (Hall and Folland 1970), on the Tywood series, Pembroke (Rudeforth 1974), and in the middle Teign valley and the Exeter district of Devon (Clayden 1964 and 1971). He cites localised wind erosion affecting soils of the Bridgnorth and Crannymoor series, which in the latter district cover 6,480 hectares, 16,010 acres (6.5% of the area surveyed).

In the Howe of Strathmore, eastern Scotland, Ragg (1973) refers to wind erosion on arable land which on occasions blocks roads with sediment. He also describes other areas along the Moray Firth and Eastern Seaboard which are prone to wind erosion where sandy soils developed in fluvioglacial raised-beach and blown sands are prevalent. Glentworth (1954) describes the soils around Banff, Huntly and Turriff and refers to wind erosion affecting light textured soils of the Corby and Boyndie association under conditions of unusual dryness in spring. Burnham (personal communication) referred to serious blowing on arable land around Aberdeen

during the dry spring of 1968 and Glentworth^{and} Muir (1963) record wind erosion on the Boyndie association which is developed on fluvioglacial sand.

3.4 Summary

1. The distribution of wind and water eroded soils in the United Kingdom is reviewed in the light of our present knowledge.

2. Data sources are principally memoirs and records of the Soil Survey of England and Wales and Scotland. This data reveals that a wide array of soil series are affected to a greater or lesser degree by wind and water erosion. Even so, in the literature there is a general reluctance to acknowledge that soil erosion by water constitutes a problem in lowland Britain.

3. The most widespread problem referred to in Soil Survey reports is loss of surface structure in arable soils which is a common feature of sands, loamy sands, sandy loams, silt loams and peaty loams, particularly where continuous arable agriculture is practised and soil organic levels are low (<3%). The mechanics and characteristics of loss of structure are considered in the following chapter.

4. In Figure 8 the distribution of sandy parent materials which give rise to light soils are mapped. The parent materials are derived from Permo-Triassic sandstones and pebble beds, glacial and fluvioglacial sands and gravels,

sandy stony morainic deposits, aeolian sands and river terrace deposits. Dominant soil groups represented are brown sands, brown calcareous earths, brown earths, argillic brown earths, podzols, gley podzols, sandy gley soils and stagnogley soils.

5. References to soil erosion in Scotland are confined primarily to the Eastern Coastal Plain and to the Central Lowlands. Evidence of wind and water erosion is cited though neither is considered to constitute a problem in Scotland.

6. The distribution of water erosion is more widespread in England and reference to it affecting particular soil series, notably Bromsgrove, Bridgnorth, Newport, Wick, Arrow and Crannymoor series reoccurs in a number of papers. Some estimates are given of soil loss per hectare during erosive storms.

7. All the principal forms of water erosion on arable soils are referred to with the most commonly encountered forms being sheet and rill erosion.

8. Whereas the distribution of water eroded soils is widespread, particularly in lowland Britain and affects both coarse, medium and fine textured soils, the greatest concentration of wind eroded soils lies in the drier eastern part of Britain. The farming systems are dominated by arable enterprises with large exposed fields characterised by sandy and organic soils which are very susceptible to

damage by wind erosion when in a dry 'fallow' condition.

9. Soils series which are liable to blow and those which occasionally blow are listed in Tables 7 and 8.

10. There has been a significant increase both in the area affected and in the frequency of serious blows since the 1930's when major changes took place in farming systems with sugar beet and subsequently continuous barley growing becoming important. The impact of these changes on the soil system is examined in the following chapter.

Chapter 4

Analysis of the principal factors affecting the erosion of arable soils by rainfall and raindrop splash

4.1 Introduction.

4.2 Mechanics of rainfall erosion.

4.2.1 Raindrop characteristics.

4.2.2 Raindrop impact and splash.

4.2.3 The effect of raindrop impact and splash on infiltration.

4.3 Basic factors affecting field soil loss.

4.3.1 Climatic factors; rainfall.

4.3.2 Soil erodibility.

4.3.3 Slope characteristics.

4.3.4 Crop and management practices.

4.4 Summary.

Chapter 4

Analysis of the principal factors affecting the erosion of arable soils by rainfall and raindrop splash

4.1 Introduction

Ellison (1944) defined soil erosion 'as a process of detachment and transportation of soil materials by erosive agents'. In this chapter the agents examined are rainfall and rainfall splash with the main emphasis being on soil detachment by rainfall, transport by raindrop splash and the effects of splash on infiltration. Soil detachment by run-off and transport by run-off which are identified as separate but inter-related phases of the process of soil erosion by water are described in Chapter 5.

The four basic factors that can be identified as affecting soil loss in the field are rainfall, soil erodibility, slope characteristics and crop and management practices (including conservation measures). This chapter seeks to examine the factors which are significant in understanding soil erosion processes. In this regard emphasis is placed here on examining previous research which is broadly relevant or is directly applicable to erosion studies in the United Kingdom.

4.2 Mechanics of rainfall erosion

4.2.1 Raindrop characteristics

Wollny recognised the destructive effect of beating raindrops

on exposed soil surfaces as early as 1877 and research up to the 1940's by a number of authors, Lowdermilk (1930), Duley and Kelley (1939), Bennett (1939), Laws (1940), Laws and Parsons (1943) and Ellison (1944) has tended to confirm his observations and investigate many new aspects of the problem. Most of the published results at that time had been obtained either by the filter paper method or the flour pellet method. In the former method, filter paper supported in a frame and treated with a powder dye is exposed to rain for short periods. The stains made by drops are counted, measured and interpreted in terms of drop sizes with the aid of a calibration curve appropriate to the paper in use. In the latter method raindrops fall into pans of sifted flour and produce dough pellets which are subsequently baked and graded through sieves (Best 1950).

The United States Soil Conservation Service carried out a series of studies in the period 1936-1940 on the relation of raindrop size to erosion and infiltration as part of a general programme of investigation into the mechanics of the water erosion process. The main properties of rainfall studied included raindrop mass size, size distribution, shape, velocity and direction. From these variables the kinetic energy ($0.5 \text{ mass (velocity)}^2$) and momentum (mass x velocity) can be determined.

Drop size

Laws (1940) described how the infiltration rate after $\frac{3}{4}$ hour of rainfall decreased with an increase in kinetic energy of

the drops falling per unit area. He also found, 'that the erosional losses, which are measured in terms of the concentration of the soil in the run-off water, increased by as much as 1200%', as the drop sizes were increased. Laws and Parsons (1943) investigated drop size distribution in natural rainfall and this was to mark the beginning of the concept 'that erosion is a work process for which energy is supplied by the falling raindrops and the slope of the land down which the run-off flows'. It appeared likely to the authors that if drop size were averaged over larger areas and for longer periods of time, the median drop-size would be a fairly strict function of rain-intensity and that an increase in rainfall intensity would show an increase in median drop size.

Drop size distribution is described by the parameter D_{50} which is referred to as the median drop size. Laws and Parsons (1943) described the relationship of median drop size to intensity by the equation $D_{50} = 3.23 I^{0.182}$ in which I is intensity in inches per hour. Best (1950) in an analysis of the size distribution of raindrops found that the frequency curve for drop size was skewed towards the large diameters with a maximum diameter of 7.2 mm. A value D_{50} was derived such that 50% of the water in the air was composed of drops with diameters smaller than D_{50} . $D_{50} = 0.69 I^{1/N} A.I.P.$ where N , A and P are empirically derived constants and I is intensity. A number of research workers found that drop size distribution may be correlated with a number of factors such as rate of rainfall, type of rain (orographic, non-orographic) and periods throughout a storm. In orographic rain, drops

seldom exceed 2.0 mm in diameter and intensities usually do not exceed 25.4 mm per hour.

Blanchard (1953) considers that the median drop diameter for this type of rain is approximately half that in non-orographic rain of the same intensity. Table 9 gives the analysis of several rainstorms and shows the distribution of drop sizes within the range 0.5 mm to 5 mm. Drop size increases as the rate of rainfall per hour increases. Mihara (1952) noted that when the intensity of the rainfall becomes 'strong' the larger drops will increase but the number of small drops will become exceedingly larger. Hudson (1971) found that drop size declined slightly in high intensity falls and maximum drop sizes appear to be in the order of 5-6 mm diameter. Blanchard (1950) found that all drops larger than 5.4 mm were broken apart when supported in turbulent air-flow whereas in non-turbulent air only drops smaller than 7.7 mm were stable for any length of time. The drop size distribution in rain acquired increased importance in the late 1940's as a result of the use of radar to locate precipitation. The radar signal reflected from precipitation is very sensitive to the size of raindrops. Studies using radar related drop size distribution and liquid water volumes per unit volume of the atmosphere (m^3) to the radar reflectivity factor Z by empirical equations of the exponential type (Smith and Wischmeier 1962).

Drop velocity

Gunn and Kinzer (1949) found that drops smaller than 0.08 mm

Table 9

Number of raindrops of various sizes in nine rainshowers

Drop Diameter (mm)	Number of drops per square metre per second								
	1	2	3	4	5	6	7	8	9
0.5	1000	1600	129	60	0	100	514	679	7
1.0	200	120	100	280	50	1300	423	524	233
1.5	140	60	73	160	50	500	359	347	113
2.0	140	200	100	20	150	200	138	295	46
2.5	0	0	29	20	0	0	156	205	7
3.0	0	0	57	0	200	0	138	81	0
3.5	0	0	0	0	0	0	0	28	32
4.0	0	0	0	0	50	0	0	20	39
4.5	0	0	0	0	0	200	101	0	0
5.0	0	0	0	0	0	0	0	0	25
Total No.	1480	1980	486	540	500	2300	1829	2179	502
Rate of Rainfall mm/hr.	5.4	3.6	6.6	3.0	19.2	43.2	34.3	21.2	15.6

Columns 1 and 2: refer to a rain which looked very 'ordinary', the wind had freshened between 1 and 2.

Column 3: rain with breaks during which the sun shone.

Column 4: beginning of a short fall like a thunder shower, distant thunder.

Column 5: sudden rain from a small cloud, calm sultry before rain.

Column 6: violent rain like a cloudburst, with some hail.

Columns 7, 8 and 9: are for the heaviest period, a less heavy period and the period of stopping of a continuous fall which, at times, took the form of a cloudburst.

Source: modified from P. Lenard, quoted in Meteorological Glossary London HMSO 3rd Edition 1939 Page 157.

in diameter obeyed Stokes' Law for their fall velocity. Laws (1941) and Gunn and Kinzer concluded that the change in shape of larger drops tends to decrease their terminal velocities. Air turbulence and winds also affect the terminal velocity of raindrops in natural rain. A horizontal wind increases terminal drop velocity by the reciprocal of the cosine of the angle of inclination of the rain with the vertical (Smith and Wischmeier 1962). 'In a heavy, driving rain with a 3 mm median drop size and a 30 degree angle of inclination, the velocity would be increased 17% and the kinetic energy would be increased by 36%. (Smith and Wischmeier 1962).

Kinetic energy of rainfall

Evidence which links the momentum or energy of rain with its ability to cause soil erosion is now well established even though present methods of measuring kinetic energy of rainstorms are not satisfactory and tend to be indirect rather than direct. Direct measurements of kinetic energy of falling rain have been attempted with the use of an impactometer, by a rain driven vane or paddle wheel (Rose 1958, Hudson 1965)* or by the use of an acoustic recorder (Kinnel 1968). None of these devices has proved to be successful primarily because wind effects tend to swamp the low levels of signal picked up by the sensors. Kowal et al (1973) describe a simple device for analysing the energy load and intensity of rainstorms by using an instrument which records graphically on a time scale the amplitude of electric pulses. These originate from the impact of raindrops on the surface of a transducer

* Quoted in Hudson 1971

disc by making use of the piezo-electric effect.

The size distribution of raindrops is calculated by analysing the graphic records of pulses on the chart, from the number and the amplitude of pulses and from the measured volume of total rainfall. The technique provides a convenient and relatively simple means of assessing the drop size distribution of storms from which the kinetic energy or momentum can be deduced using apparatus which is commercially available and requires little calibration.

Smith and Wischmeier (1962) consider that the key to the computation of kinetic energy is the intensity-drop size relationship, since intensities may be secured from recording rain-gauge records. This intensity may then be compared with calculated kinetic energy. In Figure 9 (Page 9) Hudson (1971) plots the relation between kinetic energy and intensity of rainfall from studies by various workers in different countries. An energy equation was derived by Wischmeier and Smith (1958) from published data on drop velocity by Gunn and Kinzer (1949) and by Laws (1940) and on drop size distribution by Laws and Parsons (1943). The equation is $E_K = 916 + 331 \text{ Log}_{10} I$, in which E_K is kinetic energy in foot tons per acre inch of rain, and I is intensity in inches per hour (joules per square metre of ground per mm of rain expressed in S.I. units).

Raindrop impact and splash

The principal effect of raindrop impact on an exposed soil

surface is the detachment of soil particles, thus making them available for transportation by surface run-off. Rain-drop impact and splash causes the dispersion of soil particles. The degree of dispersion depends upon the detachability of the soil and the detaching capacity of the rain. Ellison (1947) considered that the soil properties which affected soil detachment may vary with (a) the cohesive properties of the soil (b) shape of particles that may affect their interlocking (c) the distribution of particle sizes that affect their interlocking (d) sizes of particles as this may affect the smoothness of the surface that is exposed (e) chemical properties of the soil (f) biological conditioning of the soil and (g) physical condition of the soil. Other experiments showed that detachment of the same soil varied with its structural condition and that pulverizing a soil (by forcing tilths for example) greatly increased its susceptibility to raindrop action (Woodburn 1948). These soil properties are dealt with more fully in section 4.3.2.

Ellison (1944) established splash erosion as the initial phase of the water erosion process and demonstrated 'that in addition to the soil moved down slope by flowing water some soil is carried down-hill by splash from raindrops'. By measuring rain splash effects direct from splash cups, thus reducing the effects of run-off, Ellison showed that 75% of soil splash on a 10% slope moved down slope and only 25% moved upslope. He recorded an increase in the quantity of splashed soil as drop size, drop velocity and rain intensity increased. Sand particles 1 - 2 mm in size were splashed by the larger drops and there was an apparent down-

slope movement of particles as large as 8 mm. Ekern and Muckenhirn (1947) found that on a similar slope (10%) that a 60% down slope and a 40% up slope movement of soil material took place. One explanation for the differential movement by vertical raindrops striking the soil surface is that down hill splash travels further before re-joining the soil surface and the angle of impact results in a greater down slope component (Smith and Wischmeier 1962). This effect becomes more marked on steeper slopes where appreciable movement of soil materials can take place without run-off (Stallings 1957). In the field wind speed and turbulence will affect the terminal velocity of raindrops and wind direction will affect losses from slopes facing the direction of a storm.

Ekern (1953) found that fine sand (0.25 - 0.175 mm) allowed optimum transport by drop impact. Larger separates underwent less movement because of the weight of the individual particles and finer separates allowed the formation of a surface seal and the accumulation of water films on the soil surface. He found the following relation, which is shown in Table 10:

Table 10

Effect of particle size on transport by drop impact

Separate size	Diameter limits (mm)	Relative amount of transport 5-minute interval
Coarse sand	0.84 - 0.59	30.0%
Medium sand	0.42 - 0.25	77.2%
Fine sand	0.25 - 0.175	100.0%
Very fine sand	0.10 - 0.05	61.0%
Silt	.05 - 0.002	21.0%

Source: Ekern P.C. 1953 Page 25.

The nature of the erosive features of impacting force Ekern delineated as follows:-

Erosivity = F (precipitation intensity x time x (drop mass/drop cross section) x drop velocity²)

This force was shown effective in the movement of fine sand of which approximately 8 tons per acre (3.3 tons per hectare) would be transported by the impact of drops from a rainfall of 4 inches (101.6 mm) per hour continuing for a 5-minute period. This force, according to Ekern would distribute the material over distances up to 5 ft. (1.5 metres) with a preference for the downslope direction determined as:

Downslope % = 50 + slope %.

Splash erosion erodes the tops of the slopes owing to differential downslope splash movement. Mihara (1952) found that the height and distance of splash depends upon the soil surface condition and the velocity of fall of the drop. He reported a significant increase in splash height when drops fell on compacted cultivated soil (the splash from 6 mm drops reached a distance of 59 inches) (149 cm). The moisture status of the soil at the commencement of a storm is significant as Ellison reported maximum splash occurring shortly after the surface was wetted. The rate of splash then decreased probably owing to an increase in the depth of the surface film of water which tended to mask soil particles from drop impact.

The research referred to above was based on gravimetric measurements whereas other workers have used radioactive methods of labelling, detection and assay as a method of

tracing the movement of soil particles. Coutts et al (1968 a and b) used radioactive ^{59}Fe for tracing soil particle movement from trays and small ground plots using clay loam and sandy loam soils. They consider that direct labelling with ^{59}Fe offers considerable promise for erosion studies under natural conditions in cultivated fields. Four trays were used for each soil, one of which was placed horizontally, while the other three were inclined at angles of 3° , 6° and 12° . The movement of labelled particles from the trays were recorded by changes in relative total count rates and these are recorded in Table 11.

Table 11

Estimate of the percentage retention of ^{59}Fe on soil trays

Soil	Sandy loam		Clay loam	
	Assay No.			
Slope ($^\circ$)	2	3	2	3
0	-15.2	-38.0	+ 2.6	- 7.1
3	-16.2	-45.2	+ 1.7	+ 7.6
6	-19.7	-50.4	+ 0.6	-11.6
12	-56.9	-64.9	-12.8	-46.8

Source: Coutts et al 1968a Page 316.

These data show that there were appreciable losses of ^{59}Fe in all cases from the sandy loam, but that in the case of

the clay loam losses occurred mainly under the severe conditions imposed by the 12° slope. Gravimetric measurements from splash trays (without labelled particles) showed that in all cases for sandy loam the existence of a strong wind bias effect was accentuated by the slope factor, whereas it was absent with the clay loam when the rain intensity was only 1 mm/hr. even though wind velocity was high, probably because the rain intensity was too low to disintegrate the peds in the clay loam. Most deposition of splashed material was found nearest to the tray but a small proportion was found more than 70 cm beyond the catchment frame.

4.1.3 The effect of raindrop impact and splash on infiltration

Moldenhauer and Long (1964) found that the most important factor influencing soil loss was the infiltration rate. Infiltration rate has been defined by Horton (1945) as the maximum rate at which a given soil when in a given condition can absorb rain as it falls. Quantitatively, infiltration rate is defined as the volume of water passing into the soil per unit area per unit of time. Horton has shown that infiltration rate will decrease with rain duration in accordance with the equation: $F = F_c + (F_o - F_c)e^{-k_f t}$. Where F_o is the initial infiltration capacity at the beginning of the rain which initially can be quite rapid, F_c is the final constant infiltration rate which results from the combined action of loss of structure by disintegration and dispersal of soil aggregates. K_f is a constant which controls the time required under given conditions for the infiltration rate to change from the initial value F_o to nearly its con-

stant value F_c . K_f is dependent on the rate of energy application to the soil surface and $e = 2.71828$ (the base of Napierian logarithms). As F decreases during the rain-storm, run-off increases.

Sor and Bertrand (1962) in a study of the effect of rainfall energy (simulated) on permeability of soils found that the energy of raindrops falling on a bare soil surface had the greatest effect on the top layer (0 - 1.5 cm) and also caused some decrease in the water permeability of lower layers (3 - 12 cm). They established that 30 minutes of rainfall at an intensity of 2.8 inches per hour (71.2 mm/hr) was sufficient to give maximum decrease in water permeability on a Russel silt loam soil. The greatest dispersion and compaction of soil appeared to be in the top 1 mm. Soil was compacted but to a lesser degree to a depth of 3.0 cm after 30 minutes of rainfall. Bertrand and Sor (1962) reported that rainfall impact of 71.2 mm/hr intensity caused soil particles labelled with Rb^{86} to migrate to depths of up to 7.5 cm and after 40.6 mm/hr intensity, aggregate stability, specific surface, clay and organic matter contents of the top layer (0 - 1.5 cm) were 2 to 14% lower than in the sub-layers (1.5 to 12 cm). They also found that rainfall intensities of 2.8 and 4 inches per hour (71.2 mm and 102 mm) produced greater changes in the properties of the top layer and considerable changes in the second layer (1.5 to 3 cm) of the Fox sandy loam, Russell silt loam and Chalmers silty clay loam than did the 1.6 inches per hour rainfall (41 mm). Tackett and Pearson (1965) recorded surface crusts 1 - 3 mm thick in the Hartsells fine sandy loam under a simulated rainfall of 50.8 mm. The surface was

coated with a thin skin of very well orientated clay. Within the surface 1 to 3 mm layer the coarse grains and matrix were very closely packed with no visible voids, ^{thus} exhibiting a structure like that of a fragipan. Below the crust layer the structure was open and porous and water permeability was about 5 times that of the surface layer 0 - 5 mm.

Other factors which can affect infiltration rate include soil moisture status prior to the onset of erosive rainfall and the destructive effect of freeze drying on soil aggregates which leaves a thin mantle of fine soil on the surface. This would tend to reduce the infiltration rate of subsequent rainfall (Hinman and Bisal 1973). Dixon and Peterson (1971) developed a channel-system concept describing the mode and intensity of water infiltration as a function of surface roughness and openness. They stressed the importance of large pores on water movement and showed that infiltration could be increased within a few months of no-tillage operations by undisturbed earthworm activity. Ehlers (1975) reported that the number and percentage volume of earthworm channels in the Ap horizon of grey brown podzolic soil derived from loess approximately doubled during four years of no-tillage practice (i.e. direct drilling as opposed to conventional tillage). The maximum infiltration rate of conducting worm channels in the untilled soil was computed as more than 1 mm (1 litre per m²) per minute although the volume of these channels amounted to only 0.2 volume per cent.

The effects of raindrop impact and splash on soil aggregate dispersal, compaction and reduced infiltration are exacerbated by

surface and subsurface compaction caused by heavy farm machinery. Severe compaction can result in a reduction of the air filled porosity value of field soils to below 10% and as a result of excess precipitation and restricted permeability it may drop to below 5% (Soane 1970). Marked reductions in hydraulic conductivity result from an increase of dry bulk density, for example an increase of bulk density from 1.2 to 1.4 g/cm³ has been found to cause a ten-fold decrease in hydraulic conductivity (Taylor and Henderson 1959). The presence of a well developed plough pan is likely to act as a severe restriction to the drainage of excess water and lead to a rapid saturation of the Ap horizon during a prolonged storm, with the attendant risk of increased surface run-off. Further consideration is given to the problem of compaction and its effects on soil loss in later chapters.

4.3 Basic factors affecting soil loss in the field

Four basic factors which affect soil loss in the field can be identified; climatic factors, soil erodibility, slope characteristics and crop and management practices.

4.3.1 Climatic factors

In the British Isles rainfall is undoubtedly the most important single factor which affects soil loss. Freeze-thaw action is also significant in both the breakdown of soil clumps and aggregates which in turn tends to increase susceptibility to detachment by raindrop splash and wind deflation. Detached frozen sand-sized particles and small aggregates are also

easily transported by strong winds as are finer fractions which adhere to frozen snow blown off exposed fields. Drifted snow in east Shropshire during the winter of 1962-3 contained thin bands of red sand and soil (fine to very fine) see Figure 10 (Page 10). During a rapid thaw accompanied by heavy rain, run-off from partially frozen ground can cause severe erosion. This is a fairly common feature in the wider areas of North America and Europe and on occasions has been recorded in the West Midlands after cold winters (1962-3 and 1979).

The increased erosiveness of wind driven rain during storms has already been referred to and this is particularly significant in areas of strongly undulating terrain. Wind as an erosive agent on arable land is considered in Chapter 6.

4.3.1 Rainfall

The main emphasis in this section is to examine ways of estimating erosivity from rainfall data and to consider in general the principal characteristics of rains that affect run-off erosion. In Chapters 7 and 8 estimates of actual and potential erosivity are evaluated from daily rainfall records in the West Midlands and related to case studies of soil erosion in east Shropshire.

The principal characteristics of rains that affect run-off and erosion are considered to be intensity, duration, distribution of rainfall intensity throughout a storm, frequency of occurrence, seasonal distribution and areal distribution. The

potential ability of rain to cause erosion is referred to as erosivity, and is a function of the physical characteristics of rainfall discussed in Section 4.1.

Data from a wide array of field plot studies in the U.S.A. is summarised by Wischmeier et al (1958). These data show that soil loss was poorly correlated with rainfall amount even for specific storms, and correlation of soil loss with maximum 5, 15 or 30 minute intensities was also generally poor. However, the authors did find a good correlation with maximum 30-minute intensity on steep slopes or sandy loam and these findings have been authenticated by plot studies in east Shropshire (see Chapter 9). Wischmeier (1959) found that the factor most closely related to erosion was the kinetic energy of the rain. Further multivariate analysis of field plot data in the U.S.A. led to the adoption of a compound parameter called the EI_{30} index which most satisfactorily explained soil loss in terms of rainfall. The EI_{30} index is the product of kinetic energy E and intensity I , where I_{30} is the greatest average intensity in any 30 minute period during a storm. The value of this compound parameter is that it can be computed from autographic raingauge charts by isolating the greatest amount of rain which falls in any 30-minute period, and then doubling this amount to get the same dimensions as intensity in mm per hour.

The EI_{30} index evaluates the interacting effect of total storm energy and maximum sustained intensity. Smith and Wischmeier (1962) concluded that the erosive potential of a rainstorm is

primarily a function of the interacting effects of drop velocity, rain amount and maximum sustained intensity. The authors found that for prediction of losses from specific storms, precision was improved by combining with the EI_{30} index, the parameters: rainfall energy, an antecedent moisture index, and antecedent energy since cultivation (Wischmeier and Smith 1958).

Hudson (1971) developed the concept of the threshold value of intensity at which rain becomes erosive. Experimental work showed that there is a threshold level of intensity, though variable from one storm to another, and erosion is almost entirely caused by rain falling at intensities above this critical level. Hudson found that the value in Africa was about 25 mm per hour and this was presented in the KE 25 index. The amount of rainfall in each class of intensity is multiplied by the appropriate energy value, and the energy is totalled for the whole storm in joules/m^2 .

Morgan (1977) uses the index KE 10 defined as the total kinetic energy of all rains falling at intensities of 10 mm/hr or greater for at least 10 minutes. The index is similar in principle to the KE 25 used by Hudson (1971) and employs the same relationship between kinetic energy and rainfall intensity.

High intensity rainfall is associated with storms of varying severity and duration. Bleasdale (1963) considers that exceptionally heavy rainfalls are predominantly a winter phenomenon in the high rainfall areas, whilst they are overwhelmingly a summer phenomenon in areas of lower rainfall,

with a definite bias towards the three months, July to September. The causes of severe storms in this country from May to September are considered by Crossley and Lofthouse (1964) to be: instability through a deep layer of the atmosphere associated with surface heating; with slow moving cold fronts or troughs or with low pressure over the Bay of Biscay or northern France. The authors consider that all these situations favour the outbreak of storms most frequently over central, eastern and southern England and these are usually associated with heavy falls of rain.

Reynolds (1978) divides individual storms into two groups: short duration convective storms with a typical duration of 1-2 hours; and storms usually caused by groups of thunderstorm cells with durations of 24 to 48 hours. The location of the first group occurring this century with rainfall greater than 100 mm are all south of a line joining Anglesey to Newcastle and all the storms plotted occurred between May and October. The locations of daily rainfall observations greater than 175 mm shows a high concentration in or close to high mountains, and in south-west England or Wales with only a small percentage occurring in eastern England. Jackson (1974) catalogues 50 of the largest 2-hour falls of rain measured in the British Isles this century. The falls range from 155 mm at Hewenden Reservoir, near Bradford (11.6.1956) with an average rate 77.5 mm/hr for 2 hours, to 85 mm at Ipswich, Suffolk on 1st July 1902 with an average rate of 42.5 mm/hr for 2 hours. Many of these falls have a long return period and may only affect a small area.

However, Bleasdale (1974) describes 3 major rainfall events over very big areas in different parts of Britain during 1968 (end of March to mid-September) with exceptionally large one day or two-day falls and these are reproduced in Table 12.

Table 12

Major rainfall events of 1968

Event	Date and Duration	Location	Largest measured fall mm	Estimated areas (km ²) with falls exceeding selected thresholds		
				150mm	100mm	75mm
1	26-27/3/68 D2	West and NW Scotland	250	6800	12500	75mm (?)
2	10/7/68 D1	Devon to south and central Lincolnshire	170	83	2250	11500
3	14-15/9/68 D2 DC	South-east England	200	575	6250	12500

Note Duration D, is one rainfall day, D2 two rainfall days, and DC largely within one civil day.

Source: Bleasdale (1974) Page 224.

Lamb (1978) draws our attention to the fact that when due consideration is given to the relatively small area of our land surface which is covered by rain gauges, it seems probable that our sampling of the greatest downpours of rain is inadequate. He considers that convergent air motions and great vertical (upward and downward) velocities in funnel clouds can concentrate the water content from great volumes of air and occasionally precipitate them on areas a few tens of metres wide and long.

a few tens of metres wide and up to a few hundred metres long. Cloud bursts resembling this type have been recorded in east Shropshire and have caused spectacular soil erosion.

Soil erosion monitoring in the West Midlands (1967-1979) has shown that erosion occurs at levels of intensity and duration much less than those quoted above. Rainfalls of 10 mm or more within a 24-hour period are sufficient to initiate erosion on exposed, compacted sandy soils. When estimating the erosivity of local rainfall it is also necessary to examine the cumulative effect of a number of days of rain and this has been done for selected stations in east Shropshire using the pentad system of subdividing the year into 73 five-day periods or pentads. In this respect pentads exceeding 30 mm of rainfall have been identified with erosive episodes during periods of the year when soils are in a susceptible fallow state. Soil erosion monitoring also makes it clear that when estimating rainfall erosivity the parameter should not be considered in isolation but in conjunction with soil erodibility and management practices.

4.3.2 Soil erodibility

Field observations indicate that some soils erode more readily than others even when rainfall, slope, crop cover and management practices are the same. This difference is referred to as soil erodibility and is a function of the soil properties. The properties that influence soil erodibility by water are (a) those that affect the infiltration rate, permeability and water holding capacity, and (b) those that resist the

dispersion, splashing, abrasion and transporting forces of rainfall and run-off. Hudson (1971) considers that erodibility is influenced more by management than by any other factors and this consideration is examined in more detail in Section 4.3.4.

Soil erodibility may be assessed either by actual measurements of soil loss under controlled conditions afforded by measured plots or by the isolation of particular soil properties as indices of erodibility. Bryan (1968) reviews the development and use of indices of soil erodibility during the period 1938-1968 and concludes that no erodibility index can be regarded as efficient for universal use in the absence of plot run-off data. Wischmeier and Mannering (1969) examined the physical and chemical properties which influence soil infiltration capacity and detachability in a 5-year field, laboratory, and statistical study, including 55 selected Corn Belt soils. Properties that contributed significantly to soil-loss variance included percentages of sand, silt, clay and organic matter; pH, structure and bulk density of plough layer and subsoil, steepness and concavity or convexity of slope, pore space filled by air, residual effects of leys, aggregation, parent material and various interactions of these variables.

4.3.2.1 Relation of erodibility to soil texture, soil aggregates and organic matter

It is generally accepted that soils high in silt, low in clay and low in organic matter (<2%) are the most erodible. In

most cases a decrease in silt fraction of a soil type renders it less erodible regardless of whether the corresponding increase is in the sand fraction or the clay fraction Wischmeier et al (1971) found that the ability of these parameters to predict erodibility (singly or in combination) was disappointing in all preliminary analyses until the silt grade was redefined to include very fine sand and the sand grade defined as particles from 0.10 to 2.0 mm and this improved the prediction values of the two parameters considerably.

Barnett et al (1965) in a study of soil erodibility factors for selected soils in Georgia and South Carolina found soil texture to be more important in the determination of soil erodibility than was considered in the original estimate of K-factor values (in the universal soil loss equation referred to in Section 1.3 Page 21). The relationship of texture to increasing erosion per EI unit (K factor) was from sand to loamy sand to sandy loam to sandy clay loam to silt loam. One particular soil, the Iredell sandy clay loam was considered to be very erodible. As clay content increased and the sand fraction became coarser erodibility increased. Erodiability increased as surface texture became coarser, particularly where stones were present in large numbers. The presence of gravel* is considered to afford protection from raindrop impact but causes increased run-off because of the decreased surface available for infiltration. This

*This is corroborated for stony soils in east Shropshire but only where the soil surface has been compacted thus reducing infiltration between the stones.

increased microchannel flow and attendant increases in erosional energy resulted in higher erosion losses. The erodibility of Iredell soils was attributed to the ease with which soil aggregates dispersed and the density and impermeability of the aggregates to water.

It is considered by a number of workers that the most significant soil property in determining erodibility is the quantity of water stable aggregates. Bryan (1974) maintains that this far outweighs the importance of any particle size range except on extremely poorly aggregated sandy soils. The main mechanism of aggregate breakdown on hydration is considered to be slaking rather than differential swelling and therefore clay mineral type is not considered as an important control of erodibility, although montmorillonite content can influence infiltration capacity (Bryan 1974). Aggregate formation is the result of the interactions between different soil components such as mineral soil particles, organic matter, chemical soil components and water. Other factors such as vegetation, micro-organisms, earthworms, climate and cultivation methods also play an important part in the aggregation process (Harris et al 1966). The role of organic matter is particularly important as it serves as a granulating agent in soils for together with clay, organic colloids are responsible for the major portion of soil aggregation. Bayer^{et al} (1972) found a very high correlation existing between organic matter and aggregation in soils containing less than 25% clay. Daniel et al (1938) found colloidal organic matter more effective than clay in causing the formation of stable aggregates with sand. Wischmeier et al (1971) consider that overall, organic

matter content ranked next to particle size distribution as an indicator of erodibility. The rainfall energy needed to start run-off and the final infiltration rates increased directly with organic-matter increases, while soil content of the run-off was inversely related to organic-matter content.

4.3.2.2 The effect of induced soil compaction and bulk density of the plough layer on erodibility

When a load or pressure is applied to a soil surface by the passage of vehicles and machinery an increase in bulk density and shear strength will result, together with reduced porosity, air and water permeability. The changes brought about in a soil through applied ground pressure depend on both the strength characteristics of the soil and the nature of the applied load. Soil strength will depend on the soil moisture content, the degree of compaction and aggregation, the texture and the presence of roots and organic matter (Soane 1970).

The distribution of particle and aggregate size has been shown to have a marked influence on compactability of mineral soils. The plough layer of agricultural soils usually shows marked aggregation. The content of organic matter present also influences soil compactability, and field evidence suggests that the reduction in the content of organic matter in arable soils may be a major influence in the deterioration of soil structure and leads to increased problems of soil compaction.

Soil strength usually varies greatly with depth depending upon previous management and on the distribution of moisture content (Soane 1970). When a wet soft surface layer of a recently tilled or rotovated soil overlies a drier compact subsoil, soil strength increases with depth. The passage of heavily laden wheels over such a soil will result in considerable wheel sinkage*. The degree of sinkage will depend on the inflation pressure and the type and dimensions of the tyre (Soane 1970). See Figure 11 (Page 11).

Tyres which are inflated to high pressures behave as if they were rigid when moving over soils of low strength whereas low-pressure tyres may deflect appreciably under all conditions. On soils of high strength the lug pattern on tractor drive wheels can be the only part of the tyre in contact with the soil whereas on soil of low strength a considerable proportion of the area between the lugs may be in contact with the soil. Field observations of sloping sites where arable soils have been eroded reveal the importance of the above data in assessing the causal factors of erosion. Four main contributing factors can be identified associated with the passage of tractor wheelings; sinkage or depth of track, width of track, the pattern of lug impressions and the angle of cultivation lines relative to field slope. It can be seen from Figure 11 (Page 11) that the contact area on a wet soil is nearly $2\frac{1}{2}$ times as great

* Sinkage: a term used in agricultural engineering to describe wheel compression of the soil (ground pressure) which is conditioned by soil type, moisture content, wheel size, pressure and load.

for the same tyre pressure on a hard dry soil, the depth and width of track shows a marked increase on a wet soil. The compaction effects can be readily traced to the depth of ploughing even though subsequent tillage operations after seeding may obliterate wheel track evidence on the surface of the field. It is estimated that some 90% of the total area of a field may be affected by tractor wheelings made during the preparation of a cereal seedbed (Soane 1970). The effects of these tracks or wheelings in channelling run-off on sloping sites is discussed with examples in Chapter 5.

4.3.3 Slope characteristics

Slope characteristics are important in determining the amount of run-off and erosion from field surfaces. The slope characteristics which influence soil loss are degree of slope, slope length, curvature and to a lesser extent, slope aspect, though locally this can be very important. As gradient has a marked effect on mechanised farming, consideration is given here to slopes which are classified as gently sloping ($0-3^{\circ}$) to moderately steeply sloping ($11-15^{\circ}$) as ploughing (in arable enterprises) of slopes greater than 15° is uncommon.

When considering the effect of slope characteristics on soil loss it is necessary to evaluate the influence of changes in field layout and cultivation practices as these can modify or increase the effect of slope and consequently increase or decrease the risk of run-off and erosion.

In landscapes with long established agriculture the length of natural slopes has usually been sub-divided by field boundaries. In the post-war period the rapid increase in mechanisation has created the need for larger field units and field amalgamation has resulted in enlarged fields with longer slopes and increased exposure. In undulating terrain the incorporation of several fields into one large unit often means slopes of different degree, length and aspect have to be managed as one unit and even with the best management practices, up and down slope cultivation invariably affects some part of the unit. Other significant factors include the extent of surface and sub-surface compaction along a field slope, the relative surface roughness and the amount of cover, if any, afforded to the soil during erosive rains.

4.3.3.1 Slope degree

Zingg (1940) made the first comprehensive study of the effect of slope on soil loss. Using data from a number of soil conservation experimental stations he concluded that erosion varied as $XC = 0.65S^{1.49}$ where XC is the total soil loss and S is the land slope in per cent. He found that doubling the degree of slope increased the total soil loss 2.8 times. He demonstrated that although the total run-off increased with the degree of slope, the effect of slope on run-off was not as great as on erosion. Run-off was found to increase significantly with increase in degree of slope even on soils which were of different texture and this was substantiated by other workers. Duley and Hays (1932) found that a silty clay loam gave a greater erosion loss on flatter slopes while

a sandy soil eroded more on steeper slopes. Soils subject to surface sealing tended to increase the effect of slope on run-off. This is borne out by field observations of soil erosion in the West Midlands.

Smith and Wischmeier (1957) evaluated the slope-soil loss relationship on the basis of plot data under natural rainfall collected by several investigators and the combined data gave a very good least square fit to the equation $A = 0.43 + 0.30S + 0.043S^2$ where A is the soil loss in tons per acre, and S the slope per cent. The curve from this equation matches that obtained with Zingg's equation.

The slope classes referred to in this text are those used by the Soil Survey of England and Wales (1976).

- 0 - 3° Gently sloping
- 3 - 7° Moderately sloping
- 7 - 11° Strongly sloping
- 11 - 15° Moderately steeply sloping
- 15 - 25° Steeply sloping
- 25°+ Very steeply sloping

4.3.3.2 Slope length

Studies in the U.S.A. of the relationship of length of slope to soil loss have demonstrated a large variation in experimental results which have^{been} attributed in part to different interpretations of what constitutes length of slope (Smith and Wischmeier 1957). A slope practice conference at Purdue University in 1957 proposed a definition of slope length as

follows: 'Slope length is the distance from the point of origin of overland flow to either of the following, whichever is limiting for the major portion of the area under consideration: (1) the point where the slope decreases to the extent that deposition begins or (2) the point where run-off water enters a well-defined channel. A channel is defined as a part of the drainage network of a size that is not readily obliterated by cultivation.'

It is generally accepted that soil loss per unit area increases as the length of slope increases. This results from the greater concentration of run-off as the slope length increases. Zingg (1940) studied the effect of slope length on soil loss and showed that total soil loss varied as the 1.6 power of the length, and soil loss per unit area as the 0.6 power of the length. He found that doubling the horizontal length of slope increased the total soil loss in run-off 3.03 times. From a study of various types of plot data Zingg concluded that a rational equation representing total soil loss for a general condition could be expressed as $X = CL^n$, in which X is the total soil loss, C is a constant, L is the length of slope and n is an exponent of horizontal length of land slope with a value of 1.6. Later Musgrave (1947) proposed 0.35 as the average value for the slope length exponent for soil loss per unit area and Smith and Wischmeier (1957) proposed for field use the value of the length exponent should be 0.5 ± 0.1 . Wischmeier and Smith (1965) use a combined topographic factor L.S for assessing slope length (L) and slope steepness (S) in the universal soil loss equation. Doubling the length of slope increases soil loss approxi-

mately 1.5 times. Doubling the steepness increases erosion approximately 2.5 times. The numerical value of L.S is the expected ratio of soil losses from a given length and steepness of slope to corresponding losses from the standard plot (9% slope 22 m long 1.83 m wide) L.S ratio for slopes of 2-20% in steepness and from 20 to 800 feet in length are available in charts or tables to calculate soil loss with this formula (Wischmeier 1977) (see Figure 12 Page 12).

The L.S values derived from this graph are for uniform gradients. For irregular slopes an adjustment must be made to the values (provided in special tables) to allow for the effects of the gradient changes and this is done by subdividing the slope into a number of equal length segments (with each segment being considered of uniform gradient) and multiplying the L.S values by a conversion factor (see Wischmeier 1974).

4.3.4 Crop and management practices

From an early date the value of crop and vegetative cover in controlling soil erosion was acknowledged. Soil conservation experimental stations in America carried out a wide range of field plot studies to assess the effects of different crops and cropping practices on erosion. It was observed that soil losses were largest from plots planted to inter-tilled crops and least from plots in grass. Soil loss from continuous corn was shown to be 50% less than from open fallow on the same slope and a rotation of corn, wheat and clover was instrumental in diminishing soil losses by 86% (Baver et al 1972). It was also demonstrated that the loss of topsoil resulting from erosion was reflected in a decline in crop yields from desirable levels and to minimise the risk

of soil erosion rotations with cropping sequences spread over three or more years together with suitable soil conservation practices were the considered goal. In the U.S.A. soil conservation experimental stations produced a wealth of data on the effects of crop management on soil loss. Wischmeier (1960) has proposed ratios for a comprehensive range of cropping systems in the U.S.A. which vary with the growth stage of the crop and are used to evaluate the crop-management factor C in the Universal Soil Loss equation. The total influence of factor C has been sub-divided by Wischmeier (1974) into three distinctive types of effects: canopy, mulch and residual effects of long-term land use. Of these, surface mulches are most effective in dissipating raindrop impact and have the added advantage of reducing surface run-off and sealing. The effectiveness of crop canopy in dissipating raindrop impact is influenced by its density and elevation above ground. Crops in an early stage of growth usually afford little protection to the soil. Closely spaced row crops like grains afford more protection at early stages of growth than sugar beet. The effectiveness of crop cover is reduced on steep slopes when rain is driven obliquely by strong winds. The overall erosion-reducing effectiveness of a crop depends largely on how much of the erosive rain occurs during those periods when the crop or management practice provides the least protection. The residual effects of long-term land-use will differ depending upon the cropping and management practices. Continuous arable cultivation will tend to depress soil organic levels which in turn heighten the risk of soil erosion on some soils.

* For a description of these ratios see pages 22 and 23.

Continuous corn growing with cultivation parallel to slope can lead to serious soil erosion, with a reduction of soil depth and a decline in crop yields. Therefore, past land use practices have to be assessed when considering soil conservation measures. An extensive programme of soil conservation was introduced in the U.S.A. during the late 1930's and 1940's with the widespread adoption of contour tillage, contour strip cropping, terracing, listing and mulching practices. Soil erosion hazard was reduced significantly though economic pressures in the last two decades have led to shortening of rotations and an increase in continuous cropping with renewed erosion.

A system of crop production which provides for the continuous use of a mulch blanket of crop residues to protect the soil, the 'no-till' system, exhibits the potential for becoming the most significant single conservation measure yet developed to control erosion and sedimentation (Gard and McKibben 1973). Land which was previously considered as usable only for pasture because of wind or water erosion hazards can now be utilized for more profitable row crops using the 'no-till' method. McClure et al (1968) show in Table 3 Chapter 1 (Page 27) the potential increase in land use which can be achieved through the use of no-tillage cropping practices. Further consideration is given to this system in Chapter 10.

4.4 Summary

1. The mechanics of rainfall erosion have been outlined in the chapter under the headings of raindrop characteristics, raindrop impact and splash, and the effects of raindrop

impact and splash on infiltration.

2. The main physical properties of rainfall are identified as raindrop size, size distribution, shape, velocity and direction and from these variables the kinetic energy of a storm can be determined. Using the drop size distributions of rainfall determined by Laws and Parsons (1943) and terminal velocities for various drop sizes of rainfall, Wischmeier and Smith (1958) derived a rainfall energy equation which together with the maximum 30 minute storm intensity I_{30} forms the basis of the E.I variable which is a key component of the Universal Soil Loss equation.

3. Hudson (1971) developed the concept of the threshold value of intensity at which rain becomes erosive and found that the value in Africa was about 25 mm per hour (KE 25). Morgan (1977) uses KE 10, an index similar in principle to Hudson's. The KE 10 index is defined as the total kinetic energy of all rains falling at intensities of 10 mm/hr or greater for at least 10 minutes - a much more realistic figure for the United Kingdom.

4. The principal characteristics of rains that affect erosion are considered to be intensity, duration, distribution of rainfall intensity throughout a storm, frequency of occurrence, seasonal distribution and areal distribution. Bleasdale (1963) considers that exceptionally heavy rainfalls are predominantly a winter phenomenon in the high rainfall areas of the U.K., whilst they are overwhelmingly a summer phenomenon in areas

of lower rainfall with a definite bias towards the three months July to September.

5. The location of short duration convective storms (1-2 hours duration) occurring this century in the U.K. with rainfall >100 mm are reported by Reynolds (1978) as being all south of a line joining Anglesey to Newcastle and occurred between May and October.
6. Raindrop impact is the main source of energy for detaching soil from unprotected arable land and it also plays an important, though contested role in sediment transport by producing turbulent flow in thin films of surface water. Evidence indicates (Ellison 1947), Mihara (1952), Mosley (1974), Mutchler et al (1975) that raindrop impact is most erosive where a very thin layer of water is present and is relatively non-erosive where still water covers the soil to a depth of three drop diameters or more (Mutchler et al 1975).
7. The impacting force of raindrops during intense rains causes the breakup and dispersion of soil aggregates and consolidation of surface particles to form a seal or crust. The disintegration of soil aggregates is referred to in the United Kingdom by the general term, loss of structure, and surface sealing as capping.
8. Moldenhauer et al (1964) found that the most important factor influencing soil loss was the infiltration rate. Sor and Bertrand (1962) reported that raindrop impact on a bare soil surface had the greatest effect on the top layer

(0-1.5 cm) and also caused some decrease in the water permeability of lower levels (3-12 cm). These processes lead to the natural compaction of exposed surface soils and their effects on soil loss are influenced by three important basic factors: soil erodibility, slope characteristics and crop and management practices.

9. It is generally accepted that soils high in silt, low in clay and organic matter are the most erodible. Bryan (1974) considers that the most significant soil property in determining erodibility is the quantity of water stable aggregates and that this outweighs the importance of any textural separate (except for very poorly aggregated soils). Wischmeier et al (1971) ranked organic matter content next to particle size distribution as an indicator of erodibility.

10. These parameters are important when assessing the effects of soil compaction induced by farm vehicles and machinery. The passage of heavy equipment causes an increase in bulk density and shear strength together with reduced porosity, air and water permeability. Induced compaction of surface and sub-surface soil with its adverse effect on infiltration now ranks high as a major causal factor of erosion on arable land.

11. These adverse effects are heightened on sloping arable land. Slope characteristics which are important in influencing soil erosion losses are slope gradient, slope length, curvature and aspect. Duley and Hays (1932) found that soils subject to

surface sealing tended to increase the effect of slope on run-off. Soils severely compacted by farm traffic show similar relationships.

12. Hudson (1971) considers that erodibility is influenced more by management than by any other factors. The influence of crop and management practices on soil erosion is complex and has been intensively studied in the United States.

Wischmeier (1960) has proposed ratios for a comprehensive range of cropping systems which vary with the growth stage of the crop and are used to evaluate the crop-management factor C in the universal soil loss equation.

13. Research by State and Federal agencies into the causes of soil erosion in the U.S.A. led to the adoption of a comprehensive range of conservation measures, such as contour and terrace cultivation to offset the worst effects of slope on run-off. Wischmeier (1974) found surface mulches the most effective in dissipating raindrop impact, decreasing surface run-off and surface sealing.

14. An advanced form of minimum cultivation referred to as the no-till system is regarded by Gard and McKibben (1973) and others as having the potential for becoming the most significant single conservation measure yet developed to control erosion and sedimentation. Research has shown that the adoption of the no-till system (referred to as direct drilling in the U.K.) has not only markedly reduced soil loss from row cropping but has enabled land which, hitherto has had restricted cropping because of erosion hazard, to be brought into more profitable grain production.

Chapter 5

A study of the principal factors which influence the development of concentrated and unconcentrated surface run-off on arable soils in the United Kingdom and their identification and classification in the field

5 Introduction.

5.1 Unconcentrated run-off.

5.2 Concentrated run-off 1: rills.

5.2.1 Confined rill erosion.

5.2.2 Unconfined rill erosion.

5.3 Concentrated run-off 2: gully erosion.

5.3.1 Confined forms of gully erosion.

5.3.2 Unconfined forms of gully erosion.

5.4 Depositional sequences.

5.5 Classification of erosional forms by concentrated and unconcentrated surface run-off on arable land.

5.6 Summary.

Chapter 5

A study of the principal factors which influence the development of unconcentrated and concentrated surface run-off (rills and gullies) on arable soils in the United Kingdom and their identification and classification in the field

5 Introduction

In general terms rain which falls at a rate greater than the infiltration capacity of the soil is considered to be potentially erosive, particularly on sloping sites. The infiltration rate of an arable soil is influenced by a number of factors referred to in the previous chapter which include soil texture, slope characteristics, degree of surface and sub-surface compaction, the amount of cover afforded by crops and crop residues, antecedent moisture and methods of cultivation.

The object of this chapter is to examine soil detachment by run-off and transport by run-off as separate but interrelated phases of the process of soil erosion by water. Soil detachment and transport by run-off may take place as unconcentrated low-energy surface flow often referred to as sheet erosion, or by concentrated high energy flow in rill and gully systems. The transition from unconcentrated to concentrated surface flow and the processes involved are difficult to identify in the field and are the subject of controversy.

As arable fields are affected in varying degrees by tractor

wheelings and implement markings, rainfall run-off rarely affects a soil surface devoid of some measure of compaction and this affects the surface expression of erosion. Two forms of rill erosion are described here as confined and unconfined forms. The former develops in ready made channels formed principally by tractor wheels and to a lesser degree in implement wheelings and furrows. The erosional and depositional sequence remains essentially in the confines of the wheeling or furrow. The latter, as the term suggests, develops random channels unhindered by wheelings and tillage lines.

5.1 Unconcentrated surface run-off

Once soil particles are detached by the process of splash erosion they become available for transport by unconcentrated and concentrated run-off. Many writers describe unconcentrated run-off as sheet erosion which Baur (1952) defined 'as the removal of a fairly uniform layer of soil material from the land surface by the action of rainfall and run-off.' Other writers doubt the validity of the sheet flow concept. Splash erosion is the only process which can detach a fairly uniform layer of soil and soil loss only occurs from a particular area where a slope factor is present. When rainfall exceeds the infiltration rate of the soil, on sloping ground detached particles are removed by surface flow. The nature of this flow is complex and a problem arises when attempts are made to describe and identify each stage of this process in the field. When raindrop impact and splash detach soil

particles, which in turn choke the natural through pathways in the soil for percolating water, the infiltration rate slows and if the supply rate of rainfall continues to exceed the infiltration capacity of the soil, films of water begin to accumulate in small depressions or detention hollows. When overtopping takes place between hollows films of low energy water will begin to flow on sloping ground. Mutchler and Young (1975) found that the horizontal velocities of flowing water under impacting raindrops greatly increased the potential of this surface flow to transport detached soil particles and aggregates. Bryan (1977) considers that a particularly critical control of splash entrainment is the depth of the surface water layer in relation to raindrop size and quotes studies by Mihara (1952) and Palmer (1963) which show that splash entrainment increases with the depth of water up to a critical depth. Mutchler (1971) considers the critical depth to be approximately one-fifth to one-third drop diameter when raindrop impact is the most erosive, and is relatively non-erosive when the soil is covered with a water depth of three drop diameters or greater. He contends that the major portion of splash originates from surface water and this provides the potential to transport suspended soil by splash action alone though the particle sizes are limited by the small size of the splashed droplets (Ibid). Ekern (1953) considered that an evaluation of the mechanics and the efficiency of the combined force of drop impact into shallow flows of water would bring to light the nature of the 'sheet' erosion process.

It is evident that despite extensive research the precise nature of soil detachment, surface sealing and unconcentrated

flow in the field are imperfectly understood. Laboratory studies using simulated rainfall and small plots of disturbed soil tend to magnify micro-relief problems on artificially smoothed surfaces and underestimate or mask the effect of surface roughness, tractor wheelings and tool marks which are encountered in the field.

During a ten-year survey of soil erosion monitoring in east Shropshire, run-off from arable fields and experimental plots during storms has been observed by the writer, though sheet flow as defined by Baur was never seen in the field. Overland flow has been observed on a number of occasions during storms when the supply rate of rainfall exceeded the infiltration rate of the soil. The speed at which overland flow commenced during a storm was conditioned by a complex of factors but was well correlated with surface compaction induced by machinery. Other factors which affect the condition of the soil surface and affect run-off are the degree of surface roughness including stoniness and clod size, the direction and form of cultivation lines (wheelings and tool marks) the moisture status at the onset of a storm, and the effect of prior erosive rains on the state and extent of natural soil compaction.

In cultivated arable fields the soil surface is rarely uniform and smooth and may contain varying amounts of stones, crop residues as well as implement tool marks. It is, therefore, important to recognise the more common cultivation features which characterise arable fields as these will exert a major influence on the form which run-off will take initially.

Against this background two types of unconcentrated surface flow are recognised from field observations made by the writer. These generate from (a) discontinuous hollows when the soil surface is in a puddled state caused by the trampling action of sheep and cattle, (b) micro-ridge and furrow features formed during seed bed preparation. The first type (a) is usually associated with compacted and puddled soils, particularly where sheep have been folded in situ on roots or beet tops. As this type of folding tends to be essentially a winter practice, days of wet weather and the trampling action of a large flock of sheep quickly cause loss of soil structure and the surface becomes puddled and pitted with hoof marks. These act as small detention hollows when rainfall exceeds the infiltration rate, which at this stage has been found to fall to less than 15% of its normal capacity on a sandy loam soil (organic matter less than 2%). On level sites heavy rainfall > 1 mm/hr yielding 10 mm will produce ponding. On sloping sites overtopping begins between detention hollows and a shallow low-energy flow takes place. This type of unconcentrated surface flow has been observed on a number of occasions in east Shropshire and approaches closely to Baur's definition of sheet erosion. In one example during the last moments of an intense rain shower (yielding 5 mm in 20 minutes) the entire surface of a convex-concave 5° slope (sandy loam soil) appeared shrouded in rain-drop splash and films of muddy water flowed from the numerous small hoof depressions. At some distance away the whole field surface appeared to be affected by a thin sheet of moving water. Close inspection of the surface, however, revealed that flow was taking place mainly over the lower

rims of shallower hollows leaving the more elevated rims and small ridges of soil unaffected. The flow of muddy water continued for two or three minutes after the cessation of rain. A discontinuous veneer of fine and medium sand was seen along the base of slope and fine sand, silt and clay occupied hoof depressions. The amount of sediment transported in such events is usually small and appears to be generated by raindrop impact and splash. Some particles are detached by run-off where localised damming releases more water and in places incipient rill development can be seen.

In type (b) field surfaces which have been rolled (with rib-rollers) or traversed with general purpose seed combine drills exhibit a pattern of micro-ridge and furrow. In sandy and silty textured soils low in organic matter, raindrop impact and splash very quickly breaks down the small ridges and infills the furrows which in turn reduce infiltration. Where cultivation has taken place parallel to the contour overflow may take place where parts of the micro-ridges become flattened by splash erosion.

In the example illustrated by Figure 13 (Page 13) splash erosion during several days of erosive rainshowers flattened the small ridge crests and the shallow furrows became choked with sand. During a prolonged intense rain (six consecutive hours with a rate of > 1 mm/hr) shallow flow took place across the ridges leaving behind a severely puddled surface which sealed on drying.

The term 'flash flooding' could be used to describe some of the characteristics of a third type which is associated with higher energy surface flows and has often been seen in fields sown to sugar beet during the early stages of growth. This type contains elements of both (a) and (b) and is best seen when intense rain falling from thunder showers strikes very dry compacted ground. Run-off associated with this type of rain under these conditions can take place even on relatively gentle slopes ($2-3^{\circ}$) and is capable of moving large quantities of soil material, including gravel, up to 12 cm in diameter in very broad shallow flows. In the example illustrated by Figure 14 (Page 14) the area of damage affects only part of the field although here all the beet plants are washed out. Splash entrained particles are moved in low energy run-off along wheelings and implement lines which for much of the field run parallel to the contour. Overflow from these channels breaks out lower down slope as rainfall supply rate increases significantly over infiltration and run-off reaches a peak. At this stage velocity increases as the depth of flow and the slope of the land increases. The abrasive capacity of this run-off can cause considerable erosion and entrainment, and the large base of slope fans with gravel spreads attest to the transporting capacity of these wide but shallow flows which resemble miniature flash-floods.

5.2 Concentrated surface run-off

Wherever surface run-off is concentrated and flows are sufficiently intense small rills develop. In the field it is easy to identify concentrated flow in rills but is very difficult to observe the sequence of events in the inter-rill areas.

Experiments with simulated rainfall on indoor plots which have been referred to previously support the conclusion that raindrop energy, rather than surface-flow energy is the major force initiating soil detachment on inter-rill areas. Young and Wiersma (1973) observed that when rainfall energy was reduced by about 89% without decreasing intensity, the reduction in amount of soil moved to rills was 91, 95 and 90% respectively for a loam, silty loam, and a sandy loam. Over 80% of the soil moving off this 4.5 m long plot was transported in rills.

Mosley (1974) used fallow plots and simulated rainfall at a constant intensity of 90 mm/hr in laboratory experimental study of rill erosion. He found that run-off collected almost immediately into more or less distinct flow lines which were the locus for the later development of integrated networks of rill channels. For rills which had reached an 'equilibrium' stage of development, sediment yields were positively related to surface slope and length but were also related to total rill channel length and drainage density. He also found that slope shape in plan modifies soil erosion rates by rilling with rates being generally higher on convergent and lower on divergent surfaces than on plane sloping surfaces. Variability in erosion rates was highest on convergent and lowest on divergent surfaces because of the geometric characteristics of the rill systems. In arable fields two forms of rill erosion are recognised by the writer as confined and unconfined types. Confined rill erosion results from the concentration of overland flow along ready made com-

compact channels formed by agricultural machinery (see Figure 15 Page 15). The unconfined type results from the concentration of overland flow in small closely spaced random channels, the development of which is not controlled or hindered by cultivation lines (see Figure 16 Page 16). On strongly sloping land both types are frequently seen affecting the same field (see Figure 18 Page 18).

Field tillage operations leave behind ready made 'channels' of varying depth and width as well as small, medium and large ridge and furrow patterns. Channels made by tractor rear wheelings in moist soils can be deep and very compact. During heavy rain the supply rate often exceeds infiltration rate of the soil as compaction has already radically reduced the area of macro-pores and fissures in the soil. A number of illustrated examples are included which will help demonstrate the relationship between tillage 'channels' and stages in the development of rills as conditioned by a range of site variables such as slope characteristics, type and direction of cultivation lines with respect to slope and the nature of the storm which produced run-off. In the West Midlands rilling was the most common form of erosion encountered on arable fields and was predominantly of the confined type.

5.2.1 Confined rill erosion

In the confined type, the pattern of rills which develop depends upon the spacing of the tillage lines and tractor wheelings, and this in turn is conditioned by the type of

crop being cultivated and the type of tillage equipment being used. Although there are many different types of machinery in use, it is nevertheless possible to identify erosive damage which emanates from compaction caused in the sowing and subsequent tillage of grain crops, sugar beet and potatoes.

The speed at which rills develop and whether they remain confined in the wheeling depends upon the interaction of a number of general factors outlined above. In particular, for a given set of soil and site conditions, intensity and duration of rainfall are critical factors as these influence the amount of detached soil available and the transporting capacity of run-off.

Figure 19 (Page 19) shows incipient rill development along tractor wheelings on a 5% slope and a pattern of micro-channels which result from the passage of a ribbed roller over the soil. The micro-channels are infilled with splashed sand by raindrop impact and thin sheets of sand occupy small declivities in field surface. These result from low energy flows of run-off along the micro-furrows and from larger flows where overtopping has taken place along wheelings. On gentle slopes like these raindrop impact is responsible for the largest amount of soil detachment which is transported only short distances by turbulent flow in the micro-channels and in shallow surface flows along the tractor wheelings.

The seed drill which produced the pattern of small ridges and furrows illustrated in Figure 20 (Page 20) has left a surface free of visible compaction yet sediment movement has taken

place along the furrows. Two incipient rills have formed where run-off has partially excavated mole runs. Much of the sediment is clean washed sand which is splashed into the furrows from the ridges. Movement of this material in the furrows is achieved by shallow flow energised by raindrop impact.

A combination of factors such as changes in slope direction (convergent and divergent slopes) and in tillage direction tend to produce a combination of confined and unconfined rill development as illustrated in Figures 18 and 21 (Pages 18, 21). In Figure 18 (Page 18) the upper slopes have rills developed along tractor wheelings but these have been 'beheaded' by a branching system of unconfined rills which are channelling run-off from a much larger catchment area. Only the presence of the grassed area prevents gully development where master rills intersect. These pictures illustrate two types of soil detachment; by raindrop impact and by scouring action of run-off water within the rill systems. In Figure 21 (Page 21) only the larger soil aggregates remain intact and these are essentially rounded forming the remains of the micro-ridges. The intervening furrows are infilled with dispersed soil material and here the slopes are steep enough for unconcentrated flow to take place producing fans of fine material downslope.

Even stony soils with a high infiltration rate can erode when steep fallow slopes are exposed to heavy rainfall as illustrated by Figure 22 (Page 22). A prerequisite for erosion in this example was the presence of tractor wheelings and tillage lines in an up and down-hill direction. Only the relict

features of wheelings are visible on the crest of the slope as tillage lines have been completely obliterated by splash. The efficiency of the largely confined rills in moving detached soil and scouring channels can be seen from the huge fan of sand and gravel (375m^2) held up against the lower field boundary.

Initially no reason could be advanced for the apparent haphazard development of small rills, which, at this stage were contained within the wheel depression. Some wheelings showed deeper rill development than others, even on the same section of a long straight slope. In some sets of wheelings the lug pattern remained intact while in others it was virtually destroyed (Figure 23 Page 23). Closer inspection revealed that well-developed rills were associated with tractor wheelings moving in a down-slope direction, which left behind lug imprints with a 'v' pattern, whereas less-developed rills were associated with tractor wheelings moving up-slope leaving a lug pattern in the form of an inverted 'V' (see Figure 24 Page 24).

In the initial phase of erosion in a wheeling produced by a tractor passing in a down-slope direction water from rain and splash collects in the lug imprints which act as temporary detention hollows. The left and right lug imprints are offset from each other to form a zig-zag pattern with each limb of the 'V' being separated from the next by a small plug of soil approximately 3 cm in width. This soil plug is rapidly broken down by erosive rain (>1 mm/hr) through the combined action of raindrop impact, splash, slaking action of ponded

water and eventually by overtopping.

The erosion process in a wheeling produced by a tractor moving in an up-slope direction shows some significant differences in the initial stage to ones described above. The lug pattern resembles an inverted 'V' (see Figure 24 Page 24) and although the lug imprints act as detention hollows, initial storage collects towards the side of the track and no overtopping takes place until the lug imprint becomes full. Overtopping is, therefore, retarded and the effects of storage water minimised as it is deflected towards the sides of the track. The sequence of events in the erosion of tractor wheelings is shown by a number of illustrations in Figures 25 and 26 (Pages 25, 26).

Spectacular erosion can result from closely spaced erosive events which take place during seed bed preparation as evidenced by Figure 27 (Page 27). Three sets of wheelings are in evidence on this large field (15 hectares which was prepared for winter barley in September 1976). The most prominent set of wheelings running parallel to the main slope were made in very moist ground and caused considerable wheel sinkage (see Figure 28, Page 28). These acted as efficient channels for run-off when storms on the 24, 25 and 26th yielded between 2.5 and 7.6 mm/hr with the total reaching 83 mm (3.26 inches) over the 3-day period. Here (Figure 27 Page 27), most rill development was largely confined to the wheelings, some of which were widened appreciably by scour though deepening was mainly within the Ap horizon. Where drainage from a number of wheelings was intersected by another set (centre of picture)

increased volume of run-off caused excessive lateral corrosion of between 1 and 2 metres in width totally removing the Ap horizon down to a well-developed plough pan. At this point excavation of the plough pan and B horizon produced canyon-like features up to half a metre deep and 20-30 cm wide, tapering to 10-15 cm at the base.

5.2.2 Unconfined rill erosion

In unconfined rill development the dimensions of the channels are controlled by the erodibility of the soil which they cut into. As the flows of run-off water are usually of short duration rill development is limited and the channels are quickly obliterated by subsequent cultivation, or run-off is markedly reduced at a later stage through crop interception. In the ten-year erosion survey (Chapter 8) it was observed that the same fields eroded every year and in some adverse seasons two or even three episodes of rill erosion occurred on the same field but not always in the same location. This changing location will produce a more or less even lowering of the slope as subsequent cultivation infills rill channels from the inter-rill areas. Mosley (1974) found that sediment contribution is positively correlated with rill drainage density and consequently a rill catchment with a high drainage density should have a high mean rate of soil erosion. Morgan (1977) observes that in spite of spectacular visual evidence, rill erosion is an insignificant contributor to soil loss (on soils of the Cottenham series) because the density of the rill system is too low. He considers the possible reasons for this, compared with the situation in

the U.S.A., may be the sandy nature of the soil, the more moderate intensity of rainfall and the shortness of slope available for rill development. It can be seen from Figure 16 (Page 16) that the density of unconfined rills is high and is developed on a short slope (100 m) in a sandy loam soil though in this instance rainfall intensity was relatively high-2.7 to 7.5 mm/hr. for 10 hours. Likewise in Figure 29 (Page 29) the slope is 108 m long and has a well-developed unconfined rill system which cuts across cultivation lines which run parallel to the contour. Sediment yield from rills in the centre of the picture completely obliterated a well-kept cottage garden after run-off washed out part of the hedge.

Nearly all of the examples of unconfined rill activity which have been observed in the field have taken place on slopes in excess of 6° . Examples of well-developed rill systems are usually seen on steep convex slopes which are backed by a large catchment area beyond the crest. In many instances run-off is delivered quickly to the crest zone via tractor and implement channels. This type of run-off tends to produce long straight rills without branching where convex slopes exceed 10° . On arable soils the question arises as to what extent cultivation and induced compaction inhibit or influence the development of natural or unconfined rill systems. An example of unconfined rill development was observed on an experimental plot which is shown in Figure 30 (Page 30). The plot, which is 60 m long and 10 m wide, has an average slope of 10° and this was rotovated a day before the outbreak of a series of thunderstorms which yielded 83 mm at intensities

of between 2.5 mm and 7.6 mm/hr. Prior to ploughing, the slope had been in grass for six years and the organic matter content was 5-6% (loss on ignition). It is important to note that there were no wheelings visible or apparent signs of surface compaction though penetrometer readings (Vicksberg) indicated the presence of a plough pan at 22 cm. After the storm a well-defined pattern of long straight rills was seen averaging 8-13 cm deep and 9-15 cm wide. Their position on the slope seemed to follow closely the estimated position of the tractor wheelings, the surface pattern of which was obliterated by the rear mounted rotovator. The main point of interest in this example is the fact that 83 mm of rain at known intensities was required to cause rill erosion on a newly-rotovated sandy loam without any visible signs of surface soil compaction. The soil surface which contained numerous clumps of turf and stones would have been initially highly receptive to rainfall.

A final example (Figure 31 Page 31) illustrates a complex pattern of tillage marks and rill development in a field which eroded during the same storm referred to above. Three sets of tool marks can be identified made during the preparation for a crop of winter wheat. Small ridges and furrows made by spring tines traverse the main slope from left to right of the picture. A second set run from the crest line down the steepest facet of the convex concave slope. Confined rill development has taken place along these tine-furrows with an unconfined pattern of rills diverging across the steepest slope facet being deflected in places for a short distance (towards the viewer) along tractor wheelings

running at right angles to the other tillage lines. This example illustrates both divergent and convergent rills and emphasises the difficulties encountered in cultivating land of this type with a high susceptibility to run-off erosion.

5.3 Concentrated run-off 2

Gully erosion

When rill channels become overdeepened to the point that they cannot be smoothed over by normal tillage operations they are classified as gullies*. Although gully development is the most dramatic form of water erosion it usually affects a much smaller total area of arable land when compared to the combined effects of rill erosion and unconcentrated wash. On arable soils in the United Kingdom gully development is usually short-lived as it is often associated with one or two closely spaced rainfall events. Gullies which do form are rarely permitted to develop further and are quickly backfilled as they interfere with tillage.

Of the many examples of gully erosion on arable soils seen in the West Midlands two particular types can be recognised and, for convenience, classified in the same way as rill erosion, into confined and unconfined forms. The former is usually associated with tractor wheelings which have, or have not been, affected by prior rill erosion (see Figures 32 and 33, Page 32). The latter forms are those developing along the

* This definition which is currently in use is revised in Section 5.5

axis of well-defined depressions, which may or may not be affected by induced compaction (see Figures 35 and 36, Page 34). The development of both forms is conditioned by site characteristics outlined above for rill development but with the addition of greater concentrations of run-off water. Many of the quoted examples of gullies were developed on sandy soils overlying deep unconsolidated deposits. The degree of dissection was conditioned by slope characteristics and the volume of water reaching the wheeling either directly by rainfall or indirectly as run-off along cultivation lines bisected by the wheeling. In sandy or gravelly sand textured materials, the gully form tended to be U-shaped. Gully form tended to change to a V-shape in more coherent sandy clays, silty clays and silty colluvium (see Figure 36 Page 34).

5.3.1 Confined forms of gully erosion

Tractor wheelings usually provide ready-made channels for run-off which may have been affected by rill erosion prior to gully development. Where this has happened a well-defined efficient channel exists which can be quickly over-deepened by storm run-off. An ideal situation for confined gully development is illustrated by Figure 32 (Page 32) where tractor wheelings traverse and run parallel to a long slope (average 3°) which locally steepens along a convex-concave section (average 9°). The channels formed by wheelings are some 350 m long and had been partially excavated by rill erosion in a previous storm. A large number of tine-furrows linked into the wheelings and more were added by lateral corrosion of the channels by rill erosion to a depth of 16-18 cm which reached

the upper surface of the plough pan. At the onset of a further storm which followed several hours later the soil was above field capacity and rainfall at a rate 2.7 to 7.5 mm/hr rapidly exceeded infiltration. The run-off which ensued cut gullies, which ranged from 1 to 1.5 m deep and 1.5 to 2 m wide and which developed headward on the steepest section of the slope excavating beds of rythmites and sand and gravel. Bands of tough silty clay in the rythmites acted as knick points until being undercut. Details of long profile and cross sections of one of the largest gullies shown in Figures 33 and 34 (Pages 32, 33).

Another very large confined gully can be seen in the bottom left-hand corner of Figure 32 (Page 32). This was over a metre deep and 1.5 m wide and was cut into a large fan of glacial sand. This was in turn fed by another smaller confined gully higher up the field, together with numerous large confined rills. In Figure 37 (Page 35) the transition from confined rills to gullies is illustrated and this example again points to the importance of tractor wheelings running parallel or obliquely to slope direction in channelling run-off. Here the gradient of 2-3° runs towards the observer and the slope steepens to 9° where a small re-entrant dry valley intersects the main field slope at right angles. Some indication of the density and pattern of wheelings on this 15 hectare field can be seen on Figure 27 (Page 27). The main line of confined gully development is seen just below the crest line on either side of the re-entrant valley. These cut into the stony phase of the Newport series which

is developed on terrace gravels giving well drained to excessively well drained soils with deep profiles. By American standards such soils are considered to be of very low erosion risk. However, Newport soils have inherently weak structures and when in continuous arable cropping organic levels often fall below 2% and this further reduces the soils' resistance to splash erosion and surface sealing. The major contributory factor here, however, is the extent of induced soil compaction produced during seed bed preparation for winter wheat. It is estimated that approximately 90% of the field surface was affected by wheelings of various types. Three sets of wheelings are identifiable on Figure 37 (Page 35), one running parallel to slope, one obliquely (top right to bottom left) and one along the contour. Run-off from three closely spaced storms in September 1976 at intensities of 2.5 - 7.5 mm/hr produced the following pattern of events. The first storm produced widespread splash erosion and surface sealing. Concentrated surface flow along wheelings caused incipient confined rilling. In places large shallow declivities can be seen (Figures 27 and 28 (Point A) Pages 27, 28) where overtopping took place between wheelings and unconcentrated flow moved run-off into obliquely orientated wheelings. Where the slope steepened confined rills reached the upper surface of the plough-sole and the pattern of rill development was markedly affected at points where lines of wheelings intersect producing both straight and branching confined rills. The second storm emphasised this pattern on the steeper slopes with master rills developing with incipient gullies forming along the steepest slope segments. The run-off of the third storm breached the well-developed plough

sole and excavated broad flat-bottomed gullies in beds of coarse sand, grit and gravel. Run-off from these channels on both sides of the re-entrant concentrated in the valley bottom and excavated two parallel gullies (2m x 1.5 m) which developed from a set of wheelings running parallel to the long profile of the re-entrant (see Figure 38 Page 36).

5.3.2 Unconfined forms of gullying erosion

This form is usually seen occupying the long axis of well-defined depressions and small dry valleys where run-off from adjacent slopes has concentrated. Although this form can be easily identified in the field as it exhibits characteristics which differ from the confined types, its development is nevertheless affected by surface and subsurface compaction which tends to influence gully shape. These forms tend to be much longer and generally larger in cross section and gully development has been seen to recur in the same situations on a number of occasions. The example illustrated by Figure 39 (Page 37) contains elements of both confined (in the upper and lower sections) and unconfined form in the longer middle section. (Smaller gullies have been observed here on two other occasions (see Figure 40 Page 38) and parts of an older system was re-excavated during the most recent event in September 1976). The middle section averaged 2 m wide and 1.5 m deep over a distance of 120 m. This unconfined section bisected 14 sets of wheelings, each averaging 80 m long. A potentially much larger catchment was beheaded by another confined gully system occupying wheelings in part of a farm track.

Softer bed rock materials like Upper and Lower Mottled Sandstones of the Triassic are easily eroded by superimposed gully systems. Harder stringers of sandstone and marl bands tend to act as nick points where encountered locally. This is illustrated in Figure 41 (Page 39) where unconfined gullies cut across tillage lines which run parallel to contour. Gullies develop headward in a flight of steps with small plunge pools which are cut into a marked plough pan. On the steeper slope facet (8°) the Upper Mottled Sandstone has been eroded to an average depth of 0.6 m (see Figure 42 Page 40). Three phases of development can be visualised commencing with splash erosion which leads to a rapid loss of structure (loamy sand-sandy loam Bridgnorth series) and reduction in infiltration causing ponding along wheelings and tillage lines. Overtopping of ponded water in the wheelings would be facilitated as the small implement ridges were broken down by splash erosion. Unconcentrated surface flow appears to be responsible for the removal of the top 4 cm of soil in Figure 42 (Page 40). The local concentration of surface wash led to the formation of a system of unconfined rills fed by increased run-off from a large catchment above the crest: a depression in the field area above the crest caused a greater concentration of run-off which cut the deeper unconfined gullies seen in the centre of Figure 41 (Page 40). A final example (Figure 43 Page 41) shows unconfined gully erosion affecting Bridgnorth and Newport soils over a long convex-concave slope which is complicated by the presence of small depressions just below the crest. These acted as concentration points for initial run-off eventually producing a series of long shallow gullies (325 m long)

which cut across cultivation lines running parallel to the contour.

Each of the examples quoted has a number of features in common. In particular each field has been enlarged by hedgerow removal which has tended to form steep convex-concave slopes to a larger area with more gentle slopes. The net effect is to produce longer slopes and hence a greater catchment for run-off which tends to become concentrated at the very point where the slope steepens and thus greatly increases the erosion potential. Soils of the Newport and Bridgnorth series have inherently weak structures which break down easily when exposed to rain-drop impact and splash and the tendency to surface sealing quickly results in a marked decline in infiltration rate. All the soils in question have a long history of arable use and have low organic matter levels (averaging <3%). In all cases gully development has been influenced by the presence of marked plough pans. Finally the rate of rainfall in each erosion event exceeded 1 mm/hr and yielded totals of >10 mm

To conclude this section reference is made to wide trough-like gullies largely of the unconfined type which develop on the long axis of gentle slopes ($2-3^{\circ}$) in soils which have been rotovated. Rotovation depth is seldom greater than 20 cm in sandy soils and this produces a very compact pan below this depth. This is well illustrated by Figure 44 (Page 42) which shows such a feature over 1 m in width and 20-25 cm in depth. At the onset of an erosive rainfall event splash erosion causes structural breakdown and the

infiltration rate of the soil which is already reduced by induced compaction, declines further, and shallow flows of surface wash begin to move down slope along tillage lines. Steeper slopes ($4-5^{\circ}$) to the left and right of the picture channel in both concentrated and unconcentrated run-off and rapid excavation of the main central channel is effected to the depth of the pan. Lateral corrasion is responsible for the rapid removal of the less coherent surface horizon. Although these features are more easily eradicated by tillage they should not be classified as rills (see below). Judging from the huge fans of material deposited by these gullies they are capable of generating large flows of run-off.

5.4 Depositional sequences

Depositional sequences vary from thin discontinuous spreads of materials 2-3 cm in thickness which amount to soil removal of approximately 1-2 tonnes per hectare (see Figure 20 Page 20) to huge overlapping fans averaging 20 cm in thickness (see Figure 45 Page 43) and amounting to an estimated soil loss of 156 tonnes per hectare (east Shropshire data). Deposition usually occurs at points where the velocity of run-off is reduced as for example along the base of slopes, at the mouth of gullies, against hedgerows and fence lines or where run-off enters temporary ponds or enters streams in flood.

The amount of material deposited is conditioned by the detachability of the soil, the amount and velocity of run-off and the presence of ready made channels from tractor and implements which run in the direction of slope. The elongation of

slopes through hedgerow removal is another important influential factor. Soil materials deposited by flowing water are graded in particle size and depositional sequences are influenced by the textural characteristics of the soil and the nature of the erosional processes at work. Stallings (1957) maintains that the amounts of fine and highly transportable materials that are removed from a watershed area tend to be proportional to the amount of splash erosion. This process is more efficient in breaking up soil aggregates and releasing the highly transportable silt, clay and organic matter than is usually achieved by the action of flowing water.

A further factor of importance is where the deposition takes place, and the relative 'fertility' of the overwash being deposited. Here it is useful to distinguish between soil movement within a field and soil loss where significant amounts of material are transported out of the field. In general most sites where erosion has been recorded in the West Midlands by the writer showed that the coarser grades tended to be deposited within the field boundary (see Figure 45 Page 43) whereas finer grades were moved out into adjoining fields or into the drainage system. This process is seen in action in Figures 46-48 (Page 44) where run-off is continuing after the passage of a thunderstorm. A large fan of coarse debris was deposited and a great volume of run-off passed through the wire mesh fence which became choked with debris and caused temporary ponding to take place. At the time of the photograph surface flow of 4-6 cm was seen in the deeper braids with dissection of the larger fan. Diminished muddy flow continued for 15 minutes after cessation of rain (see Figure 48 Page 44).

Unconcentrated surface wash resulting from intense thunderstorm rain (rate $\gg 13$ mm/hr) which caused widespread ponding against the hedgeline is well illustrated in Figure 49 (Page 45). As the base of the hedge was below road level this facilitated the ponding of run-off. Rapid loss of structure in the sandy loam soil by splash erosion caused surface sealing and ponding along cultivation lines which ran parallel to the contour in the large gently sloping (3°) field of sugar beet. Overtopping of detention water held in the tillage lines produced unconcentrated surface flow which appears to have approached most closely to the concept of sheet flow. In places along natural spill-ways flow became more concentrated in broad sheets which built out small deltas of coarser sand into the ponded run-off (see Figure 50 Page 46).

Deposition from unconcentrated surface wash usually contains fertile soil ingredients and as the spreads are usually thin serious damage to emergent or young plants is rare. Where a number of similar events have taken place in the same field, the soil affected by this type of overwash may become more loamy. More marked textural change may take place where coarse sandy material excavated from C and D horizons by gullying is deposited in a thick overwash as illustrated in Figure 45 (Page 43). Here fans of coarse debris (coarse sand, grit and pea gravel) covered an area 5000 m^2 to an average depth of 200 cm. Assuming a bulk density of 1.3 some 1,300 tonnes of soil were deposited amounting to a loss

of 200 tons per hectare for the 6.5 hectare field.

Further deposition took place in an adjoining field down slope. Here run-off deposited large fans and built out deltas into the flood waters of Hilton brook which received much of the finer grades of transported sediment (see Figure 51 Page 47). This field has eroded every year since soil erosion monitoring commenced in this area in 1967, culminating in the disastrous gully erosion in September 1976.

Since arable cropping commenced in 1942 base of slope deposition has built up against the hedge to an estimated height of 1.5 m so that only the top of the original hedge is now visible. Translated into annual soil loss figures these data give a crude estimate of 4 cm per annum for the 37-year period, which is an alarming, though conservative, figure for it refers only to material retained by the hedgerow.

Other less spectacular erosion episodes have resulted in large tonnages of soil being washed off fields into adjoining country lanes (Figures 52 and 53, Page 48) and the infilling of small ponds by deltaic growth (Figure 54 Page 49). On a smaller scale confined rills running parallel to slope direction tend to produce elongated shallow fans which coalesce where the slope angle decreases. In Figure 55 (Page 50) the estimated sediment yield is approximately 12.5 tonnes per hectare. Run-off which moves along the ready made channels provided by potato furrows which run parallel to slope direction (see Figure 56 Page 51) would appear to receive much of the detached sediment from splash erosion from the tops and sides of the ridges judging from the high proportion of

silt and clay contained in the base of slope furrow infilling. Incipient rill development can be observed and is restricted to those furrows where wheelings have compacted the soil. The centre furrow in Figure 56 has no rill development and shows much less sediment accumulation. The way in which this pattern of tractor and implement wheelings is formed is explained in Figure 57 (Page 51).

5.5. Classification of erosional forms by concentrated and unconcentrated surface run-off of arable land; a first approximation

The Soil Survey Handbook (1976) attempts a very generalised classification of water erosion under the three headings:

1. Sheet erosion - which is described as the erosion of a thin layer of surface soil which can include small rills.
 2. Rill erosion - a rill is described as a small channel which is completely smoothed by normal cultivation i.e. <35 cm deep and
 3. Gully erosion - a gully is a channel too big to be smoothed out by normal cultivation. This is a simplified version of the more detailed classification contained in the U.S. Department of Agriculture's Soil Survey Manual (1951).
- There are a number of disadvantages in both classifications which stem in part from the basic objectives of each scheme. The approach in each case tends to be orientated to land-use and management problems rather than setting out to record pedological changes. Splash erosion is not considered in either scheme and this raises the fundamental issue of drawing a clear distinction between soil loss and soil erosion. The

absence of soil loss does not automatically rule out soil erosion for the latter can be effected in situ by raindrop splash and this process is very important on a wide range of soils and therefore should be recorded.

The effects of raindrop splash which lead to breakdown of soil aggregates is often referred to by the general term, loss of structure, which is widely reported in Soil Survey memoirs and records for England and Wales. Soils which are prone to loss of structure are most likely to be affected by overland flow during prolonged rainfalls or short duration storms. However, overland flow may commence even during short-lived low intensity rainfalls where the soil surface is severely compacted and unprotected. Many examples of soil deposition resulting from sediment transport by low-energy flows are referred to in literature as sheet erosion. Reference has already been made to the controversy surrounding the use of the term sheet erosion to describe such events and here it is considered that unconcentrated wash offers a more accurate and acceptable term.

Concentrated run-off in the forms of rills and gullies should be described more precisely in both pedological and land-use management terms which acknowledge the varied effects of induced soil compaction by machinery. It has been demonstrated that the effects of induced soil compaction can exert a marked influence on the initial development and later stages of channel form.

In previous classifications, rills and gullies have been con-

sidered in terms of their effect on cultivation. Channels which can be easily smoothed out by normal cultivation are classed as rills and channels too deep to be crossed by tractors and implements and requiring special equipment to infill them, are classed as gullies. Such a classification has a number of disadvantages. The wide range of modern powerful tractors and implements on present day farms would facilitate the infilling of incipient gullies by 'normal' cultivation.

A more important factor to consider is the depth of channel development in terms of the type of materials being excavated. In the Soil Survey of England and Wales classification the choice of 35 cm as the depth of a rill would mean that channel excavation could be taking place in the upper B horizon in many mature soils. Rill depth should, therefore, be considered in terms of the profile characteristics of the affected soil, with particular note being taken of the depth of the Ap horizon. The area of the Ap horizon eroded will depend upon the depth, width and spacing of rill channels. An acceptable compromise may be to restrict the term rill erosion in arable soils to the Ap horizon. In the majority of examples of rill erosion observed by the writer, channel development has been confined to the Ap horizon. It would appear that rill channel depth for all but high energy flows is restricted by the presence of plough and cultivation pans, which are common features in many arable soils. Channel development below the Ap horizon into the B which breaches compacted layers may be referred to as incipient gullies. Channels which breach the C horizon and beyond (D horizon if present) would be classed as gullies.

The terms confined and unconfined have been used to describe both rill and gully development. This distinction has been made to facilitate the description of the two most common forms of channel development seen on arable land. It also serves to emphasise the fact that a high proportion of rill activity on arable land is generated by run-off along wheelings and implement lines running parallel to slope. The density of confined rills may be very high as illustrated in Figure 37 (Page 35). In the confined types of rill erosion a fairly accurate estimate can be made of channel density and as each rill can be regarded as a separate system some estimate can be made of the total amount of soil eroded in each system. An outline classification is proposed in Table 13 (Page 151) which embodies the main observations made above. A five point scheme is envisaged which attempts to identify the main erosional forms seen on arable land. The relationship of these forms to rainfall and site characteristics is illustrated in a sediment model flow chart (see Table 14 Page 152).

5.6 - Summary

1. A large number of carefully selected photographs have been included in this chapter in an attempt to identify and illustrate the principal factors influencing the development of concentrated and unconcentrated surface run-off on arable soils in the United Kingdom. A five point classification of erosion forms is presented. As a major part of this research relates to sandy arable soils, the proposed classification is applicable primarily to this group of soils.

Table 13

Classification of erosion forms on compacted and non-compacted sandy arable soils by raindrop-splash and run-off

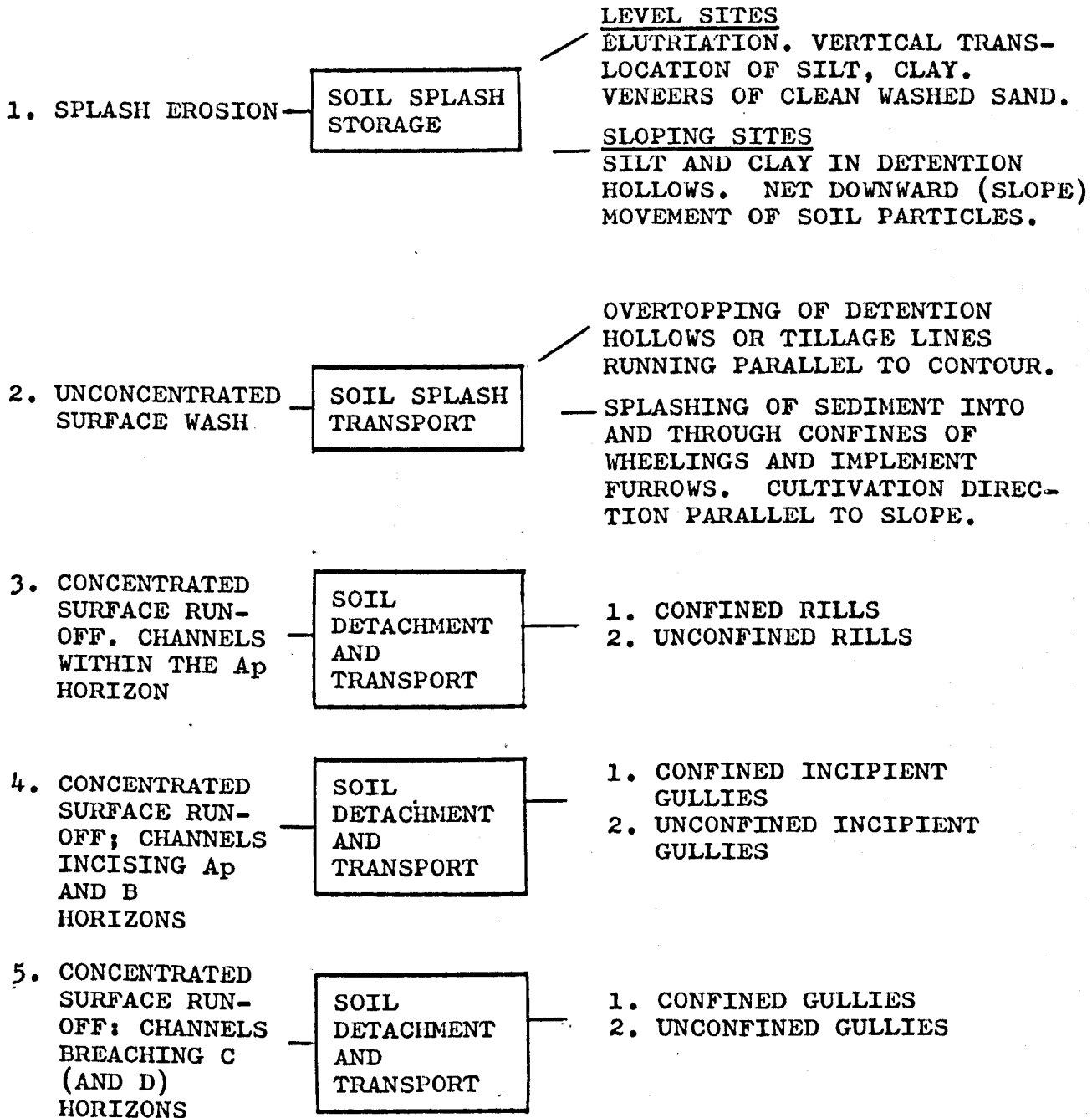
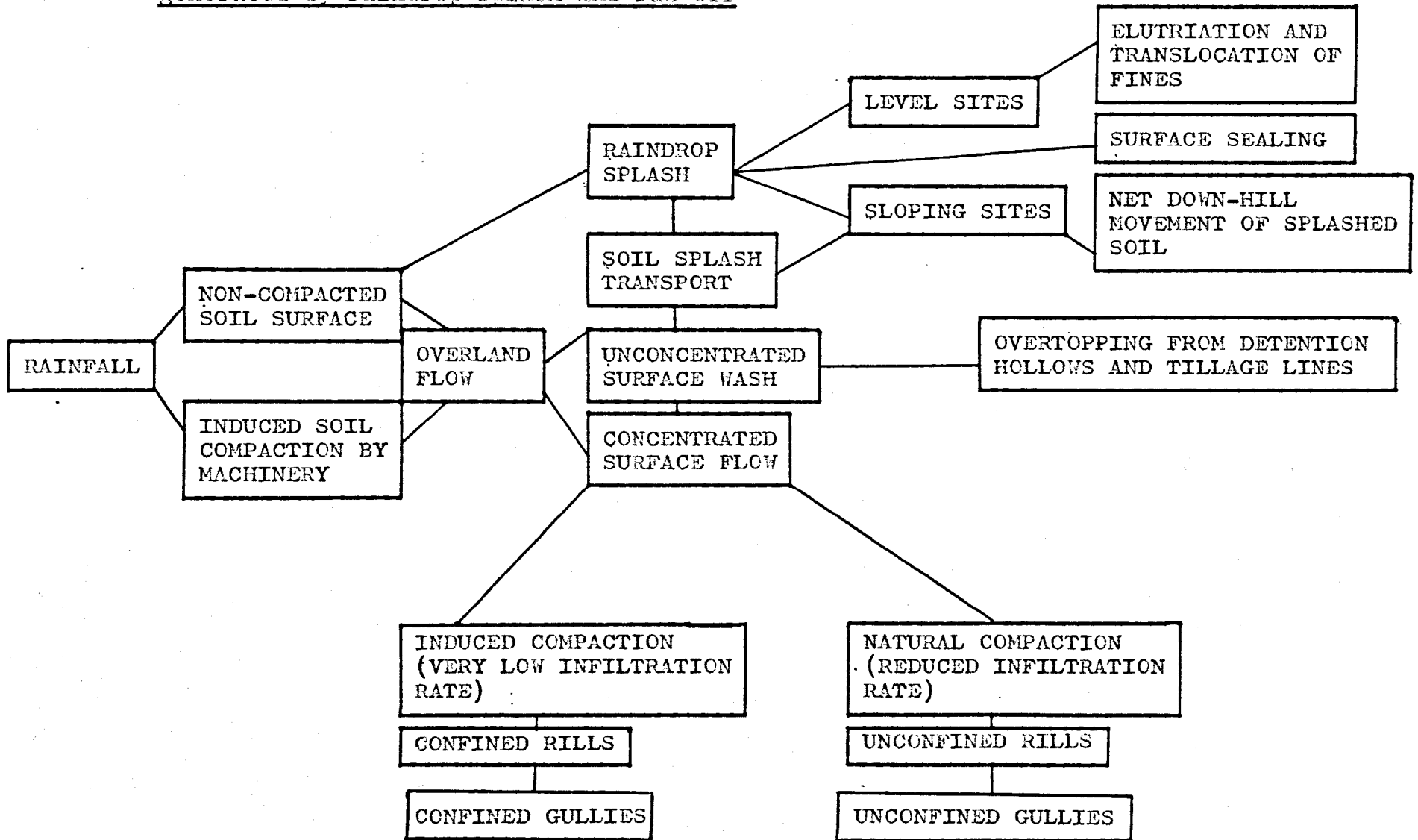


Table 14

Sediment model flow chart for compacted and non-compacted sandy arable soils
generated by raindrop splash and run-off



2. However, reconnaissance surveys by the writer elsewhere in England together with data from other research workers points to the wider applicability of this classification. Whilst soil type and soil erodibility are still important factors influencing soil erosion hazard, modern farming methods in general and soil compaction in particular in the last decade are tending to mask some of those differing soil characteristics most notably in the way in which they affect run-off. It is, therefore, important to take cognizance of the fact that until there is a significant change in arable farming methods the persistent use of up and down slope cultivation using heavy machinery, together with other significant changes such as field enlargement, will inevitably lead to an increased risk of soil erosion through run-off on a wider range of soils.

3. In an attempt to identify and describe the ways in which run-off is affected by surface patterns of induced compaction it has been necessary to widen and modify the accepted three-fold classification of soil erosion by water. The less dramatic run-off, in the form of surface wash, is here described as unconcentrated surface wash, in preference to the use of the disputed term sheet erosion. It is noted, however, that in the pre-rill stage, the movement of surface wash is, nevertheless, influenced by the presence of cultivation lines and induced compaction. Such features in general, and tractor wheelings in particular, are responsible for the concentration of run-off during intense rains. In recognition of this two types of rill erosion are identified as confined and unconfined forms. The former which develops along tillage lines running parallel or oblique to slope

can result in the formation of a high density of rills. The unconfined type develops a 'normal' network of rills unimpaired by surface tillage lines. On steep slopes which are backed above the crest by a large catchment a dense network of rills can develop during one significant storm (> 20 mm). A similar sub-division of gully forms into concentrated and unconcentrated types is adopted. In the confined type there exists a close correlation between surface and subsurface induced compaction and gully shape. Whilst it is recognised that soil erosion by water takes many varied forms which makes classification difficult, one primary aim should be to identify and describe the parts of the profile which are being eroded. In this respect it is proposed to limit the term rill erosion to the Ap horizon and channels cutting the B horizon are described as incipient gullies.

4. The term gully, *sensu stricto*, is reserved for channels cutting the C-D horizon. This approach shifts the emphasis in former classifications from the infilling of rills by normal cultivation and the barrier effect of gullies to one which concentrates on and identifies the characteristics of the materials being excavated, transported and eventually deposited. For rill development the depth of channel formation will tend to be limited by the plough sole or indurated layers formed by induced compaction. In the case of gullies, vertical channel development is influenced by the depth at which coherent rock is encountered. On steep slopes with shallow soil profiles gully development will tend to be inhibited more quickly than where uncoherent materials are being excavated.

5. This suggested classification helps clarify the approach to the description and recording of depositional sequences. This is particularly important where gully erosion excavates sub-soil materials of low base status which are deposited as deep overwash on more fertile soils down slope. Depositional sequences may take place within the field unit and this represents a redistribution of soil materials within the field boundaries. A net loss of soil occurs where run-off carries eroded materials into adjacent fields or into the drainage system. Short-lived rain storms tend to produce the former, whereas storms of longer duration or higher intensity more commonly produce the latter. Whereas some gross estimate can be made for soil materials deposited in fans and spreads these will tend to underestimate total erosion losses as quantities of fines and organic matter may be removed entirely where run-off enters the drainage system.

Chapter 6

Analysis of the principal factors affecting the erosion of arable soils by wind in the United Kingdom

- 6.1 Introduction.
- 6.2 Mechanics of wind erosion.
- 6.3 Basic factors affecting field soil loss.
 - 6.3.0 Wind speed and direction.
 - 6.3.1 Soil erodibility.
 - 6.3.1.2 Surface tilth and roughness.
 - 6.3.2 Principal types of wind erosion damage on arable soils in the United Kingdom.
 - 6.3.3 Conservation measures.
- 6.4.0 Summary.

Chapter 6

Analysis of the principal factors affecting the erosion of arable soils by wind in the United Kingdom

6.1.0 Introduction

The problem of wind erosion is usually associated with semi arid areas like the Great Plains of North America, the Steppes of Western Siberia and Kazakhstan and the desert fringe of Australia where arable agriculture and grazing have disrupted the delicate balance between climate and vegetation. It is surprising, therefore, that wind erosion can become a severe, though local problem in the more humid areas of Europe.

Severe localised wind erosion has been reported in Southern Sweden in the Vomb valley of Southern Central Scania (Ahman 1975), in the Netherlands on sands and peaty podzols, Lumkes et al (1974) and Knottnerus et al (1972), in Czechoslovakia (Southern Moravia, Riodl (1969). In Hungary, Borsy (1975) describes wind erosion on relict and contemporary dunes which cover 20% of Hungary. He estimates that some 40% of the country's cultivated area is affected by soil erosion and 10% is threatened by wind deflation. Bodalay et al (1976) describe wind erosion in the Bacska loess ridge where Chernozem soils have truncated A horizons. In Poland Skrodzki (1972) describes wind erosion in north-east Poland on podzols and brown soils of the southern outwash plains. Reference has already been made to wind erosion in the United Kingdom (Chapter 3) which can be severe particularly in eastern England and Scotland. Many of these areas are characterised by sandy

soils derived from glacial, fluvioglacial or lacustrine sediments; are on exposed terrain which is flat, undulating or knolly, and experience the seasonal occurrence of strong erosive winds notably during springtime and early summer when large hectarages of land are bare. Other significant factors which increase the risk of wind erosion are farm and field amalgamation, cropping practices which lower soil organic matter content and particular crops like sugar beet which are very susceptible to wind erosion damage. All of the above mentioned factors apply to the British Isles. In this chapter the mechanics of wind erosion are reviewed and the basic factors which affect soil loss in the field are identified as wind, soil erodibility, topography and crop and management practices. Consideration is given to the extent to which soil erosion hazard can be reduced or eliminated by erosion control practices.

6.2.0 Mechanics of wind erosion

The wind erosion system can be considered as comprising a number of variables related to surface winds and climate, surface materials and the condition of the field surface. Various attempts have been made to describe a threshold wind velocity at which soil grains start to be moved by the wind. A Task Committee progress report on wind erosion and transportation (1965) identified the three forces exerted on a soil grain by a moving fluid to be impact or velocity, viscosity and static or internal pressures. These forces may be resolved into a drag force acting horizontally in the direction of the wind and a lift force acting vertically. The

The drag force is visualised as being composed of two parts, one of which is referred to as form drag and results from normal wind pressure on the grain, and the other is known as skin friction drag and results from tangential stresses on the grain. The vertical component of the force on the grain is referred to as lift and is the result of the tangential and normal stresses applied at the grain surface. Other influences on the initiation of movement of a grain are summarised in the report as diameter, shape, immersed density of the grain, angle of repose, closeness of packing and impulses of wind turbulence. Wind erosion commences when air pressure on surface soil particles overcomes the force of gravity acting on the particles. For this to occur, surface soil particles usually must be loose, dry and small enough so that they become mobile in an air stream. Chepil (1958) reports that the particles become mobile not in relation to the actual velocity of the air stream but rather in relation to the rate of increase in velocity with height. This rate of increase in velocity is referred to as drag velocity. Chepil defined the drag velocity just sufficient to cause a given particle to move as the threshold drag velocity which he demonstrated is related to particle diameter.

At the onset, the particles are moved through the air with a bouncing motion, known as saltation. The impact of saltating particles causes further movement of soil grains as the impact force is probably much greater than the force of the moving air. Soil particles move by saltation, surface creep,* and suspension which usually operate simultaneously.

* surface creep = traction load

Chepil (1958) gives estimates for a range of soils he examined where 50-75% of the weight of the eroded soil was carried in saltation, 3-40% in suspension and 5-25% in surface creep.

The wind erosion process can be envisaged as having the three distinct phases of particle detachment, particle transport and particle deposition. The basic factors which affect soil movement and soil loss in the field can be summarised as wind, soil erodibility, topography and crop and management practices, each of which will be considered.

Basic factors affecting field soil loss

6.3.0 Wind speed and direction

Surface winds which exceed approximately 3.2 km per hour are turbulent. Soil movement is caused by turbulent flow of wind at the surface and the minimum velocity of wind required to initiate soil movement is known as threshold velocity. Grains 0.1 to 0.15 mm in diameter require a velocity of 12.8-14.5 km per hour at 15.2 cm above the ground (16 km at 30.48 cm). The threshold velocity increases with either an increase or decrease in the size of grains from these diameters (Stallings 1957). On relict and contemporary dunes in Hungary Borsy (1975) found that movement of sandy soil occurred at wind velocities of 5.5-6 m/sec. (19.8-21.6 km per hour). Bakowski (1964) reported the greatest damage to light soils in the Laskowice area (Poland) occurs with dry south easterly winds of 7 m/sec. velocity (25.2 km per hour). Dust storms in the steppes of Western Siberia and Kazakhstan reported by Zhirkov (1964) are associated with a wind velocity of 7-9 m/sec. (25.2-32.4 km.

per hour). Sneesby (1953) considers that a 15-20 mph (24.2-32 km per hour) gusty breeze may set up soil blowing in East Anglia more readily than a steady wind of 25 mph (40.2 km/hr). Severe wind erosion in the West Midlands in March 1968 was caused by northerly winds which averaged 35 km/hr with gusts up to 42 km/hr.

Wind direction

In eastern England most of the damaging winds during the high risk period of March to June have been from the south-west (Sneesby, 1953, Archer and Wilkinson, 1969). Robinson (1968) quotes wind speeds and direction during the severe blow in Lincolnshire on 15-20th March 1968 (see Table 15).

Table 15

Wind speeds in knots at 12.00 hrs on 15 to 20th March 1968

Date	General Wind Direction	RAF Manby	Kilnsea	RAF Wittering	RAF Finningley
15/3/68	North-west	15	25	24	17
16	South-west	20	28	19	25
17	West	27	34	26	26
18	West	30	38	35	33
19	South-west	24	24	24	29
20	West	33	45	30	32

Source: Robinson (1968) page 356.

The weather conditions which brought about the wind erosion are

described by Robinson (Ibid) as being caused by a series of vigorous troughs of low pressure, associated with depressions mainly to the north of Scotland moving eastwards across the British Isles giving rise to westerly gales in many areas. Records of dust storms sighted at the weather station at Mildenhall in west Suffolk (1935-1953) show that soil blowing has taken place predominantly in late March and in April on fifteen out of the recorded sixteen occasions. Sneesby and (1953),[^]Robinson (1968) consider that the most damaging winds in Lincolnshire appear to blow from a westerly direction, mainly south west, although erosion can be caused by easterly winds.

In the West Midlands erosion has been recorded associated with strong winds from the west, north and occasionally east. Short-lived blows have occurred during squally north-westerly and south-westerly winds. In the east Midlands and Fens although some erosion occurs in most years, severe damage can be expected on average once every five years, (Robson and George 1971, Seale 1975,⁽²⁾[^]Reeve 1976).

6.3.1 Soil erodibility

Soil and surface conditions relating to erodibility include texture (particle size and density), structure and surface tilth and roughness. Davies and Harrod (1970) propose a three-fold division of erosion risk to soils of various textures in predominantly arable systems.

1. Soils of high erosion risk

Fine sands, medium sands, loamy fine sands, loamy medium sands, sandy peats, loamy peats and light peats (high organic matter peats 35%).

2. Soils of medium erosion risk

Coarse and very fine sands, coarse loamy sands, peaty loams (low organic matter peats).

3. Soil of low erosion risk

All soils with higher silt and/or clay content. Gravelly and stony soils will be less easily eroded than the stone free counterpart. However, the Pierre granulated clay of South Dakota, U.S.A., is highly erodible as frost action produces a high proportion of small aggregates in the surface layers.

Soils low in organic matter which contain a high percentage of sand (grains < 1 mm) are very susceptible to wind erosion. Such soils which are low in silt and clay tend to form weak aggregates which are easily broken down by splash erosion and offer only weak resistance to wind blasting. Even so, such soils are much less subject to erosion when moist than when dry as Chepil 1956 demonstrated (see Table 16).

Table 16

Rate of soil flow in a silt loam at different moisture contents

Equivalent Moisture*		Soil flow in 32 mph wind, mg/cm width/sec
0.25	Very dry	780
0.71		390
1.03	Slightly moist	40

* equivalent moisture = % moisture of soil in field ÷ by % moisture of a soil at permanent wilting point -

Source after Chepil 1956, Page 281.

et al
Chepil (1963) designates the most erodible fraction of a soil to be the fine sand fraction which has an equivalent diameter of 0.1-0.2 mm (equivalent diameter = $PD/2.65$ where P = particle density and D = average diameter of particle). Particles of 0.8 mm in diameter and larger are moved only by very strong winds. Particles of diameter less than 0.02 mm exhibit strong cohesion and are only moved by impact, therefore smooth surfaces comprising particles in this size range are relatively resistant to erosion unless triggered.* However, once these particles are moved they are capable of being carried great distances in suspension. Delany et al (1975) found that the aerosol produced by wind erosion of soil has a significant organic component. They found that the ^{particle size} distribution of the aerosol exhibited the expected shift towards smaller sizes and that the percentage of organic carbon increased in all sizes, particularly in the 10-100 μ m size range. There was an overall enrichment of x 20 in the organic content of the

* triggered by saltating particles

aerosol when compared to the original soil, (a Brownfield fine sand from an experimental plot, Plains Texas). The authors consider that fractionation occurs during the wind erosion process and the size distribution and composition of the generated aerosol are different from that of the parent soil. The organic matter in the soil is present either as low density vegetative residue or as humic substance associated with the fine clay fraction and tends to be particularly susceptible to differentiation and transport by erosive winds. Organic soils are particularly prone to wind erosion when in a dry exposed state. Frost action and cultivation practices which force tilths increase the soil's susceptibility to wind erosion. Davies and Harrod (1970) consider that in deep peat soils the particle density may be as low as 0.2 and the most erosive aggregates of the order of 1 mm in diameter; a size which is produced by natural weathering. The approximate diameters of soil particles moved by saltation, surface creep and suspension are given in Table 17.

Table 17

Soil particle movement

Size range mm.	Type of movement
0.005 to 0.5	Saltation
0.5 to 2.0 (according to density and wind velocity)	Surface creep
< 0.02	Suspension

The sorting action of wind affects the removal of soil material either in a non-selective or a selective way. In the case of loessial soils wind erosion removes virtually all the surface soil and is largely non-selective. On soils derived from glacial till and sandy soils of various origins, wind erosion tends to remove the silt and clay and this action eventually leads to the concentration of the coarser sand fractions.

6.3.1.2 Surface tilth and roughness

The surface of cultivated arable fields will change appreciably from being very cloddy after ploughing, discing and harrowing to more even and smooth after seed bed cultivations. The resultant field surface tilth will depend upon a number of factors, some of which will be influenced by the character of the soil and the nature of the season during which cultivations took place. An initial cloddy and rough surface may be quickly broken down by splash erosion with the formation of a partial cap or crust which may be broken by subsequent cultivations. The degree of surface roughness has a marked effect on average wind speed at the surface which in turn affects the rate of soil blowing at that surface. This is demonstrated in Table 18 which summarises wind tunnel experiments of Chepil and Milne (1941) using a fine sandy loam with ridges 22.8 cm apart and 6.4 cm high.

Table 18

The effect of surface roughness on rate of erosion by wind

Wind velocity mph (Kilometres p.h.) at 12" height (30.48 cm)	Rate of soil flow g/cm width/sec.	
	Smooth surface	Rough surface
17 (27.4)	0.32	0.10
22 (35.40)	0.88	0.19
30 (48.3)	2.10	0.20

Source: Chepil et al (1941).

Two distinct types of surface roughness can be identified; one which is formed by tillage implements during seed bed preparation into a marked pattern of ridge and furrow of varying amplitude (see Figure 58 Page 52) and the other into micro-ridges and furrows formed by seed drills and ribbed rollers (see Figure 59 Page 53). Chepil and Milne (1941) examined the effects of ridges on soil erosion by wind and found that (a) ridges 6.4 cm high placed at right angles to the wind reduced erosion rates to $\frac{1}{4}$ to $\frac{1}{3}$ the rate from a smooth surface, (b) ridges constructed of natural dune material eroded quickly having virtually no wind erosion controlling effect, (c) on cultivated soils, clods protected the ridges and maintained them near their original height, (d) ridges reduced erosion by reducing the wind velocity at the average soil surface and by trapping soil particles in the furrows between ridges and (e) non-beneficial effects of ridges included increased wind velocity at ridge crests and increased wind eddying. Armbrust et al (1964) evaluated the relative effects of ridge heights with varying degrees of simulated cloddiness on soil erosion by wind (wind tunnel). Ridges 5.1 to 10.2 cm high

eroded little due to trapping of soil particles between ridges and attendant decreases in wind velocity. Ridges below 5.1 cm high proved less effective in trapping soil particles and in reducing wind velocities. Ridges above 10.2 cm experienced extensive erosion which resulted from higher wind velocities at the ridge crests and increased wind eddying. Observations of wind erosion on arable soils in the West Midlands by the writer substantiate these findings which are directly applicable to conditions here despite the smaller field units and consequent reductions in wind fetch. Even in less exposed situations the direction of tillage lines relative to an erosive wind are of great importance. In Figure 58 (Page 52) the ridges are at right angles to the dominant wind and ridge crests height varied from 12-15 cm. Surface roughness of the crest zone varied from large angular aggregates 4-6.5 cm in diameter which predominated and included stones of the same diameter and smaller and a large number of partially decomposed shells of sugar beet. The aggregates on the crests and margins were quickly eroded by a persistently strong N to NNW wind which averaged 26 km/hr (for 8-10 hours). Saltating medium sand grains became concentrated in the furrows but became airborne when strong gusts (up to 40 km/hr) renewed the saltation load, (Figure 58 Page 52 middle distance). After two days of persistently strong winds the ridge crests in the more exposed part of the field were broken down leaving more resistant aggregates and stones lining the former crests and the furrows infilled with drifted sand (see Figure 60 Page 54). A diagrammatic cross-section of a ridge is shown in Figure 61 (Page 55) which attempts to show zones of soil removal, accumulation and direction of movement when wind blows at right angles

to a ridge. Details of the eroded ridge crests on Figure 60 are shown in Figure 62 (Page 56) which reveals a high proportion of rounded and sub-angular aggregates on the crests with small accumulations of sand forming in the leeward side of them. Eddy effects in the lee of ridge crests can be identified in incipient micro-dune formation in the furrows. Where the dominant erosive wind blows parallel to ridge crests clods and large aggregates develop a marked pattern of elongated tails of sand on the leeward side. The furrows infill with material which is blown down and out obliquely from the ridge crests and is swept along the furrow (see Figure 63 Page 57). In fields where the surface is broken by clods and turf residue (see Figure 64 Page 58) a pattern of ripples forms at right angles to the dominant erosive wind. Sand shadows form in the lee of the larger obstacles.

Alternate ridges and furrows trap saltating particles thus reducing the normal build-up of eroding material downwind. The more elevated forms of ridges, as shown in Figure 58 (Page 52) protrude higher into the turbulent wind layer and are subjected to greater wind forces. In most sandy soils the clods and aggregates on the tops of ridge crests are rarely resistant enough to withstand the added abrasion and quickly erode off. The effect of ridging is, however, considerable in reducing soil loss, but because of the inherently weak structure of most sandy soil the beneficial effect is quickly lost if strong erosive winds persist for more than 24 hours. When the erodible soil fractions are removed from the ridge crests and become trapped in the furrows - a process known as detrusion, surface roughness decreases and the smoother surface causes

a progressively increased rate of soil movement with distance down wind. Chepil (1957) refers to this increase of soil discharge with distance down wind over an unprotected eroding area as soil avalanching. As erodible soil fractions tend to accumulate on the surface with distance downwind a progressively more erodible soil condition is created to the leeward. The greater concentration of saltating and creeping grains downwind increases the frequency of impacts and abrasion of soil aggregates and clods which are in turn moved by wind. The Task Committee (1965) found no distinct demarcations of size between various grades of windsorted materials but rather the tendency for size distribution of one grade to overlap considerably that of another grade.

6.3.2 Principal types of wind erosion damage encountered on arable soils in the United Kingdom

The principal types of wind erosion damage sustained by arable soils in this country are brought about by the processes of soil drifting by deflation and surface creep and the subsequent deposition of wind transported material. The amount of damage varies regionally and is conditioned by a number of factors in addition to soil erodibility. These include management practices which tend to increase wind erosion risk on susceptible soils such as field enlargement, continuous arable cropping, prolonged soil exposure together with certain cultivation practices such as forcing tilths. When wind erosion does occur much of the soil drifting normally results in a redistribution of soil materials within the affected field or farm unit. However, the deflation and soil drifting process may result in significant changes in surface texture,

particularly where selective sorting takes place. Further, severe blows may result in large quantities of fine grade material (particles less than 0.1 mm in diameter) being removed entirely from the farm unit.

Arable soils which are exposed over a period of years to wind erosion suffer a depletion of fertility. Analysis of fine dust particles moved from a wind eroded arable field in the Canadian Prairies contained up to twice as much nitrogen, organic matter and phosphorus as material remaining (Department of Agriculture, Canada 1966). Wilkinson et al (1968) give mean values of soil characteristics for eroded and non-eroded sites on sandy soils in parts of Lincolnshire (Kesteven and Lindsey) and Nottinghamshire and these are reproduced in Table 19. Whilst no significant differences were registered in phosphorus between eroded and non-eroded soils, the levels of K were lower in the eroded area compared with the non-eroded, though the authors consider that the difference has little practical significance. Whereas plant nutrient deficiencies can be easily rectified the very low levels of organic matter are a cause of concern and will have an adverse effect on crop growth during dry seasons.

Arable soils may suffer partial or complete removal of the Ap horizon (plough horizon). In many profiles of freely drained sandy soils, particularly brown earths low in organic matter (<2%) there is usually little colour differentiation in the upper portion of the profile to facilitate identification of truncation. Evidence indicative of truncated soils may appear after ploughing deflated parts of a wind

Mean values of soil characteristics for eroded and non-eroded sites

Location and number of fields	Soil pH	CaCo ₃ %	Readily soluble nutrients p.p.m.			Organic Matter	Sand Content %		
			P	K	Mg		Coarse	Fine	Total
Lincolnshire									
Within fields (232)									
Eroded areas	7.0	0.23	28	115	41	1.9	51	38	89
Non-eroded areas	7.0	0.37	29	136	59	2.8	45	39	84
Fields liable to complete erosion (44)	6.9	0.32	28	94	41	1.8	60	29	89
Nottinghamshire									
Within fields (40)									
Eroded areas	6.9	0.31	22	94	121	1.9	62	22	84
Non-eroded areas	6.8	0.18	23	100	126	2.1	61	22	83
Fields liable to complete erosion (13)	7.0	0.27	11	86	112	2.6	59	26	85

Significance tests refer to the comparisons between eroded and non-eroded parts of fields only.

Source: Wilkinson et al 1968 Page 55.

Table 19

Mean values of soil characteristics for eroded and non-eroded sites

eroded field particularly where there is colour difference between the Ap and Eb/Eg or B horizons. Hodge and Seale (1966) refer to a field on Isleham soil near Mildenhall, north-west Suffolk, where wind erosion had removed the Ap horizon (very dark greyish brown to black), revealing the brown sub-soil (Eg horizon) of the peaty gley. In the parts of the field where this had occurred the growth of sugar beet was visibly inferior compared with the surrounding crop.

In the British Isles deflation of glacial sands and a range of sandy textured soils of various derivations, will tend to increase the concentration of coarse material on the surface by the process of selective sorting. This results in a change in the texture of the surface layer. The rate of change will be conditioned by the frequency and severity of erosive episodes. In Nottinghamshire analytical data suggest that some marginal loamy Newport soils could be eventually transformed to sandy Newport soils (as defined) by deflation of silt, (Robson and George 1971). Jarvis (1973) considers that wind erosion has led to the accumulation of deep topsoils in the lee of exposed knolls (on Newport series) and reports the accumulation of sand on the east side of fields in the Stockbridge series as for example at Carrside farm (SE 696 022).

The deposition of wind drifted material may take the form of a large continuous sheet which has formed and migrated by saltation and surface creep (see Figure 65 Page 59) or can come to rest against a large hedge as in Figure 66 (Page 60) or spill through gaps in a hedge line. Usually only parts

of fields are affected by these depositional sequences which can range in depth from a few centimetres to over half a metre - the latter usually being representative of hedge line accumulations. The change in soil texture caused by soil drifting is of greater long term importance for not only does it affect productivity and available water capacity of the soil but once this process is initiated on sandy arable soils it has a cumulative effect as the soil becomes more erodible - particularly soils which are in continuous arable cultivation.

Seale (1975.1) considers that after oxidation wind erosion now causes the most serious loss of surface peat and in particular peats high in organic matter are most susceptible to erosion. The sorting action of wind erosion is of great importance when considering the types of material being deposited. Large spreads of coarse sand over more fertile soil may inhibit crop growth if the blown material is deep enough (>10 cm). If the supply rate is very intermittent plough action and subsequent mixing will limit the effect, but with a more frequent supply rate ploughing will only rework deposited material and the surface soil will be characterised by a change in textural grouping. This latter situation is more common in eastern England on glacial sandy soils in parts of Lincolnshire and East Anglia than in the West Midlands.

Apart from the serious consequences of wind erosion in terms of soil loss there can be significant losses in farm income and general social costs to consider. Losses incurred directly by the farmer include possible loss of seed, deflation of

fertilizer input, increased costs arising from re-seeding and ground preparation, abrasive damage to young crops, together with the adverse effects of partial or complete burial of a growing crop by deposited soil. Additional costs may be incurred for clearing out soil infilled drainage ditches and partially blocked farm tracks. Social costs are difficult to estimate as no realistic value can be allocated to the loss of ^amajor non-renewable resource like soil. Other social costs which can be calculated include cleansing regional drainage ditches and roads. The nuisance value and health hazard of wind erosion-generated aerosols is again a difficult one to assess. Further reference will be made to some of these problems and their general impact on the soil system in Chapter 10.

6.3.3 Conservation measures

The Food and Agriculture Organisation (1960) offer four measures which act as a basis to control soil erosion by wind. They are:

- (a) produce or bring to the soil surface aggregates or clods which are large enough to resist the wind force;
- (b) roughen the land surface to reduce wind velocity and trap drifting soil;
- (c) establish barriers or trap strips at intervals to reduce wind velocity and soil avalanching;
- (d) establish and maintain vegetation or vegetative residues to protect the soil.

The effectiveness of these principles of control varies with local soil, climate and land use practices. As is the case

with many conservation measures the difficulty lies not in understanding the problem but in designing and applying control measures which can be realistically adopted without causing appreciable losses of income to farm operators. Control measures can be subdivided into short-term and long-term practices. Both rely directly or indirectly on the stabilization of sandy soils characterised by single grain structure and low levels of organic matter. Short-term measures have included soil marling in areas where suitable material is readily available. Marling improves both soil structure and nutrient status and has a beneficial effect on surface texture. This is, however, a costly operation, particularly if the marl is not available on the farm. A marling experiment has been set up at Gleadthorpe Experimental Husbandry Farm (Lincolnshire) to measure long term soil changes, the effect on wind erosion and on crop yield (Wilkinson et al 1968). Marling has been practised in many parts of lowland Britain to improve light sandy soils but the practice is not common today because of cost. Another short-term measure is rotational ley grass which has tended to go out of favour in many wholly arable systems as it is considered uneconomic. Although a grass ley will stabilize a field surface its effects are relatively short-lived, particularly on a soil which has become more erodible through previous selective sorting by wind. Inter-row cropping or nurse cropping is another method which is used to protect more sensitive root crops such as sugar beet through the early stages of growth. This method has been well-used but is expensive and introduces some management difficulties.

Salter (1967) and Wilkinson et al (1968) refer to the use

of pulverised fuel ash (from electricity power stations) as a possible measure of improving available water capacity of sandy soils, ameliorate texture and help control wind erosion. As other short-term methods such as soil conditioners, bitumastic or synthetic latex mulches which are used to stabilize sandy soils and to improve seed germination, prove to be very expensive the prospect of the increased use of direct-drilling is regarded by some writers as the most important single conservation measure yet introduced. This practice is considered in Chapter 10.

Long term measures include the installation of permanent wind breaks in the form of shelter belts and hedges. Their location must be carefully planned to ensure the maximum protection and avoidance of unwanted down-wind effects on adjacent fields. Discussion has been centred on ways to offset the worst effects of wind erosion without making any significant alteration to farming practices which exacerbate the problem of wind erosion. Unless direct drilling provides a suitable technological break through to permit the continuation of modern cropping practices some changes will have to be made in order to offset unacceptably high soil losses by wind erosion.

In the United States of America it is possible to calculate the amount of wind erosion on arable soils by using the wind erodibility equation - an equation similar to the universal equation for soil loss by water referred to in Chapter 4. However, the wind erosion equation is much more complicated to use because the relations between variables in the equation are complex and require computer programmes and a large data

store. At the present time the wind erodibility equation could not be easily adapted to solving wind erosion problems in the United Kingdom because of a lack of compatible data. The concept of how the equation works is described by Woodruff and Siddaway (1965). The amount of erosion E, by wind is expressed by the potential wind erodibility equation:-

$$E = F(I.K.C.L.V)$$

Where E = total erosion loss in tons per acre

F = indicates that erosion is a function of the various parameters

I = soil erodibility index based on texture and aggregation. 'I' ranges from 0 (as stony) to over 300 (very fine non-aggregated sands). These values can be derived from prepared tables.

K = surface roughness: it varies from 1.0 for smooth soil surfaces to 0.5 if rough surface has at least 4 inch (10.2 cm) vertical microrelief variation.

C = climate factor (windspeed and effective soil moisture). These values can be obtained from made up tables.

L = effect of field size (length). This value ranges from 0 (small protected areas) to 1.0 (wide open area for many hundreds of metres) without effective barriers values of 0.8 to 1.0 can be used depending on degree of openness.

V = equivalent quantity of vegetative cover, calculated from tables according to the kind of cover (stubble, cut residues) on the field.

6.4.0 Summary

1. Contrary to popular opinion wind erosion damage is not confined only to the arid and semi-arid parts of the world but occurs widely in parts of Europe where its occurrence can be correlated to cultivated soils derived from glacial till, outwash, loess and fen peats. In all of the regions where wind erosion has been recorded the problem seems to be far from being eradicated. To the contrary, the growth of modern farming methods in Europe seems to be increasing the risk of erosion hazard, particularly in those areas which are now, or are becoming, highly mechanised.

2. Soils which are particularly susceptible to wind erosion damage are at greatest risk when exposed during dry windy periods which occur most frequently during spring and early summer. Consideration is given to the question of the threshold velocity at which wind becomes erosive and the mechanics of the wind erosion process. Soil movement is caused by the turbulent flow of wind at the surface and by the impact of saltating grains of soil. The minimum velocity required to initiate this movement has been designated by Chepil (1945 (2)) as the minimal fluid threshold velocity. As the wind strengthens all grades of erodible particles begin to move and this Chepil (IBID) described as the maximum fluid threshold velocity. The minimal threshold for the most erodible sections determines the threshold velocity for the field. The velocity of surface winds increases with height above the surface and this can be expressed by the following equation:-

$$V_z = 5.75V_* \log \frac{z}{K}$$

where V is mean velocity at any height Z , V_* is drag velocity and K is a roughness constant. It is, therefore, the gradient in velocity which determines the magnitude of the force exerted. Once large quantities of soil material become airborne the momentum, and hence the velocity of the surface wind, are reduced. Where soil erodibility is high the greater will be the concentration of moving grains during a blow and consequently there will be a greater reduction of surface wind velocity.

3. Once movement of soil particles is initiated they are transported in three distinct types of movement, saltation, surface creep and suspension, depending upon their size in relation to the velocity and turbulence of the wind. Chepil (1958) estimates that the highest proportion of eroded soil moves by saltation (50-75% by weight) and the least by surface creep (5-25%). Estimates of the threshold velocity of erosive winds varies but can be averaged around 20 km/hr. Erosive winds can come from any direction but are commonly west to south west in the British Isles.

4. Soil and surface conditions relating to erodibility include texture, structure and surface tilth and roughness. Soils low in organic matter which contain a high percentage of sand grains < 1 mm are very susceptible to wind erosion. This susceptibility declines as particle sizes increase with those of > 0.8 mm diameter being moved only in very strong winds. Particles < 0.02 mm exhibit strong cohesion and are only moved by impacting cascading grains. Delany et al (1975) found that the aerosol produced by wind erosion of soil contained a significant organic content, particularly in the 0-100 μ m range with an overall enrichment of x 20 when compared with

the original soil. This is attributed to a greater selectivity by wind of finely divided organic matter.

5. Ridged surfaces of fields have been shown to be less erodible than smooth surfaces depending upon the height of the ridge crests and wind velocity. Ridges 5.1 to 10.2 cm high eroded little but over this level their effectiveness in strong winds (>25 km/hr) declines. Likewise ridges below 5.1 cm high proved less effective in trapping soil and in reducing wind velocities. The effect of ridging parallel to and at right angles to the prevailing erosive wind is demonstrated by a number of illustrations of erosion taken from east Shropshire. Chepil (1945) describes the increase of soil discharge with distance downwind over an exposed field surface as the process of avalanching.

6. The principal types of wind erosion damage on arable soils in the United Kingdom are examined. In many areas affected by wind erosion selective sorting has tended to increase the concentration of coarse fractions on the soil surface. This is particularly notable in those areas characterised by sandy tills and outwash deposits. Wind erosion of eolian sediments, however, brings about non-selective sorting and is less likely to shift a soil from one textural grouping to another as in the case of sands (loamy to sandy). However, instances are quoted, notably in central and eastern England, where truncation of the Ap horizon has occurred by wind erosion. The widespread deposition of sandy material by saltation and surface creep has an adverse effect where coarse grained material buries

more fertile soils, or covers growing crops or damages growing crops by sand blast. Crop damage, loss of seed and fertilizer represent losses to the individual farmer. Loss of soil on a large scale represents a serious depletion of fertility and loss of a non-renewable resource. The total social costs of serious blowing are difficult to estimate.

7. Conservation measures are briefly discussed here and have been treated under the two headings of short-term and long-term practices. The former includes marling, short leys, inter-row cropping and the use of pulverized fuel ash as well as various synthetic mulches. Expense and convenience in operating are major drawbacks to many of these measures and the feasibility of adopting conservation measures rests on their integration into the general running of the farm unit. Long-term measures such as permanent wind breaks have proved to be very successful locally in limiting the erosive effects of strong winds. New techniques of direct drilling and its likely impact on offsetting erosion damage are briefly considered here.

8. Finally reference is made to the wind erodibility equation which is used in the U.S.A. to estimate the amount of soil loss generated by a wind erosion episode. Unlike its counterpart for water erosion (the universal soil loss equation) the former is not easily adapted to solve similar problems in the United Kingdom as it relies on a complex computer programme and a large data store derived from experimental plots and field trials, the like of which is virtually absent in the United Kingdom.

Chapter 7

Soil erosion in the West Midlands: a qualitative assessment of the distribution and an analysis of the main causal factors

7.1 Introduction.

7.2.0 Distribution of soil erosion in the West Midlands.

7.2.1 Reference to erosion in Soil Survey Memoirs and Records.

7.3.0 Main causal factors of erosion 1. Soils.

7.3.1 Main causal factors of erosion 2. Rainfall.

7.4.0 Special study: analysis of rainfall in east Shropshire.

7.4.1 Introduction.

7.4.2 Rainfall analysis.

7.5.0 Summary.

Chapter 7

Soil erosion in the West Midlands: a qualitative assessment of the distribution and an analysis of the main causal factors

7.1 Introduction

Soil erosion in the West Midlands

Survey work during the last ten years in parts of the West Midlands has revealed the widespread incidence of accelerated soil erosion by rain and to a lesser extent by wind. In parts of the region an interaction of physical factors with land use and management practices combine to produce a serious erosion hazard. This chapter deals primarily with a qualitative assessment of soil erosion and identifies the parts of the region which exhibit a range of erosional problems.

Particular attention is paid to an analysis of soil erosion in east Shropshire and the adjoining areas of Staffordshire which cover some 800 sq. kilometres lying west of Wolverhampton and stretching to the Severn Valley at Bridgnorth. Newport and Kinver respectively locate its northern and southern extremities. Although there was substantial evidence of erosion on the Clee Hills (see Figure 67 Page 61), Cannock Chase and on some common land used as amenity areas, the most widespread incidence of erosion was found on agricultural land. A reconnaissance survey was carried out by the writer during the period 1966-1970 to try to ascertain the areal

extent of accelerated erosion of arable soils in the West Midlands. Evidence of erosion predominantly by rainfall and run-off was recorded in Herefordshire, Staffordshire, Shropshire, Warwickshire and Worcestershire and its occurrence was widespread in areas of intensive arable use where the soils were sandy or silty in texture and the terrain was characterised by gentle or moderate slopes (2-7°). Wind also affected a large hectarage of sandy textured soils, particularly of the Newport, Bridgnorth and Crannymoor series. Reference is made to soil erosion on these series and others within the region in a number of Soil Survey Reports.

Although in each year of the Survey erosion was observed on new as well as on known sites, by far the greatest amount occurred during the 1968-69 period and again in 1976 when it could be described as ubiquitous in the West Midlands. Bleasdale (1974) considers 1968 to be an outstanding year for multiple events with exceptionally heavy and widespread rainfall, and he regards that year as unique during more than 100 years of well-documented rainfall history. The record breaking drought of 1976 was followed by a very wet autumn when the combined England and Wales rainfall of 313 mm for September and October together exceeded the previous highest since 1727 of 310 mm in 1903 (Royal Society 1977). During the spring and early summer of 1968 there were some marked dry spells with strong winds which caused severe wind erosion in eastern England and to a lesser degree in parts of the West Midlands.

7.2.0 Distribution of soil erosion in the West Midlands

Erosion of arable soils by wind and water take place annually in parts of the intensively cultivated areas of the region. In most years the area affected is small in comparison to the total hectareage of crops and grass but it is nevertheless very significant as it tends to recur on the same sites and affect high grade soils (Capability Class 1-3). The area affected by erosion increases during adverse seasons, for example (1968-9); in abnormally wet or dry spells and freak short-lived spells of weather such as line thunderstorms* and slow moving depressions which may affect large parts of the region. The timing of these events with respect to field conditions and the stage of crop growth is of great importance when assessing potential erosion hazard. A distinction is drawn between adverse seasons which can cause widespread erosion over a wide range of soils and more isolated events such as local thunderstorms. Both may produce spectacular erosion in an area and such events may have a long return period. However, the sum of less spectacular erosive events throughout the year may in the long-term be more significant as the return period for such events is invariably shorter. In east Shropshire significant amounts of erosion have been registered every year in a ten-year survey, which is referred to in Chapter 8.

A detailed picture of the erosional history of an area can be achieved only through accurate monitoring on a field to field basis and this has been attempted in parts of east Shropshire.

For the region as a whole a qualitative assessment is made

* Line thunderstorms move in narrow belts or bands in the direction of the winds at low level and are usually more intense. 186.

based on reports of soil surveyors in memoirs and records and from personal field work.

7.2.1 Reference to erosion in Soil Survey memoirs and records

Mackney and Burnham (1966) report soil erosion in the Church Stretton district of Shropshire affecting soils of the Munslow series (silt loams) on sloping land of 3-11° during periods of heavy rain in the spring and summer. Hodgson (1972) refers to spectacular erosion affecting Munslow soils in the Ludlow district during heavy spring or summer rains on fallow or partially covered soils, and widespread erosion of soils of the Bromyard (fine silty) and Eardiston series (fine and very fine sandy loams).

Hodgson and Palmer (1971) describe erosion by rainfall and run-off on the Eardiston series and Munslow series to the south of Hereford. They record both sheet and gully erosion affecting Bromyard series (silt loam) and the Ross series (sandy loam). Whitfield (1971) describes serious rill erosion on soils of the Ross, Eardiston and Sellack series (sandy loam - loam) of the Ross-on-Wye area of Herefordshire. Palmer (1972) again cites soils of the Eardiston and Bromyard series as being prone to sheet and gully erosion when sloping land is cultivated and capping is considered to be a serious problem on silt loams of the Dove series (silt loam). Hollis and Hodgson (1974) refer to spectacular gully erosion occurring on the fine sandy loams of the Bromsgrove series near Kidderminster, Worcestershire. The same soils are also liable to blow and

are considered to be very susceptible to both water and wind erosion. Whitfield (1974) and Whitfield and Beard (1975) describe nine soil series near Leamington Spa and Alcester in Warwickshire which are affected by loss of structure and capping and a further five series which have a high risk of structural damage. Jones (1975) describes soils in Eccleshall district of Staffordshire and cites erosion of the Bridgnorth and Wick series (sandy loams) and considers four other series (Bromsgrove, Newport, Arrow and Ollerton - all sandy loams) to have minor erosion hazards on slopes and to be affected by weak structure, slaking and capping.

Location of soil associations in the West Midlands with reported structural and erosional problems

The main soil series which are quoted in the text as having structural and erosional problems under arable agriculture are identified on the Soil Association map of the West Midlands (Mackney and Burnham 1964) (see Figure 68*) and are referred to in Table 20. A range of soils in seven associations are identified as liable to erosion. However, reference is made only to those areas of the Soil Associations where erosion has been observed in the field. As the seven associations represent over three quarters of the area of West Midlands soils out of which a high proportion is in arable use, soil erosion must be regarded as a potential or actual hazard on a high proportion of this land. Since the completion of the Soil Association map in 1964 some series names have been

* Figure 68 is located in Pocket A of Volume 2

superseded and new soil series have been designated, together with the incorporation of a new classification of soil subgroups (Avery 1973). This new system is adopted throughout the text.

Table 20

Soil associations in the West Midlands with soil series liable to structural and erosional damage

Soil association 1

Subgroup	Soil Series
Gleyic brown earths	Arrow, Astley Hall
Typical brown sands	Newport
Gleyic brown sand	Ollerton
Typical (Humo-ferric) Podzol	Crannymoor

This association comprises 6 main areas:-

- Shropshire:
1. Shrewsbury area and south to Dorrington.
 2. Shrewsbury - north-west to Oswestry.
 3. Shrewsbury (Shawbury, north to Whitchurch).
 4. East Shropshire, Newport to Kinver.
- Staffordshire:
5. South Staffordshire west of the conurbation to the Shropshire border.
- Warwickshire:
6. East Warwickshire - Coventry - Rugby area.

Table 20 continued 1

Soil association 2

Subgroup	Soil Series
Typical brown earths	Bromsgrove, Ross, Clive
Gleyic brown earths	Inkberrow
Typical brown sands	Bridgnorth
Stagnogleyic Argillic brown earths	Hodnet
Typical (Humo-ferric) Podzol	Crannymoor

This association comprises 5 main areas:-

- Staffordshire: 1. Stafford - Rugeley Cannock area.
2. Lichfield area south to Sutton Coldfield.
3. South west of Wolverhampton to Kinver and Stourbridge.
- Worcestershire: 4. Kidderminster - east to Belbroughton and south to Bromsgrove.
5. Kidderminster south to Ombersley.

Soil association 8

Subgroup	Soil Series
Typical brown earth	Newnham, Wick
Gleyic brown earth	Norton

The main area identified is in parts of the Severn and Wye valleys and in scattered pockets in Staffordshire and Worcestershire.

Soil association 12

Subgroup	Soil Series
Typical brown sands	Newport
Stagnogleyic Argillic brown earths	Flint, Salwick
Typical Stagnogley soils	Salop

This association is widespread covering much of north and west Shropshire below 152 metres, Staffordshire and northern Warwickshire.

Soil association 14

Subgroup	Soil Series
Typical Argillic Pelosol	Worcester
Typical Argillic brown earths	Lilleshall, Shifnall
Stagno-Argillic brown earths	Donnington Heath Whimple
Typical Stagnogley soil	Brockhurst

This association comprises 3 main areas:-

Shropshire: 1. Shifnal district.

Staffordshire: 2. Keele district.

3. The central lowland of Worcestershire and Warwickshire.

Soil association 15

Subgroup	Soil Series
Typical brown earths	Eardiston, Dore
Typical Argillic brown earths	Bromyard

This association occupies a broad belt (approx. 25 km wide) which runs south of Much Wenlock in Shropshire through Bromyard to Ledbury in Herefordshire. Another large area is found north of Ross-on-Wye running west to Pontrillas and north-west to Hay-on-Wye. A third area lies to the north and west of a line from Hereford to Hope under Dinmore.

Soil association 16.

Subgroup	Soil Series
Typical brown earth	Munslow
Typical Argillic brown earths	Stanway Wilderhope Yeld

The main area described here is the Scarpland belt which runs from Ironbridge on the Severn 35 km south-east to Ludlow and south and east through Wigmore in Hereford towards Kington. Alternating beds of hard limestone (Wenlock and Aymestrey) and softer shales (Wenlock and Lower Ludlow) give rise to scarp and vale topography and the distribution of soils is closely related to scarps, dipslopes and vales.

7.3.0 Main causal factors of erosion 1. Soils

In the arable areas of the region a number of soils are identi-

fied with varying degrees of structural weakness which render them more susceptible to erosion, particularly when in continuous arable cropping. The soils listed in Table 21 are reported in Soil Survey memoirs and records as being susceptible to erosion. Table 22 lists soils which are subject to loss of structure and capping and are, therefore, liable to erode, and erosion episodes have been recorded on many of these soils by the writer. In addition, a number of other soil series which erode are listed in Table 3⁴ (Chapter 8 Page 23⁴) which refers specifically to soils in the east Shropshire parishes of Claverley, Rudge and Worfield. Altogether some 97 series have been described in the West Midlands, some of which subsequently have been redefined or included in other series. Of this total over half are in arable usage and the soil series included in Tables 21 and 22 represent the largest hectareage of arable, much of which is Class 1 to 3 land. For example, the Bromyard-Eardiston series amounts to 43,000 hectares in six of the areas mapped representing between 24% and 34% of the area in three (Ludlow, Church Stretton and Hereford south). Munslow (13025 hectares), Ross (8000 hectares), Newport (4700 hectares), Bromsgrove (3065 hectares) and Bridgnorth (1905 hectares) include other important arable soils which are predominantly graded in Categories 1 and 2 (Bibby and Mackney(1975) Land Use Capability Classification.

The texture of these soils tends to be either sandy or silty with sandy loams and silt loams predominating. This textural range reflects the distribution of underlying solid and derived drift material with lithologies dominated by sand sized particles

Table 21Soil series in the West Midlands susceptible to erosion

Series	Texture	Lithology
Bridgnorth	Loamy sand - sandy loam	Sandy over reddish sandstone (Triassic)
Bromsgrove	Sandy loam	Coarse loamy over Triassic sandstone (Keuper)
Bromyard	Silt loam	Fine silty over Devonian marl with occasional interbedded fine grained sandstones and siltstones
Eardiston	Sandy loam	Coarse loamy over fine grained Devonian sandstone
Munslow	Silt loam	Coarse silty over Silurian siltstones and fine grained sandstones
Newnham	Sandy loam	Coarse loamy and stony, reddish brown and brown terrace deposits and outwash deposits derived mainly from Devonian and Silurian rocks
Newport	Loamy sand - sandy loam	Sandy; drift (glaciofluvial deposits mainly derived from Triassic rocks)
Sellack	Sandy loam - loam	Coarse loamy over interbedded marl and medium grained Devonian sandstone
Ross	Sandy loam	Coarse loamy over medium grained Devonian sandstone
Wick	Sandy loam	Coarse loamy; drift (glaciofluvial deposits derived mainly from Triassic rocks)

Table 22

Soil series in the West Midlands susceptible to loss of structure and capping

Series	Texture	Lithology
Arrow	Sandy loams	Coarse loamy; drift (glacio-fluvial deposits derived from coarse loamy over clayey; brown and reddish brown drift over reddish brown till derived mainly from Triassic rocks
Astley Hall	Sandy loam	
Brockhurst	Loam - or clay loam	Fine loamy over clayey; thin drift over Keuper marl
Cleve	Sandy loam	Coarse loamy; over yellowish brown fine and medium grained sandstones (Keuper)
Dore	Silt loam	Silty; reddish brown drift (outwash deposits derived mainly from Devonian rocks)
Donnington Heath	Sandy loam	Coarse loamy over clayey; drift over reddish mudstone or clay shale (Triassic)
Evesham	Clay	Clayey; over calcareous clay or clay shale (lower lias)
Hodnet	Silt loam	Fine loamy or fine silty over reddish interbedded siltstone, silty shale and sandstone (Triassic) Keuper
Inkberrow	Fine sandy loam	Fine loamy; over interbedded sandstone and marl (Arden sandstone)
Norton	Sandy loam	Coarse loamy over fine loamy terrace deposits derived mainly from Triassic rocks
Ollerton	Loamy sand to sandy loam	Sandy; drift (glaciofluvial deposits derived mainly from Triassic rocks)
Salwick	Sandy loam	Loamy; reddish till (derived mainly from Triassic rocks)
Whimble	Loam - silt loam	Fine loamy or fine silty over clayey; thin drift over Keuper marl
Worcester	Silty clay loam	Clayey over Keuper marl
Yeld	Silt loam	Fine silty over Silurian shales and mudstones

(fine, medium and coarse sandstones, glacial and fluvioglacial sand and terrace deposits) or silt sized particles (mudstones, siltstones, marls and shales). In general organic levels tend to be higher (>3%) in many of the soils reported in memoirs than in parts of east Shropshire (<3%)* This may be partly explained by the fact that in many instances loss on ignition data is derived predominantly from soils on eroded sites in east Shropshire. This would tend to depress the value of soil organic matter levels, particularly in those soils which are in continuous arable cultivation.

Characteristics of the main series represented in Table 21

1. Bridgnorth series (typical brown sands)

Bridgnorth soils are mapped where Triassic Sandstone (Bunter-Upper/Lower Mottled Sandstone and Pebble Beds) occurs within 90 cm of the surface. Where similar profiles are found with solid rock occurring below 90 cm these soils are usually mapped as Newport series. Surface textures vary from sand, loamy sand to sandy loam which in part reflect variations in the grain size of the parent material with the mottled sandstones weathering to give a fine or very fine sand (see Table 23). Burnham (personal communication) considers that the sandy loam texture of some Bridgnorth soils might arise from the common practice in the past of marling. Bridgnorth soils have an Ap horizon with a weakly developed sub-angular blocky structure which quickly breaks down and caps when exposed to splash erosion. The change from the plough horizon (Ap) to the B horizon is abrupt. This horizon is usually reddish

* Based on loss on ignition data in East Shropshire (by the author).

brown in colour and sand to loamy sand in texture, with occasional stones. The organic content is very low and the bulk of the organic matter present is contained in the worm channels which penetrate this horizon. The sand is usually loose and structureless and passes into bright red sand with abundant weathering sandstone fragments. The junction with the solid sandstone is frequently marked by an increase in loaminess and a high concentration of mica along the weathered fragments of sandstone. Occasional worm channels and roots follow the cleavage of the sandstone.

Table 23

Bridgnorth series (steep) phase

Claverley (SO.794 937) Elevation: 67 m Slope and aspect 10°NNW

Land use: arable.

Horizon Depth (cm)	Ap 0-21	B 21-40	B/C 40-61	C 61-73
Sand (2 mm - 200 %	15.3	7.7	5.2	4.3
(200 - 50 %	66.1	74.4	78.2	79.3
Silt 50 - 2 %	9.9	9.5	6.8	9.1
Clay 2 %	8.7	8.4	9.8	7.3
Loss on ignition %	2.3	1.7	1.5	0.9

Bridgnorth soils are very susceptible to both wind and water erosion particularly when under continuous arable cropping. Many examples of truncated soil profiles can be seen where steep phases are developed or where wind deflation has removed all or part of the Ap horizon.

2 Bromsgrove Series (Typical brown earths)

Soft Triassic sandstones* also form the parent material of Bromsgrove soils which are distinguished from both Bridgnorth and Newport series by their higher silt and clay content (see Table 24). In cultivated soils the Ap horizon consists of a dark reddish brown sandy loam with a weak to moderately developed subangular blocky structure overlying a reddish brown B horizon. Structure is less well developed with depth and the lower horizons are often structureless. Organic matter content tends to be low in the intensively cropped areas and loss of structure during heavy rain causes capping and increased run-off. However, Hollis et al (1974) consider that erosion is less severe than on sandier Newport and Bridgnorth soils though they refer to the occurrence of spectacular gully erosion on slopes after heavy rainstorms in springtime with erosion and run-off being sufficient to block some small lanes with eroded soil. They also consider that the present practice of enlarging fields may well lead to wind erosion problems in the future.

3. Bromyard series (Typical Argillic brown earths)

The Bromyard series is developed on red marl of Downtonian and Dittonian age (Old Red Sandstone). The marl which is soft and easily eroded consists of approximately 60% silt and 25% clay with the remaining fraction largely of fine sand (see Table 25). This gives rise to a Ap horizon of reddish brown silt loam or silty clay loam with a weak or moderate subangular blocky structure overlying a silt loam or silty

* Keuper

clay loam (Eb horizon) and a Bt horizon of silty clay loam. Often all or part of the Eb horizon in shallow soils is incorporated in the plough layer.

Hodgson (1972) considers that accelerated erosion caused by cultivation is widespread on these soils and has resulted in part or all of the former upper horizons which lost clay by eluviation being washed down slope by erosion leaving a truncated soil with a relatively uniform clay content down the profile. In shallow phases of the Bromyard series on steeper eroded slopes the Ap horizon may be ploughed wholly or in part from the Bt horizon, with the upper horizons having been removed by erosion. It is generally accepted that soils high in silt low in clay and low in organic matter (<2%) are the most erodible. Despite the higher average organic levels silt loam soils in the West Midlands are very susceptible to loss of structure induced by splash erosion and subsequent reductions in infiltration. This, together with induced compaction from farm machinery increases the risk of accelerated run-off. These soils are also very susceptible to poaching by cattle and sheep.

Table 24

Bromsgrove series (SO 834 709) Skeys Farm, Hartlebury

Elevation: 31 m Slope: level Land use: Arable, fallow.

Horizon Depth (cm)	Ap 0-34	B 34-56	56-73	B/C 73-96	
Sand {	2 mm - 200 %	24.0	26.7	44.7	44.9
	200 - 50 %	40.1	39.3	27.5	35.7
Silt 50 - 2 %	21.3	20.1	12.9	8.6	
Clay {	2%	14.6	13.9	14.9	10.8
	0.2%	5.4	5.0	4.7	3.6
Loss on ignition %	3.6	2.4	2.2	1.9	

Source: Hollis J.M., ^{and} Hodgson J.M. (1974)
Soils in Worcestershire Page 39

Table 25

Bromyard series (SO 509 356) Ridge Hill, Lower Bullingham

Elevation: 120 m Slope and aspect: 3° ESE Land use: pasture.

Horizon Depth (cm)	Ap 11-22	Bt 30-38	Bt/c 63-75	
Sand {	2 mm - 200 %	4.7	3.1	1.4
	200 - 50 %	16.9	7.5	2.8
Silt 50 - 2 %	55.3	55.4	57.1	
Clay 2 %	23.0	34.2	38.7	
Loss on ignition %	6.1	5	5.2	

Source: Hodgson J.M., Palmer R.C. (1971)
Soils in Herefordshire I Page 33

4. Eardiston series (Typical brown earths)

The parent material of the Eardiston series is fine-grained micaceous reddish brown sandstone which is often present as thin impersistent bands in the marl, thus making series separation in mapping difficult. Where this occurs the soils are mapped as Bromyard-Eardiston. The series is characterised by Ap horizons of fine sandy loam or loam texture with a weak or moderate fine or medium sub-angular blocky structure overlying a B horizon of similar texture. The soils usually have a uniform ^{texture} profile with a clay content less than 20%. In Table 26 analytical data is included for a representative profile of an Eardiston soil. The weak surface structure quickly breaks down when exposed to splash erosion and capping is a widespread problem in Eardiston soils. As the B horizon is also weakly structured incipient gully erosion is potentially a greater hazard on these soils than on the Bromyard series which exhibit a better structured Bt horizon richer in clay.

Table 26

Eardiston series (SO 599 661) Lydiates Farm, Tenbury Wells

Elevation: 84 m Slope: level Land use: Permanent pasture.

Horizon Depth (cm)	Ap 0-23	B 23-36	B/C 36-50	
Sand {	2 mm - 200 %	13.4	16.5	12.3
	200 - 50 %	24.2	21.6	50.8
Silt {	50 - 20 %	18.3	19.6	6.6
	20 - 2 %	26.8	26.6	14.2
Clay 2%	17.3	15.6	16.1	
Organic Carbon	1.7	-	-	

Source: Hodgson J.M. (1972) Soils of the Ludlow district Page 115

5. Munslow series (Typical brown earth)

The Munslow series comprise well-drained soils of silt loam texture formed from decalcified siltstones and fine-grained sandstones of the Lower Palaeozoic scarplands of Shropshire and north Herefordshire. These rocks tend to weather down relatively easily to give deep profiles on uneroded sites of stony silt loams with a fairly uniform texture throughout with less than 20% clay present (see in Table 27). Two other phases are recognised: a steep eroded phase on slopes greater than 11° and a deep colluvial phase along base of slopes and behind hedge boundaries, many of which show marked talud development. Arable soils have a dark grey brown Ap horizon of silt loam or loam texture with weak to moderate fine subangular blocky structure. Ploughing often incorporates part or all of the A/B horizon on deeper sites and on shallow eroded sites an Ap/C profile is often developed.

Table 27

Munslow series (SO 408 721) Paytoe Farm, Wigmore

Elevation: 139 m Slope and aspect: 5°SE Land use: arable.

Horizon Depth (cm)	Ap 0-22	B 22-30	
Sand {	2 mm - 200 %	10.4	6.9
	200 - 50 %	3.2	3.3
Silt {	50 - 20 %	29.3	32.2
	20 - 2 %	40.8	41.6
Clay	2 %	16.3	15.4
Organic carbon %	3.1		

Hodgson (1972) considers the above profile (Table 27) to be typical of the ploughed Munslow soil where the Ap horizon with its weak structure has suffered some erosion and has been ploughed deeply into the former 'B' horizon. The lower levels of organic matter and decreased faunal activity under cultivation in these soils are believed by Hodgson to increase the risk of loss of structure and capping. He refers to spectacular erosion during spring and summer rains with erosion being most severe in the larger fields with unbroken slopes. In recent years there has been widespread hedgerow removal - particularly in the Scarpland belt and as Munslow soils are generally found on more elevated land (122 - 350 metres) there is a greater risk of exposure and splash erosion accentuated by strong and gusty winds during heavy rains. The large fields along the main dip slopes increase the risk of run-off causing damage when heavy rain falls on dry compacted land, notably where sugar beet is cultivated up and down slope.

6. Newport series (Typical brown sands)

This widespread series of typical brown sands is developed in drift deposits derived mainly from Triassic rocks and are dominantly sandy. The lower horizons are not clearly differentiated and are poorly structured with clay content decreasing with depth. The profile of a cultivated soil has a dark brown Ap horizon of loamy sand or sandy loam texture which is weakly structured and overlies a yellowish red or reddish brown B horizon of loamy sand or sand merging

with structureless C horizons of similar colour and texture. The grain size of the sand fraction varies according to the nature of the parent material and surface textures in places deflated by selective wind erosion may be of coarser sand. In arable soils elutriation tends to bring about selective sorting leading to a concentration of coarse fractions on the soil surface. Arable soils are also inherently low in organic matter and where the surface contains a high proportion of fine sand capping becomes a frequent problem. Newport soils are very porous and permeable with a medium or low packing density but this can easily be modified by severe compaction by machinery when soils are too moist and this leads to the formation of dense surface and subsurface pans which enhance the risk of run-off during storms. Four phases of the Newport series are identified, sand, loamy, stony and stony-loamy. The representative profile in Table 28 illustrates the sandy phase.

Table 28

Newport series (sandy phase) (SP 313 638) Heathcote Farm, Warwick

Elevation: 65 m Slope and aspect: 3°NW Land use: arable, fallow.

Horizon Depth (cm)	Ap 0-33	B 33-50	C1- 50-80	C2 80-105	
Sand {	2 mm - 200 %	43.6	48.8	62.1	79.0
	200 - 100 %	21.8	24.9	23.2	15.4
	100 - 50 %	5.4	4.8	2.8	1.3
Silt 50 - 2 %	19.5	15.0	7.6	3.2	
Clay 2 %	9.7	6.5	4.3	1.1	
Loss on ignition %	4.5	2.2	1.1	0.8	
Organic carbon %	1.7	0.6	-	-	

Source: Whitfield W.A.D. (1974) Soils in Warwickshire I
Page 42.

Widespread erosion by wind and water has been reported on these soils notably when in continuous arable cultivation. Hollis et al (1974) identifies and maps erosion limitations in capability classes 1-3 which accounts for over 80% of the Kidderminster sheet.

7. Ross series (Typical brown earths)

This series is widespread in parts of Herefordshire and is associated with parent materials developed from medium grained Devonian sandstones. Ross soils have sandy loam textures which are coarser (medium sand) and distinguish this series from the fine and very fine sandy loams of the Eardiston series. The profile is usually made up of a uniform sandy loamy texture overlying rock at between 45 cm and 1 m and has weakly differentiated A and B horizons. The plough horizon (Ap) is a dark reddish brown stoneless sandy loam which is weakly structured (weak subangular blocky) overlying a similar B horizon which passes into weathered soft rock fragments of the C horizon. As in other sandy soils organic matter levels are low and become lower in soils under continuous arable cropping (see Table 29). Because of considerable and rapid variations in depth the main mapping unit is the Ross series (undifferentiated) though shallow and steep phases are separated where feasible.

Table 29

Ross Series (SO 537274) Kynaston Farm, Sellack

Elevation: 103 m Slope: level Land use: arable (temporary grass)

Horizon Depth	Ap 8-15	B1 23-31	B2 43-51	B/C 56-64	
Sand {	2 mm - 200 %	45.8	40.2	51.9	55.3
	200 - 100 %	17.5	15.6	21.8	18.0
	100 - 50 %	5.7	4.4	4.6	3.0
Silt 50 - 2 %	18.9	28.2	11.5	10.6	
Clay 2 %	12.3	11.6	10.2	13.2	
Loss on ignition %	3.1	3.0	2.0	2.2	

Source: Whitfield W.A.D. 1971 Page 18.

7.3.1 Main causal factors of erosion 2. Rainfall

The West Midlands is situated in a position which in terms of rainfall is transitional between the drier east and wetter west. Within the general framework rainfall differences are closely correlated with elevation with average totals ranging from below 635 mm (25") to above 1000 mm(40") (see Figure 69)*. A distinct rainshadow effect exists to the east of the Welsh Uplands particularly in parts of Shropshire and Herefordshire where annual totals of less than 635 mm are recorded. Examples of low rainfall are to be found in the Shrewsbury area stretching south along the mid-Severn Valley, in the Avon valley from the Rugby area to Evesham, and in the Trent valley from Burton-on-Trent south to Tamworth. North of Shrewsbury into north Cheshire annual rainfall totals rise to 711-900 mm which tends to reflect a decrease in the rainshadow effect of the

* Page 62

Welsh hills. This is also shown further to the east in the uplands of north Staffordshire (c.244 m) where the mean annual rainfall is higher with the isohyet for 1016 mm tending to follow the 305 m contour, whereas in west Shropshire the 889 mm isohyet corresponds more closely to the 305 m contour.

Smith (1954) notes significant differences in humidities in the lee of hill masses which further emphasises the rainshadow effect of the Welsh hills with Shawbury (Shropshire) having less than half of the humid hours measured at Ringway (near Manchester) during north-westerly winds, a proportion which rises to two-thirds with south-westerly winds. In general rainfall is fairly well distributed throughout the year, though in particular years seasonal variations can be very marked, notably in the summer months when monthly totals are often inflated by thunderstorm activity. The main characteristics of rainfall considered here are frequency of occurrence of erosive rains, seasonal distribution and areal distribution. It has already been noted in Chapter 4 that rainfall becomes erosive on exposed soils when the rate reaches or exceeds 1 mm/hr. The meteorological conditions which give rise to such rainfalls are various but tend to be associated principally with instability through a deep layer of the atmosphere brought about by surface heating, with slow moving cold fronts or troughs or with low pressure over the Bay of Biscay or northern France. Crossley et al (1964) consider that all these situations favour the outbreak of storms most frequently over central, eastern and southern England and these are usually associated with heavy falls of rain.

In an analysis of a decade of rainfall at Keele (1952-1961), Shaw (1962) revealed that approximately 56% of the rain was derived from tropical maritime airstreams (warm front, warm-sector, occlusion and thunderstorm) and at least 28% from polar maritime airstream (polar maritime proper and polar low). She provides a more detailed breakdown as follows: rain of warm front origin 23%; from polar maritime airstreams 19%; occlusions 17%; cold front 15%; warm sector 13%; polar low 9%; thunderstorms 3%; and arctic airstreams 1%.

In terms of erosivity of rainfall a number of important points arise from these data. Persistence of rain rather than its high intensity is usually associated with prolonged frontal rain often with a very strong, moist south westerly airstream. The quantity of rainfall from an occlusion is usually greater than that from either warm or cold fronts and chart recorders may show continuous rain for more than ten hours with totals usually exceeding 10 mm. Such rains in the West Midlands can be very erosive if preceded by more intensive short-lived falls which cause widespread splash erosion. Conditions such as these produce a large amount of splash derived sediment as well as causing soil capping in susceptible soils. Capping increases the risk of reduced infiltration during prolonged rains and this consequently allows more run-off to transport detached sediment. Rainfall associated with fronts and occlusions usually affects large areas and if heavy falls coincide with periods of maximum soil exposure as in spring and autumn (winter sown grain), soil erosion can be widespread. Depending upon surface soil conditions, this type of rainfall may well cause unconcentrated surface wash and incipient

confined rilling along tractor and implement wheelings which run parallel to slope. More spectacular falls of rain occur during short duration convective storms (typically 1-2 hours long) and storms which usually have durations of 24-48 hours, caused by groups of thunderstorm cells.

Reynolds (1978) describes the geographical location of two-hour storms exceeding 100 mm and 24-48 hr storms which exceed 175 mm, neither of which categories have occurred in the West Midlands this century. From the maps showing thunderstorm activity during the months of May through to September it can be seen in Figure 70 (Pages 63, 63a) that the area with a pronounced maximum frequency is enclosed roughly between the Wash, the Severn Estuary and the Thames Estuary. However, as the smallest storm areas used to compile these maps were of the order of 1000 sq. miles, local storms, for which only an isolated report was available, were excluded from the count.

Soil erosion monitoring in the West Midlands (1967-1979) has shown that erosion occurs at levels of intensity and duration much less than those quoted above. Rainfalls of 10 mm or more within a 24-hour period are sufficient to initiate erosion on exposed, compacted sandy soils. Such falls occur both in frontal situations and thunderstorms. A more accurate guide to rainfall intensity duration during a rainfall event is obtained from hourly tabulations and the analysis of these and daily rainfall records follows in the study of rainfall in east Shropshire.

7.4.0 Special Study

Analysis of rainfall in east Shropshire

7.4.1 Introduction

During the West Midland survey attention was focussed on an area of approximately 800 square kilometres broadly delineated as east Shropshire lying west of Wolverhampton and reaching to the Severn Valley at Bridgnorth. Newport and Kinver respectively locate the northern and southern extremities (see Figure 71 Page 64). The arable parts of this area proved to be particularly susceptible to erosion by wind and water.

Of the 28 parishes found in this area (see Figure 72 Page 65) all have more than 50% of their total acreage of crops and grass under arable cultivation. Some 20 parishes are represented in the higher category of 70-96% arable. A wide range of crops are grown but barley, wheat, potatoes, beet, fodder crops and mixed field crops form the principal enterprises.

A combination of suitable landforms, light soils and proximity to a large urban market has encouraged the concentration of mixed arable farms. Though much of the area is below 150 m (see Figure 73 Page 66) it is well dissected and the steeper slopes are associated with the outcrops of Triassic and Carboniferous rocks which form low ridges and plateaux. Steep slopes characterise much of the Severn-Worfe lowland

which is predominantly below 91 m and which is one of the areas having a large acreage affected by soil erosion. Coarse textured parent materials predominate, being derived from coarse grained surficial deposits, sandstones and pebble beds and give rise to extensive areas of sandy soils.

Farm amalgamation and enlargement of fields, with the consequent loss of miles of hedgerow, have transformed parts of east Shropshire. Change has been most dramatic in those parishes which have the greatest acreages in arable. It is in these parishes and ones where a high proportion of arable land is developed on sloping terrain that the highest incidence of soil erosion is encountered.

Much of this area receives annual rainfall totals of 558.8-889 mm with the slightly higher totals occurring on the ridges and plateaux, see Figure 69 (Page 62). In seven out of ten years much of the area experiences a soil moisture deficit of over 100 mm.

A detailed analysis of daily rainfall records for all available stations (many of which have 50 years of recorded data) has been effected to relate maximum falls and spells of rainfall to periods of the year when cultivation practices render soils on sloping sites most vulnerable to splash erosion and run off.

7.4.2 Rainfall analysis

A computer analysis of daily rainfall records was run for 7

key stations in east Shropshire with data for periods exceeding 35 years together with 6 other stations with records for more than 20 years. Fourteen years of hourly records for Shawbury (Shropshire) and Pershore (Worcestershire) have been analysed to identify erosion thresholds for rainfall events. The location of Shawbury and Pershore is shown on Figure 69 (Page 62) and stations in east Shropshire and adjoining areas on Figure 74 (Page 67).

Most soil erosion events have taken place when rainfall totals have reached or exceeded 10 mm. Analysis of daily rainfall records (manual gauges) for local stations with over 35 years of data provides a useful insight into the number of occasions per annum when daily totals reached or exceeded 10 mm though this does not imply that all these events were erosive.

Rather, it enables some comparison to be made with autographic data which is available for shorter periods and, where intensity and duration periods are known, for each 10 mm fall.

Daily rainfall figures for one station, Hatton Grange (SJ 766 043), near Shifnal, east Shropshire (80 m A.M.S.L., annual average rainfall 692 mm, recording period 1907-1977) show that during the recording period 10 mm falls or more occurred on average of 15 occasions per annum with high and low values for individual years of 30 and 6 respectively. These data are set out in Table 30.

Throughout the entire recording period there are peaks for May (101), November (105), October (111), August (112) and July (116). In any year an increase in the number of rainfall

Table 30

Hatton Grange, Shifnal, east Shropshire (SO 766 043)

(80 m A.S.L.) annual average 692

Recording period 1907-1977 (N = 71)

Summary by months of falls of 10 mm or more

K = 4.9 mm	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1 10-14.9	57	39	44	39	58	51	58	55	48	73	68	52
2 15-19.9	16	15	20	8	23	23	27	31	19	17	18	19
3 20-24.9	4	2	3	5	9	5	12	15	14	12	14	7
4 25-29.9	2	3	0	0	8	2	6	4	4	5	5	1
5 30-34.9	3	0	2	0	0	2	4	3	3	2	0	0
6 35-39.9	1	0	0	1	0	1	4	3	2	0	0	1
7 40-44.9	0	0	0	1	1	1	1	0	1	1	0	1
8 45-49.9	1	0	0	0	1	0	2	1	1	0	0	0
9 50-54.9	0	0	0	0	0	0	0	0	0	0	0	0
10 55+	0	0	0	0	1	0	2	0	0	1	0	0
Total (mm)	84	59	69	54	101	85	116	112	92	111	105	81
Return Period	1.2M	M1.2	M1.1	M1.3	1.4M	1.2M	1.6M	1.5M	1.3M	1.5M	1.4M	1.2M

Average no. of events per annum = 15. Total no. of events

(10 mm and more) = 1069. Average per month = $1069 \div 12 = 89$

with a return period of 1.2M. Median value for ranked monthly

totals = 93.5. Mean deviation = 17.1 Variance $\sigma^2 = 398.4$

Standard deviation $\sigma = 398.4 = 19.9$ Monthly range 116mm - 54 mm
= 62 mm

Wettest year: 1960 1082 mm }
Driest year: 1921 467.6mm } Range 614.4 = 88.8% of annual
average rainfall

Wettest month: September 1976 190.1 mm = 27.5% of AAR

Driest month: February 1921 1.1 mm = 0.16% of AAR

Source: Rainfall analysis in east Shropshire: A. Harrison Reed

events (10 mm) will add appreciably to the risk of soil erosion, particularly during spring and early summer on exposed or partially exposed soils. An increase in the number of rainfall events in the autumn and early winter increases the risk of soil erosion on compacted beet and potato fields and can cause serious damage to land prepared for or sown to winter grain.

Frequency of 10 mm events and greater are tabled using a special notation to denote the return period e.g. 2M = twice in one year, M2 = once in two years, M71 once in 71 years. In Figure 75 (Page 68) the frequency of all falls of 10 mm and greater is shown diagrammatically for each month of the 71 year period for Newport, east Shropshire, a with class interval of $K = 4.9$ mm. For all months the modal class is 10-14.9 mm with October showing the highest value of 1.1M and February the lowest value of M2.2. July, however, is the only month with events in all of the 10 classes designated in Table 31 followed by May(9) and August (8). For events of 25 mm and greater (Classes 4-10 in Table 31) July ranks highest with 19 and a return period of M3.7 followed by August 12 (M5.9) and May, October and September with 10(M7.1). February 2 has the lowest ranking with a return period of M35.5. On the basis of this analysis Autumn sown grain (Sept-Nov)* has a much greater risk of erosive rains (= 1.4M) than spring sown grain (Feb-April)* (M1.4) This increased risk is partly offset by the fact that the hectareage of autumn (winter) grain is usually lower in this area in total than spring sown varieties.

* depending upon relative earliness or lateness of season.

Table 31

Newport, east Shropshire (SJ 371320) (64m A.S.L.)

Annual average = 663 Recording period 1907-1977 N = 71

Summary by months of falls of 10 mm or more

K = 4.9 mm	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1 10-14.9	52	33	34	34	67	52	71	59	52	79	70	50
2 15-19.9	14	5	15	9	8	18	18	36	15	17	24	14
3 20-24.9	5	4	2	4	9	8	11	12	10	6	8	3
4 25-29.9	5	1	2	0	3	3	7	4	6	6	4	2
5 30-34.9	0	0	0	3	2	1	3	3	3	1	1	2
6 35-39.9	0	1	1	0	1	0	2	2	1	0	0	0
7 40-44.9	0	0	0	0	2	1	3	0	0	2	0	0
8 45-49.9	0	0	0	0	0	0	1	2	0	1	0	0
9 50-54.9	0	0	0	0	1	0	1	1	0	0	0	0
10 55+	0	0	0	0	1	0	2	0	0	0	0	0
Total (mm)	76	44	54	50	94	83	119	119	88	112	107	71
Return Period	1.1M	M1.6	M1.3	M1.4	1.3M	1.2M	1.7M	1.7M	1.2M	1.5M	1.4M	1.0M

Average no. of events per annum = 14.3. Total no. of events
(10 mm and more) = 1017. Average per month = $1017 \div 12 = 84.7$
with a return period of 1.2M. Median value for ranked monthly
table = 85.5. Mean deviation = 21.7. Variance $\sigma^2 = 646.3$.
Standard deviation = $\sqrt{646.3} = 25.4$. Monthly range $119 - 44 = 75$.

Wettest year 1960 = 861.1 mm }
Driest year 1975 = 450.8 mm } range 410.2 mm = 62% of annual
average rainfall

Wettest month July 1958 = 181.9 mm = 27% of AAR

Driest month April 1938 = 2.5 mm = 0.003 of AAR

Source: Rainfall analysis in east Shropshire: A. Harrison Reed

This figure will be decreased further by adverse autumn weather which delays and makes cultivation difficult. The high ranking of May is of particular interest in that fields sown to sugar beet are at great risk during this month. Whereas the return period is 1.3M, May ranks second to July in that out of 10 classes of events (Table 31) 9 are recorded with only the 45-49.9 class missing. When monthly rainfall totals for Newport are expressed as a percentage of average monthly values, although all months show a considerable range of values above and below the monthly average, May ranks highest with a maximum of 302% and a minimum of 23% and October the lowest with a maximum of 202% and a minimum 18.5%.

Other analytical procedures which have been adopted to assess qualitatively the erosive effect of varying rainfall totals are based on pentad totals and on the summation of cumulative daily totals during 'wet spells'. Pentad totals which reach or exceed 4% of the annual average for the station can be regarded as erosive when arable soils are in an exposed state. For example at Hatton Grange during 1976 the pentad total (September 23-27) reached 84.6 or 12.2% of the annual average total and this rain produced widespread erosion. Likewise spells of wet weather which give cumulative totals amounting to 5% of the average rainfall for a station can be regarded as potentially erosive on exposed soils. Both pentad totals (5 x 73) and periods with measurable rain (wet spells) have been processed for each main station.

The key factor is the timing of such events with respect to the condition, state of cultivation and the amount of crop

cover afforded to the soil surface. It has already been emphasised that an analysis based on 24-hour rainfall totals only gives a qualitative assessment of the potential erosive effect of 10 mm and above falls. However, the analysis of the data alongside data of hourly falls has shown that when rainfall reached or exceeds a rate of 1 mm/hr exposed soils will erode. Autographic gauges show that in many of these 10 mm+ events rain falls as short but fairly intense showers. A daily total of 11.3 mm was recorded on 2nd May 1978 at Hilton (SO 776959) near Bridgnorth, east Shropshire with 10.6 mm falling within 1.5 hours, causing widespread splash and run-off erosion particularly on fields sown to sugar beet. Consecutive hourly rates of 2 mm, 7 mm, 3 mm, (0.5 mm in 1.7 hours) 27 mm, 2 mm and 3 mm were recorded, and after an interval of 7 hours 3.7 mm fell in 3 minutes giving an intensity of 74 mm per hour (2.9 inches per hour). The soils affected were of the Newport and Bridgnorth series (sandy loams) and the amount of erosion on each site was correlated to the extent of soil compaction and the presence of cultivation lines parallel to the direction of slope which ranged from 4-8°.

Further examples of hourly falls during erosive rainfall events will be quoted in the following chapter and referred to ground conditions prevailing at the onset of the storm.

Periods without measurable rain have been summarised for key stations and for Newport absolute droughts (15 or more days without measurable rain) occurred on 60 occasions during the 71 years of records giving a return period of M1.2 with the

longest single period lasting 34 days during August-September 1947. Of significance is the fact that of this total 43% occurred during the months of March-June.

Unfortunately the data cannot be matched up with wind speed and direction information for east Shropshire to assess potential wind erosion hazard on arable land during spring and early summer as this part of the thesis design had to be abandoned because of equipment malfunction and mistakes in the selection of recording equipment.

Instrumentation

Equipment to measure wind speed was installed at the Claverley meteorological station in 1974 (SO 791 942) and linked to Foster Cambridge six-channel recorders. The site was inspected and approved by Mr Hogg of the Meteorological Office. Data on wind speed and other parameters was to be transcribed, processed and stored on the I.C.L.1903A computer (Polytechnic, Wolverhampton) as part of a research project on evapotranspiration. Frequent failures by the Foster Cambridge recorders caused considerable interruption in the supply of data from the two 'Casella' cup contact anemometers which were installed at 1 m and 2 m above ground level. However, a large amount of data (recordings at 15-minute intervals) was incorrectly stored and 'lost' to other users.

It was planned to install a more sophisticated set-up to measure wind speed, direction and up-slope down-slope vector effects using a M.R.I. wind vector instrument. This was con-

sidered by the writer to be essential equipment for the evaluation of wind erosion thresholds, particularly on undulating terrain. In addition, a number of portable rigs were designed to record wind profile data in a number of contrasting sites. This plan has only been partly effected and in 1976 two M.R.I. portable weather stations were purchased for a new site at Hilton (referred to in Chapter 8) which measure wind speed and direction on a thirty-day chart.

Chapter 7

Summary

1. In this chapter the soils within the region which are affected by wind and water erosion are identified and their broad distribution is described. Evidence of erosion on arable soils is derived from data in Soil Survey memoirs and records for parts of the region together with personal observations made by the writer.
2. The reconnaissance survey referred to above concentrated largely on the arable areas of Shropshire, Staffordshire, Herefordshire and Worcestershire. In these counties most of the erosion was observed in the intensively arable parts and because of the size of the area a qualitative statement of the extent of erosion could only be made on the basis of chance sightings of erosion damage on fields visible from the roadways.
3. These sightings followed rainfall events of 10 mm or more which fell largely during the spring and early summer and less frequently during dry spells characterised by strong

erosive winds. It is evident, however, that a more comprehensive picture of the erosional events in an area can only be achieved through detailed monitoring on a field to field basis and this has been attempted for parts of east Shropshire and is the subject of the following chapter.

4. To be effective, monitoring of this type needs to be backed up with an analysis of rainfall in the area under study. A comprehensive analysis of daily rainfall data (manual gauges) has been made for east Shropshire, together with an analysis of hourly falls for Shawbury (Shropshire) and Pershore (Worcestershire). This analysis demonstrates that most erosion occurs when rainfall amounts reach or exceed 10 mm within a 24-hour period when rain falls at a rate which reaches or exceeds 1 mm per hour.

5. Survey work has shown that soil erosion takes place every year in parts of the intensively cultivated arable areas of the region, and although the area affected is small in total it is nevertheless very significant as it often affects high grade soils and tends to re-occur frequently on the same site.

6. A wide range of soil series are affected and these are characterised by sandy and silty textures. Some series have inherently weak structures and here the problem is exacerbated by continuous arable cropping and increased compaction from farm machinery. It is clear that locally increased erosion risk has been brought about by enlarging fields and this is a particular problem where field amalgamation has increased

the length of slope or increased wind fetch. A detailed study of field boundary changes has been made for three parishes in east Shropshire and this is described in the following chapter.

Chapter 8

Soil erosion monitoring: a ten-year survey of soil erosion in the east Shropshire parishes of Claverley, Rudge and Worfield (1967-1976)

- 8.1 Introduction.
- 8.2 Soil erosion monitoring 1. Techniques.
- 8.3 Soil erosion monitoring 2. Ten-year survey in the parishes of Claverley, Rudge and Worfield (1967-1976).
- 8.4 Soil erosion monitoring 3. Case studies of selected soil erosion events during the survey period (1967-1976).
 - 8.4.1 Case study 1. Erosion events during 1967.
 - 8.4.2 Case study 2. Erosion events during 1968.
 - 8.4.3 Case study 3. Erosion events during 1969.
 - 8.4.4 Case study 4. Erosion events during Autumn 1976.
- 8.5 Summary.

Soil erosion monitoring: a ten-year survey of soil erosion
in the east Shropshire parishes of Claverley, Rudge and Worfield
(1967-1976)

8.1 Introduction

In this chapter the results of a ten-year erosion survey of arable soils are analysed for the east Shropshire parishes of Claverley, Rudge and Worfield and are considered against a background of changes in the agricultural landscape and in farming practices in this area. The methods used in soil erosion monitoring are described and their limitations noted. Case studies of the occurrence of soil erosion in the parishes are considered for specific years and months during the survey period. The location of the three parishes is shown on Figures 71 and 72 (Pages 64, 65). The total hectarage of crops and grass for each parish is listed in Table 32.

This part of east Shropshire is intensively farmed with 96% of the available land in agricultural use. In contrast to the other parishes on the periphery of the West Midlands conurbation very little agricultural land has been lost to other uses in the post-war period. There are differences too in the size of holdings which tend to be smaller in those parishes closest to the conurbation (Pattingham and Trysull and Seisdon) where over 50% of the farms are less than 20 hectares (89%, 91%, 92% respectively) and have over 50% of the area in farms 100 hectares (42%, 62%, 68% respectively). Table 32 shows that only 3-4% of the area in Claverley, Rudge and Worfield have farms of less than 20 hectares and 42%, 64% and 68% of the area respectively in holdings over 100 hectares.

Table 32

Size of holdings in the parishes of Claverley, Rudge and Worfield

Parish	20 ha		20-40 ha		40-100 ha		100-200 ha		200 ha	
	% Area	No.	% Area	No.	% Area	No.	% Area	No.	% Area	No.
Claverley	3	21	8	9	47	24	35	8	7	1
Rudge	0	0	11	1	27	1	62	2	0	0
Worfield	4	16	4	5	24	11	37	9	31	4

Source: (June census 1975) M.A.A.F.

The landscape of the parishes is characterised by a gently undulating terrain which is underlain by Triassic Sandstones and Pebble Beds with smaller areas of Carboniferous rocks (Enville Beds) in the southern part of Claverley. Varying depths of sandy, stony drift mantle the solid geology and gives rise to soils which are dominantly sandy, easily worked and freely accessible for cultivation throughout the year. Over 60% of the agricultural land (6682 . hectares of crops and grass) in the parishes is under arable farming with the principal crops being barley, sugar beet, potatoes and wheat.

On the Agricultural Land Classification map for the area (Sheet 130 Kidderminster) over 50% of the agricultural area of the three parishes is recorded as Grade 2 land with over 80% of the remaining area being dominated by Grade 3. This broad distribution is illustrated in Figure 76 (Page 69),

which shows no Grade 1 land occurring in the three parishes. Hollis (1978) maps a high proportion of the Claverley sheet as Class 2 in the Land Use Capability Classification (see Figure 77 Page 70). Class 2 land dominates this 100 km² sheet which incorporates most or all of the parishes of Claverley, Rudge, Worfield, Pattingham, Trysull, Seisdon and Bobbington, together with smaller parts of other adjoining Shropshire and Staffordshire parishes. Of the remaining area Class 3 land makes up over 85% of the total with the remainder being Grade 4 (wet) and Grade 5 (steep slopes) which preclude normal cultivations. The latter are usually associated with minor escarpments and the steep banks of the River Worfe and its tributaries. A high degree of mechanisation is found on most of the arable enterprises and this in turn has contributed to significant changes which have taken place in the agricultural landscape in the post-war period. Increased mechanisation on farms has led to a major reorganisation of field boundaries with the loss of miles of hedgerow in this part of Shropshire. The increased weight of tractors and equipment has led to mounting problems of soil compaction.

The changes since 1947 in field boundaries in the three parishes are summarised in Figure 78 (Page 71). The most significant changes encompass the older enclosed areas around and between the villages of Claverley and Worfield. This is also the area in which farms have a higher proportion of their land in slopes and there is a marked correlation here between incidence of soil erosion and the enlargement of fields which results in an extension of slope length. One particular problem arises

where small banky fields which have strongly sloping facets (8 - 11°) are amalgamated to much larger units of moderately sloping land (4-7°) thus resulting in a larger catchment for potential run-off which becomes concentrated on the steeper slopes. Some of the most serious examples of soil erosion by water have resulted from the combination of these slope facets.

Land which was predominantly enclosed during the 19th century which in this part of Shropshire was mainly heath, was laid out in relatively large field units (for example Rudge Heath and the area east and south-east of Bridgnorth - the old Forest of Morfe). Such areas have experienced little change in field boundaries. Other notable areas of field change can be identified along the valley sides of the River Worfe south of Stableford (SO 760 986) and east of its junction with the River Severn from Rindleford (SO 737 956) to Roughton (SO 755 942).

Many of the larger arable farms follow a five course rotation of three years of cereals followed by potatoes and sugar beet with only an occasional period of ley grass. Therefore very little organic matter is returned to the soil and the practice of burning off stubble further reduces available bulk organic matter. Sandy soils are inherently low in organic matter and the practice of continuous arable cropping tends to exacerbate this situation. These changes have in turn led to widespread soil structural problems particularly loss of structure and capping, severe surface and sub-surface compaction and the formation of dense plough pans. Such changes tend to reduce

the infiltration rate and capacity of soils and increase the risk of run-off and erosion. In this area there is a correlation between farms which are continuously cropped and the incidence of soil erosion and this becomes very marked where a significant area of the farm is characterised by moderate to strongly sloping land ($4-11^{\circ}$). It is against this background that the soil erosion survey was carried out.

8.2 Soil erosion monitoring 1. Technique

The task of monitoring erosion within a sizeable area is an immense one which can only be partially offset by utilizing aerial photography and by delimiting the sites which tend to be most susceptible to erosion. The difficulties of monitoring are further exacerbated by the fact that evidence can be quickly eradicated by cultivation and partially masked by crop growth. Unless airphotography is specially flown for erosion survey work most sorties that are available at the scale of 1:10560 are of limited value as only examples of gully erosion can be easily identified, even accepting that the investigator is lucky enough to have access to photography which has been flown immediately after an erosion episode. It is, therefore, essential that the survey area can be monitored within a few days of an erosion event taking place so that an accurate assessment can be made of the area affected. The fact that monitoring of erosion in this way is rarely carried out in the United Kingdom accounts for the continued under-estimation of soil erosion hazard and for the belief that its occurrence is spasmodic and localised. Of the wide array of airphotography examined only two sorties had been flown

shortly after an erosive event. One was for an area outside of the West Midlands and the other referred to below was of a site already photographed from the ground, together with a series of obliques taken from a Royal Air Force helicopter. The value of a combination of vertical and oblique photography in erosion studies can be seen from Figures 79 and 80 (Pages 72, 73) which show widespread damage to fields of sugar beet and potatoes. Both photographs show an area affected by unconfined gully erosion which follows the long axis of a well-defined depression or miniature asymmetric valley feature (steepest slope facet 6°). Cultivation lines run parallel to the main slopes* and confined incipient rill erosion along tractor wheelings channelled large amounts of run-off into the main spill-way. Three large areas of deposition can be identified, the largest of which is shown on Figure 81 (Page 74). These are points where ponding of run-off took place and were characterised by a large number of well-defined deltas which formed along the margins.

Examples such as these have been used to build up an 'inventory' of types of erosion and depositional damage in arable fields. This forms useful background information which permits a more accurate assessment of airphotographs and provides a useful base for teaching and research.

In the absence of aerial-photo cover reliance must be placed on ground photography and in this survey each major event was recorded, usually both in colour and monochrome. With ground photography it is more difficult and at times impossible, to find a satisfactory angle which shows the whole erosion sequence.

* on either side of the asymmetric valley feature.

The effectiveness of soil erosion monitoring is related to the availability within the area under study of adequate rainfall and weather data. Reference has already been made in Chapter 7 to the analysis of daily rainfall records for a number of key stations in east Shropshire. Such records become much more useful when compared with autographic data for known erosive rainfall events. As no autographic data was available for the study area it became necessary to establish a meteorological station which was located at Claverley.

Instrumentation

Autographic records commenced in 1967 with the installation of a Casella Natural Siphon Rain Gauge with an 8" diameter ring (20.3 cm) at Claverley (SO 797 936) together with a standard Snowdon 5" (12.8 cm) check gauge. Despite the disadvantage of a weekly chart with a movement of 3.7 cm per day it was possible to record duration of rainfall. The slow chart speed caused trace lines to merge during heavy falls, a disadvantage which was not rectified until 1972 when a Dines tilting siphon gauge became available (chart speed 11 mm per hour on a 24 hour chart). Apart from periods of malfunctioning, this gauge provided a valuable record of rainfall events in the Claverley area. Hourly falls at Shawbury were compared along with data for Pershore, Worcestershire. At the meteorological station, Claverley, a Plessey type 46 tipping bucket gauge was installed (each tip = 1 mm), with a collecting area of 150 cm. This proved to be most unreliable as rainfall amounts less than 1 mm went unrecorded.

In 1976 a new recording site was set up at Hilton (SO 782 949) equipped with a Hellmann Autographic raingauge with a chart drive mechanism (20 mm per hour on a 31-day clock). After siphoning rainfall every 10 mm, the water is stored in a large check container. Also, for the first time it was possible to record wind speed and wind direction using a M.R.I. portable weather station.

Data from a number of raingauges, together with bought-in records from the Meteorological Office (hourly and daily falls) form the basis of the analysis of erosive rainfall events and the case studies referred to in the last section of this chapter.

One major advantage was living more or less in the centre of the area being monitored as this facilitated a comprehensive search for eroded sites after an erosive event. After a period of monitoring it became evident that a rainfall of 10 mm or more where the rate reached or exceeded 1 mm per hour was sufficient to cause erosion on exposed or partially exposed soils. In the case of wind erosion, wind speeds of 25 knots and over would prove erosive on sandy soils on exposed fields during dry spells of weather. After an erosive event attention was focussed on those areas of known susceptibility to erosion depending upon the degree of soil exposure and the type of crop being grown at that particular time. Site characteristics, (soil type soil-surface characteristics and degree of compaction, slope cultivation direction and management practices) were noted and the type of erosion recorded, together with the dimensions of channels and deposi-

tional sequences. It soon became evident that there were a number of sites which were particularly susceptible to erosion. Predictably these were found along the margins of the Worfe Valley and on the dip slopes and scarp-slopes of the more prominent ridges. More prolonged rainfalls (>20 mm) or wet spells tended to affect a wider area with fields or more gentle slopes being affected. Each eroded site was recorded and entered on a 1:10560 map and this information forms the basis of the analysis of erosion at the parish level which follows below.

8.3 Soil erosion monitoring 2. Ten-year survey in the parishes of Claverley, Rudge and Worfield 1967-1976

In this section the tentative results of a ten-year erosion survey of arable soils are analysed for the parishes of Claverley, Rudge and Worfield, east Shropshire. The figures set out below (see Table 33) represent a conservative estimate of the total hectarage affected by erosion during the period 1967-1976 and it is probable that the figures quoted represent an underestimate of total erosion as there were occasions when it proved impossible to monitor the entire area after closely spaced rainfall events. Of the total arable hectarage of each parish 17%, 27% and 38% respectively were affected by both wind and water erosion. These data were compiled by summing the hectarages of all the fields eroded in each parish during the stated period. The location and distribution of these fields in each parish is shown in Figure 82 (Page 75) with the greatest concentration being centred between the villages of Claverley and Worfield. Two other marked con-

Table 33

East Shropshire parishes - Claverley, Rudge, Worfield

Total hectarage affected by accelerated erosion (1967-1976)

based on parish agricultural statistics for 1969

Parish	Total Hectarage Crops and Grass	Total Hectarage Arable	Total Hectarage Eroded	Wind Erosion	Water Erosion
1. Claverley	2952	1780	492 (27%)	12%	88%
2. Rudge	483	296	50 (17%)	6%	94%
3. Worfield	3247	2021	782 (38%)	33%	66%

Source: Field work (monitoring survey)

centrations lie east of Quatford and around Ackleton. The significance of these concentrations will be discussed below. As the actual removal of soil by erosion affected only half the area of some fields, the figures quoted represent a qualitative statement of the area affected by erosion rather than the total area of eroded soil. These figures reveal only part of the erosion story as they represent one erosion event per field during the decade. For example, a proportion of fields have been eroded on more than one occasion during the decade. The frequency of erosion is shown in Figure 83 (Page 76) on a field to field basis in five categories. Of the 267 fields affected 38.6% (103) were eroded on one occasion during the survey period, 28.5% (76) on two occasions, 19.5% (52) on three, 4.8% (13) on four and 8.6% (23) on five or more occasions. Some fields in this latter category have registered up to 15 occasions during the decade. This group tends to be found on moderate to strongly sloping land ($4-11^{\circ}$) along the valley sides of the River Worfe and its tributaries, particularly on fields which are in continuous arable cropping.

Four main concentrations of eroded fields can be identified on Figure 82 (Page 75) with the largest being centred in the area between the villages of Claverley and Worfield. Other smaller clusters of eroded fields are located around the village of Ackleton in the north, to the east and north of Bridgnorth and to the south east of Quatford. When this distribution is examined in terms of relief and slope, soil type, land use and land capability, a number of marked relationships become evident. On Figure 84 (Page 77) the distribution of eroded fields is shown in relation to relief. The marked concen-

tration of eroded sites centred between the villages of Claverley and Worfield follows the valley sides and shoulders of the River Worfe and its tributaries largely between 45 and 76 m. O.D. Just below 76 m (250-ft.) the main dissected area of the Worfe valley is encountered. This is an area dominated by complex slopes which steepen locally to over 15° . Although these steeper facets are rarely in arable cultivation there are many arable fields with slope facets in the $10-15^{\circ}$ class. It is largely in this area and to the south of Worfield in a dry valley system where continuously cropped fields tend to erode every year with both wind and water erosion being frequent occurrences.

To the north, around the village of Ackleton, eroded sites are distributed around the main valley of the Worfe in the west (at 45 m) and across a major interfluvium (76-91 m), then descending to a tributary valley to the east. Here and to the south of Ackleton on a wedge shaped interfluvium area many fields have been enlarged and this factor has undoubtedly led to increased erosion hazard. An intermittent line of eroded sites is found along the dissected scarp and dip slope of the outcrop of Keuper Sandstone and pebble beds, most of which lies above 91 m (300-ft.). South-east of Quatford a cluster of eroded sites is centred on the 'newly' enclosed (Parliamentary enclosure) area of the ancient Forest of Morfe on the dissected outcrop of the Bunter Pebble Beds. Here and to the east and north of Bridgnorth wind erosion is a particular problem during dry windy periods in spring and early summer. On the more exposed dip slopes of the Keuper outcrop which parallels the

Severn Valley north of Bridgnorth periods of wind erosion have occurred on exposed arable soils during very cold spells when frozen soil particles have been saltated by strong winds.

There is a close correlation between soil type and the distribution of eroded fields shown on Figure 82 (Page 75). Over 80% of the eroded sites contain soils of the Brown Sand group with Newport and Bridgnorth series being the dominant representatives. The remainder is made up of Brown Earths with the main series represented being Bromsgrove, Wick and Arrow soils. The full list of soil series affected is shown in Table 34, which is adapted from the classification of soil series on the Claverley sheet (SO 79/89) of the Soil Survey* which covers approximately two-thirds of the area under study. The writer completed a reconnaissance map of soils in the three parishes in 1972 at the scale of 1:25,000. Since then some of the old series names have been changed and new ones introduced and the most recent titles are included in Table 34. All the soils represented are dominantly sandy (sand, loamy sand and sandy loam) with only one, a minor representative, the Hodnet series being of clay loam texture. The Bridgnorth, Bromsgrove and Newport series all have representative phases which are stony. Some of the represented series (Bromsgrove, Shifnal, Wick Arrow) have coarse loamy textures. These soils by American standards are considered to be of low erosion risk when compared to soils high in silt. However, the monitoring survey in the three parishes has shown that a combination of site, land use and managerial practices interact to produce a high erosion risk on these soils.

* Hollis J.M. (1978)

Table 34Soil series susceptible to erosion in the parishes of Claverley,Rudge and Worfield, east Shropshire

Soil Group	Soil Sub Group	Soil Series	Texture
Brown Earths	Typical Brown Earths Gleyic Brown Earth	Bromsgrove (Shifnal) Wick Arrow	Sandy loamy Sandy loam Sandy loam Sandy loam
Brown Sands	Typical Brown Sands	Bridgnorth Newport (Rudge) (Ebtree)	Sandy loam - loamy sand Sandy loam - loamy sand Sandy loam Loamy sand - sand
Argillic Brown Earths	Stagnogleyic Argillic Brown Earths	Hodnet Salwick (deep sandy phase)	Clay loam Sandy loam
Podzols	Typical (Humo-ferric) Podzol	Crannymoor Delamere	Loamy sand Loamy sand
Sandy Gley	Typical (Non-Calcic) Sandy Gley soils	Blackwood	Sandy loam to loamy sand

Source: Adapted from Hollis (1978) Claverley Sheet SO 79/89 Soil Survey.

Hollis (1978) identifies eleven series on the Claverley sheet which he considers to have minor risk of erosion and two others which are liable to topsoil slaking and capping (Quorndon and Blackwood series). The distribution of these soils for the area he mapped is shown in Figure 77 (Page 70) which is a simplified version of his land capability map. There is a good correlation between the distribution of eroded sites shown on Figure 82 (Page 75) and the map of soils with minor erosion risk adapted from Hollis (Figure 77 Page 70) with the exception of the eastern part of the parishes of Claverley and Rudge. Although many sites have been recorded in this area of splash erosion and minor rill activity along tractor wheelings the latter has been limited to very small areas of the fields where farm traffic has been particularly heavy. The fact that this area is less dissected and has a higher proportion of gentle slopes and has had less field amalgamation may be considered as contributory factors in reducing erosion hazard.

The land use capability classification scheme of Bibby and Mackney (1975) records the suitability of land for agriculture under a moderately high level of management and not necessarily on its present land use. A problem arises here when considering the implications of the term moderately high level of management. It can be argued that this relates to the production of consistently high yields of crops and keeping the soil in good heart. However, such management often includes practices such as up-down hill cultivation which today pose a much greater erosion risk because of the high degree of compaction from heavier farm machinery. Actual erosion risk

is, therefore, heightened by a combination of site factors, cropping and management practices and the chance occurrence at a sensitive period of cultivation or crop growth of erosive rain or wind. It is this complex interrelationship of factors which have combined to produce the pattern of eroded fields shown in Figure 82 (Page 75).

8.4 Soil erosion monitoring 3. Case studies of selected soil erosion events during the survey period (1967-1976)

In this section a number of case studies are presented which aim to show that although the risk of soil erosion in 'normal seasons' may only be slight, the risk increases significantly during adverse seasons. The latter may be defined in terms of soil erosion hazard as spells of abnormal weather which may last a few weeks, a season or even a year, as for example 1968. In most cases rainfall totals for such periods are above average or conversely in the case of wind erosion well below average. For 'normal' seasons rainfall totals are usually average or slightly below average, though the season may experience some erosive rainfall events associated with short wet spells or local thunderstorms.

The years 1967-1969 have been selected as each proved to be notable in terms of the number of erosive events which occurred in each year and ⁱⁿ individual months, as for example May 1967 and 1969, when an above average frequency occurred of hourly rainfall at rates exceeding 2 mm per hour. This period also emphasises the fact that erosion hazard is not limited only to adverse seasons which may have a long return period.

In lowland Britain 1968 was considered to be exceptional in the adverse weather which affected agriculture and wind erosion was acknowledged for the first time to be a major problem in eastern England. In the West Midlands water erosion proved to be the most widespread and damaging and in this respect 1967 and 1969 can also be regarded as notable. The case studies also show that erosive rainfall events can be well distributed throughout the year. It has already been emphasised that the timing of arrival of adverse weather is all important in terms of potential erosion hazard and this can be demonstrated by Table 35 and Table 36.

Data for Newport, east Shropshire (Table 35) shows that during the ten-year survey period 1967-1976 May had the highest total rainfall for the decade (724.4 mm), the highest single monthly total (178.3 mm) and was ranked second (November - 18) with 17 rainfalls of 10 mm or more. May also ranked second highest with a monthly range of 164.3 mm (maximum 178.3 mm, minimum 14.0 mm) during the 71 years of records at Newport. Rainfall intensities are often notably higher in May with an increase in the occurrence of rainfall rates of over 2 mm per hour.

The significance of this data is more apparent when examined alongside Table 36 which shows diagrammatically soil erosion susceptibility during each month of the year. It can be seen that the early summer months are particularly susceptible as a large hectarage of arable land has only part protection from crop cover.

In Table 35 the importance of November is apparent as the month has the second highest rainfall total for the decade

Table 35

Distribution of the wettest and very driest months (1967-1976) for Newport (Harper Adams)

(S.J. 712204) Elevation 64 metres Annual average rainfall 663 mm

	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
1967				(21.3)	115.6							
1968							124.7	(27.4)				
1969					178.3					(10.4)		
1970					(20.1)						133.1	
1971		(19.6)						104.7				
1972								(32)				88.1
1973			(17.4)				108.6					
1974				(8.7)					92.9			
1975	61.7									(18.4)		
1976				(12.1)					153.2			
Annual Average	55.1	41.4	34.7	44.4	56.3	50.1	67.5	67.8	58.7	63.4	62.9	59.4
Ten Yr. Total	573	462	426	423.5	724.4	419	567.7	546	628	515.2	644.4	491.6
Ranking	4	9	10	11	1	12	5	6	3	7	2	8
Falls of 10mm+	8	8	7	7	17	9	11	11	13	8	18	10
Ranking	7	7	8	8	2	6	4	4	3	7	1	5

(644.4 mm) and the third highest individual monthly total (133.1 mm) but has the greatest number of rainfall events of 10 mm or more (18). Adverse weather during November can be particularly damaging to land severely compacted during beet and potato harvesting and depending upon the favourable nature of the autumn season large hectarages of winter grain can be at risk.

Finally, autumn 1976 has been selected as a case study because of the exceptional conditions which prevailed. September was a notable month with the second highest monthly total of 153.2 mm. Six very erosive rainfall events took place which produced widespread and serious erosion. Some of the highest hourly rates were recorded during the entire period of monitoring.

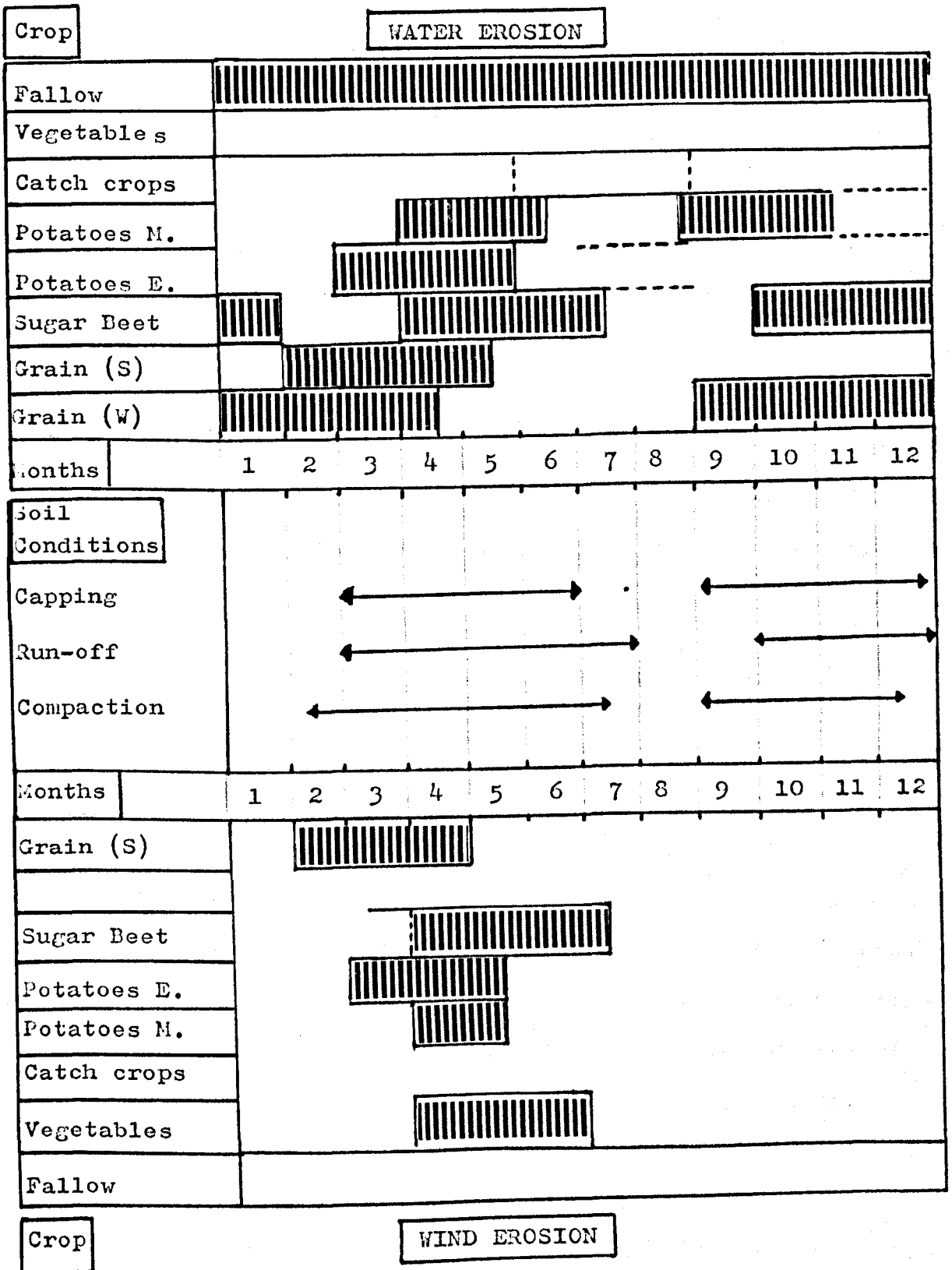
In the remaining years periods of erosive activity were less marked but each year produced some recordable events with the areas affected being mostly on sites where erosion had been previously recorded.

8.4.1 Case study 1: Erosion events during 1967

Analysis of rainfall data for a number of key stations referred to in Table 38 reveals that on average fifteen rainfall events were recorded during 1967 (a rainfall event is a daily total which reached or exceeded 10 mm). Of these, seven proved to be erosive and the average rates per hour are catalogued in Table 38. Of the remaining eight rainfall events, five proved to be non-erosive as the rate of rainfall failed to reach the


Table 36

Soil erosion susceptibility related to crop calendar for east Shropshire



Notes:

- Grain (S) Spring sown grain
- Grain (W) Winter sown grain

 Period of erosion susceptibility - includes preparation, early stages of growth and harvesting (potatoes and sugar beet)

level of 1 mm per hour. The other events took place in August and September when crop cover was at its maximum and the effect of erosive rainfall was minimised. Two minor periods of wind erosion were recorded during March and April, each of which affected a small area of exposed 'banky' fields.

In addition, rainfall during the months of May and October proved to be notable with May being the wettest in England and Wales since 1773 and October the second wettest since 1903 (following October 1960). Both months were marked by a number of erosive rainfall events which resulted in widespread soil erosion in the study area. Most of the recording stations show high values for pentads 25-30 (May 1st to 30th) with rainfall totals between 17% and 20% of the annual average total for the station representing a 10-13% deviation.

In Table 37 a summary of rainfall for Shawbury is presented as this station has a complete set of hourly rainfall data since 1965. In terms of site characteristics and annual average rainfall it closely resembles stations in the research area. In this respect it can be used as a 'bench mark' station and hourly rates compared to those for Claverley and Hilton. It can be seen (Table 37) that the mean monthly rate of rainfall can be used as a guide to the potential erosiveness of rainfall when the rate reaches or exceeds 1 mm per hour. The figures for Shawbury record seven months with a mean rate reaching or exceeding this value. The wettest month May (140.4 mm) had a mean rate of 1.4 with 105 occasions when the hourly rate reached or exceeded 1 mm per hour. October, the second wettest month (105.5 mm) had a mean rate of 1.4 and

92 occasions when the hourly rate reached or exceeded 1 mm per hour. When compared with rainfall stations in the study area, the only anomaly in the Shawbury data is for the month of June which records the high mean rate of 3.6 mm per hour, which in part derives from one localised thunderstorm which missed the study area.

Differences in station totals for erosive rainfall events reflect in part differences in elevation notably for Enville (99 m) and also inflated totals from chance heavy falls associated with localised thunderstorms (C.F. event No.6 Table 38 - Hilton 37.6 mm Enville 3 mm). Frontal rains associated with eastward moving depressions usually bring a more even distribution (events 8 and 9) though the rain is more prolonged.

Table 37

Summary of hourly rainfall values for Shawbury 1967

(SJ 553 220) Elevation 72 m Annual average 660 mm

	Duration (hours)	Total Amount mm	Mean Rate per hr.	Rate per hr. mm*	Actual rate 1 mm per hr. or more	Number of events of ≥ 10 mm
Jan	30.9	24.5	0.792	30	8	0
Feb	64.3	65.0	1.01	50	26	3
March	31.9	41.3	1.29	44	13	1
April	22.9	16.4	0.716	19	2	0
May	100.5	140.4	1.397	105	43	3
June	11.6	42.0	3.620	16	7	1
July	35.1	49.9	1.222	38	10	1
Aug	33.8	30.6	0.905	34	10	0
Sep	34.2	89.9	1.658	51	35	1
Oct	77.2	105.5	1.366	92	37	4
Nov	47.9	42.8	0.893	36	10	1
Dec	57.7	54.99	0.951	40	20	1
Totals	568 hrs	692.2 mm	Average 1.2 mm	555	221	16

Source: Hourly rainfall returns for Shawbury, Meteorological Office.

* When rate reached or exceeded 1 mm/hr.

Table 38

Calendar of Soil Erosion events in the monitored area for 1967

Event 1: 27 February

Splash erosion on recently prepared land sown to spring grains. Unconcentrated surface run-off and localised incipient confined rilling. Only a small hectare of grain already sown by this date.

Rainfall: Claverley 16.7 mm in 10.5 hours (average rate 1.6 mm/hr)
Shawbury 18.9 mm in 12 hours (average rate 1.6 mm/hr).
Hilton 17.8 mm; Hatton 17.8 mm; Enville 17.0 mm;
Bridgnorth 26.7 mm.

Event 2: 8 March

Splash erosion and unconcentrated surface run-off on newly and prior sown spring grain. Some localised unconfined rill erosion.

Rainfall: Claverley 20.3 mm in 15 hours (average rate 1.4 mm/hr).
Shawbury 21.0 mm in 21 hours (average rate 1.0 mm/hr).
Hilton 15.5 mm; Hatton 13.7 mm; Enville 24.1 mm;
Bridgnorth 12.7 mm.

Event 3: 17-19 March

Localised wind erosion on exposed banky fields sown to spring grain near Worfield and east of Quatford (no data on wind speed).

Rainfall: Only 2.3 mm in 7 days of strong drying winds.
Dry period lasted until 24th.

Event 4: 4-8 and 21 April

Spasmodic soil blowing on newly sown beet fields with small areas of seed uncovered (no data on wind speed).

Rainfall: 0.5 mm in ten days.

Table 38 continued 1

Event 5: 11-16 May inclusive

Erosion period commenced with widespread splash erosion. Confined rill erosion affected sloping fields of emergent sugar beet. Marked confined rill development on steeper slopes 6° sown to potatoes.

Rainfall: Claverley 76.1 mm in 42.3 hours (average rate 1.8 mm/hr)
Shawbury 61.8 mm in 41.2 hours (average rate 1.5 mm/hr).

Hilton 62.3; Hatton 85.3; Enville 70.6 mm; Bridgnorth 78.5 mm.

Event 6: 18 July

Further confined rill erosion primarily on sites affected by Event 5 predominantly sugar beet fields. Spraying operations left deep wheelings on some fields which eroded rapidly where slopes exceeded 8° .

Rainfall: Claverley 16.1 mm in 2 hours (average rate 8.05 mm/hr).
Shawbury 10.2 mm in 1.1 hours (average rate 9.3 mm/hr).

Hilton 37.6 mm in 4.2 hours (average rate 8.9 mm/hr).

Hatton 20.8 mm; Enville 3 mm; Bridgnorth 11.7 mm.

Event 7: 18 October

Splash erosion and unconcentrated surface run-off on newly drilled winter grain (only small hectareage planted to date).

Well developed confined rill erosion. Confined gully erosion on three fields where potatoes had been harvested ($>8^{\circ}$).

Rainfall: Claverley 32.5 mm in 14.3 hours (average rate 2.3 mm/hr)
Shawbury 28.7 mm in 12.3 hours (average rate 2.3 mm/hr).

Hilton 31.5 mm; Hatton 31.0 mm; Enville 60.5 mm;

Bridgnorth 33.3 mm.

Event 8: 30 October

Splash and confined rill erosion on newly sown winter grain. Confined and unconfined rill erosion on well compacted ground after potato harvesting.

Rainfall: Claverley 10.2 mm in 8.4 hours (average rate 1.2 mm/hr).

Table 38 continued 2

Shawbury 12.6 mm in 9 hours (average rate 1.4 mm/hr).

Hilton 9.7 mm; Hatton 11.4; Enville 10.7 mm;

Bridgnorth 10.7 mm.

Event 9: 5 November

Localised well developed rill erosion affecting sites noted in Event 8 as well as on compacted sugar beet fields where harvesting was under way.

Rainfall: Claverley 11.0 in 9.8 hours (average rate 1.1 mm/hr).

Shawbury 17.4 mm in 10.7 (average rate 1.6 mm/hr).

Hilton 10.7 mm; Hatton 8.9 mm; Enville 13.2 mm;

Bridgnorth 14.2 mm.

8.4.2 Case Study 2: Erosion Events during 1968

Reference has already been made to 1968 as an outstanding year for notable rainfall events (see Page 101 Chapter 5). It was also characterised by severe wind erosion in eastern England during March and April. The year proved to be a notable one in the West Midlands and in the study area out of an average of 23 rainfall events 17 proved to be erosive. However, only 12 are described here in Table 40 as the remaining 5 were outside of the study area. Four events which occurred in January, February and December were associated with heavy snow falls and the run-off from melted snow. Where rapid snow melt was accompanied by heavy rain, run-off over partially frozen ground was considerable with resulting erosion on unprotected arable land. There were two periods of wind erosion which were the most damaging recorded during the ten-year survey.

Not only were there more erosive rainfall events which affected a wider range of slopes and crops but these events were well distributed throughout the year. There was also a greater incidence of well developed confined and unconfined rill erosion and several examples of confined and unconfined gully erosion. On level sites splash erosion produced marked accumulations of clean washed sand along cultivation lines.

Using Shawbury as a reference station it can be seen from Table 39 that there were seven months when the mean rate per hour exceeded 1 mm; a similar figure to 1967. However for 1968 there is a greater concentration of events in the period

Table 39

Summary of hourly rainfall values for Shawbury 1968

(SJ 553220) Elevation 72 m Annual average 660 mm

	Duration (Hours)	Amount (mm)	Mean Rate mm per hr.	Rate per hour mm*	Actual rate of 1 mm per hr. or more	No. of events ≥ 10 mm
Jan	90.9	64.3	0.707	41	20	2
Feb	30.1	21.5	0.714	9	7	1
March	33.8	32.2	0.953	28	11	0
April	40.3	48.3	1.199	28	14	1
May	55.0	82.7	1.504	41	21	3
June	44.1	81.7	1.853	40	23	3
July	44.2	120.3	2.716	41	33	4
Aug	32.9	45.5	1.383	34	15	0
Sep	53.7	82.7	1.540	49	24	1
Oct	39.2	77.0	1.964	44	18	1
Nov	56.0	41.1	0.734	25	17	1
Dec	64.9	47.3	0.729	22	14	1
Totals	585.1	744.6	1.3	403	217	18

Source: Hourly rainfall records for Shawbury Meteorological Office.

* When rate reached or exceeded 1 mm/hr.

April to July (11 as compared to 5 for 1967) with one third more hours at the actual rate of 1 mm per hour

Table 40

Calendar of soil erosion events for the monitored area 1968

Event 1: Wind erosion 6-20 March

Soil blowing affected a number of fields between Ackleton and Worfield and south of Worfield and to the east and south of Quatford. Strong northerly winds along the eastern flank of an anticyclone (stationed to the west of the British Isles) reached gusts of 42 knots and for six hours averaged 35 knots. This followed a period of absolute drought of 17 days with overnight frost which ended on the 4th March. Rainfall on 5th and 6th (1.1 mm) was in the form of squally showers and a further dry period of seven days ensued. Soil blowing continued despite occasional rain showers. In several fields germinated spring barley seed was exhumed and the fine root system undermined by deflation. In other fields newly emergent grain was abraided and covered by saltating soil.

Event 2: 23 and 24 March

Two closely spaced rainfall events caused widespread splash erosion and unconcentrated soil washing on slopes less than 5° . Around the Worfe valley on slopes exceeding 5° confined rill erosion along tractor wheelings was very evident on spring barley and early potatoes. One large unconfined incipient gully 203 m long, 40 cm wide and 35.5 cm deep terminated in a large fan of debris 6 m across (depth of deposited soil averaged 10 cm).

Table 40 continued 1

Rainfall: A series of vigorous troughs moving eastwards across the country brought gales and heavy rain.

Claverley 20.7 mm; Bridgnorth 33.1 mm; Hatton 25.9 mm; Enville 13.4 mm; Shawbury 8.9 mm in 10.2 hrs (average rate 0.87 mm per hour). No data for Claverley.

Event 3: 26 March to 1 April Wind erosion period

Variable winds (east and south-west) which reached gale force at times brought renewed wind erosion particularly on fields prepared for sugar beet. Apart from 1.5 mm of squally rain on the 27th the weather remained dry for seven days. Large fields of sand to loamy sand (Newport, Delamere and Crannymoor series) on the exposed interfluves between Ackleton and Worfield proved particularly susceptible. Drifted soil was banked against hedgerows down wind with accumulations of over 76 cm in places. Other exposed fields prepared for potatoes also blew badly.

Event 4: 18 April

Splash erosion and concentrated surface washing affected fields of sugar beet around Claverley and Worfield with rill erosion damaging potato furrows.

Rainfall: Frontal troughs moving north east across the country associated with a deep depression south west of Ireland brought heavy rain on the 18th with scattered thunderstorms.

Claverley 17.7 mm in 6 hours (average rate 2.9 mm/hr), with 10.3 mm in 1.5 hours (average rate 6.8 mm/hr). Shawbury 13.9 mm in 8.8 hours (average rate 1.6 mm/hr). Bridgnorth 16.8 mm; Hatton 19.1 mm; Enville 17 mm.

Table 40 continued 2

Event 5: 12 May

Splash erosion and concentrated surface wash affected several of the steep sites eroded during Event 4. Increased crop growth afforded a little more protection to soil, but confined rill erosion along tractor wheelings after band spraying produced numerous small base of slope debris fans.

Rainfall: A number of thundery showers affected the Midlands on the 11th and 12th. Claverley 14.1 mm in 6.1 hours (average rate 2.3 mm/hr). Shawbury 14.8 mm in 5.5 hours (average rate 2.7 mm/hr). Bridgnorth 15.0 mm; Hatton 13.7 mm; Enville 12.2mm.

Event 6: 25-27 May

Thunderstorms brought renewed erosion to sloping beet and potato fields particularly along tractor wheelings and furrows running parallel to slope. Several new sites were noted after these closely spaced events.

Rainfall: Outbreaks of heavy rain on the 25th and 26th were associated with a deepening depression which approached southwest England from the north-west. As this depression moved into the Bay of Biscay thunderstorms developed over a wide area of southern Britain and the Midlands.

(All stations 3 consecutive readings)

Claverley 38.2 in 15 hours (average rate 2.5 mm/hr).

Shawbury 42.0 in 16.8 hours (average rate 2.5 mm/hr).

Bridgnorth 30.4 mm; Hatton 47.7 mm; Enville 21.2 mm.

Event 7: 22, 26 and 28 June

Heavy periods of rain produced between two and three erosive events depending upon location. This caused renewed erosion on sites which were adversely affected by Event 6. Squally

Table 40 continued 3

showers accompanied by strong gusty winds flattened a large hectarage of grain crops and washed out rows of sugar beet along slopes exposed to wind driven rain.

Rainfall: A series of troughs moved in from the Atlantic, together with two depressions which crossed the Midlands causing periods of rain which often became heavy and thundery (22, 26, 28).

	22	26	28
Claverley	10.9*	10.1*	14.2* *Check gauge.
Shawbury	18.4 (in 7.4 hrs)	(Average rate 2.5 mm/hr)	17.9 in 4.3 hrs. (4.2 mm/hr)
Hatton	10.2	10.4	15.7
Enville	12.7	14.2	3.3
Bridgnorth	12.4	12.4	4.6

Event 8: 14 September

Thundery rain caused rapid run-off from a number of compacted fields where potatoes had been harvested (confined rill erosion along wheelings). Splash erosion affected a number of fields being prepared for winter barley.

Rainfall: A depression off south-west England deepened very rapidly on the 14th and a pronounced trough of low pressure associated with the depression brought exceptionally heavy rain and thunderstorms to the Midlands area.

Claverley 26.4 mm in 7 hours (average rate 3.7 mm/hr).

Shawbury 10.2 mm in 5.6 hours (average rate 1.8 mm/hr).

Bridgnorth 32.0 mm; Hatton 30.5 mm; Enville 10.9 mm.

Event 9: 28 October

Erosion again affected compacted fields where potatoes had

Table 40 continued 4

been harvested and was particularly marked in a number of fields with steep slope facets ($>8^{\circ}$) around Claverley and Worfield. Splash erosion and concentrated surface washing affected fields recently drilled with winter grain.

Rainfall: Troughs of low pressure moving eastwards across the Midlands brought heavy rain on the 27th and locally on the 28th a thunderstorm.

Claverley 22.0 mm in 7.3 hrs (average rate 3 mm/hr).

Shawbury 27.0 mm in 7.8 hrs (average rate 3.5 mm/hr).

Bridgnorth 12.7 mm; Hatton 8.6 mm; Enville 11.2 mm.

Event 10: 26 November

Compacted sugar beet fields caused a high proportion of this prolonged relatively low intensity rainfall to run off channelled along tractor wheelings. Run-off was appreciable on fields of winter grain affected by event No.9.

Rainfall: Rain associated with a depression approaching southwest England spread northwards to affect the Midlands on the 26th giving a period of prolonged rain.

Claverley 18 mm in 12 hours (average rate 1.5 mm/hr).

Shawbury 11.1 mm in 12.3 hours (average rate 0.9 mm/hr).

Bridgnorth 16.3 mm; Hatton 15.2 mm; Enville 15.7 mm.

8.4.3 Case Study 3 Erosion events during 1969

The analysis of daily rainfall records for the key stations referred to in Table 42 reveals that on average 21 rainfall events were recorded during 1969. Of these, 11 proved to be erosive and the average rates per hour are catalogued in Table 42. Of the remaining 10 rainfall events 3 proved to be non-erosive (the rate per hour not reaching 1 mm). The other events took place during July (2) and August (3) when crop cover was at its maximum and the effect of erosive rainfall was minimised. Although a small hectareage of arable land is potentially at risk in the study area during late July, August and early September (land reseeded from early potatoes, catch crops, field vegetables, newly broken land) no examples of erosion were observed during this period. One period of wind erosion was recorded during April, which affected only a small area of the three parishes.

May and November proved to be the wettest months and both were marked by a number of erosive events. Many parts of Britain had more than twice the normal rainfall in May. It was the wettest May for over 20 years at Shawbury (172.2 mm) (see Table 41) and Pershore (Worcestershire). Birmingham with 156 mm showed a difference from the average of +90 mm. The West Midlands recorded an above average number of days of thunder (11). Rainfall was also twice the normal in many areas during November due to heavy falls on one or two days (11th and 16th). This caused severe gully erosion on a number of fields where potatoes and beet had been

recently lifted. A notable feature in May, and to a lesser extent in November, was the occurrence of erosive rainfall events which were characterised by an above average number of hours when the rate of rainfall exceeded 3 mm per hour. During May this is partly accounted for by the fact that thunderstorm activity in the West Midlands was over twice the average. By contrast, October, September and June were drier than normal with the October total for Hilton only being 6.6 mm. No erosive events were registered during these months.

Table 41

Summary of hourly rainfall values for Shawbury 1969
 (S.J.553220) Elevation 72 metres Annual average 660 mm

	Duration (Hours)	Total Amount mm	Mean Rate Per Hr. mm	Rate Per Hr. mm *	Actual Rate of 1mm Per Hr. or more	Number of Events of 10mm or more	Number of Erosive Events
Jan	75.1	45.8	0.610	12	7	0	0
Feb	68.4	62.5	0.914	37	18	1	0
March	53.9	46.4	0.861	14	14	2	1
April	43.1	46.8	1.09	18	11	1	1
May	88.9	172.7	1.943	24	56	5	5
June	16.2	17.1	1.056	22	4	0	0
July	28.5	36.9	1.260	8	15	2	0
Aug	48.9	111.4	2.278	17	32	5	0
Sep	19.8	24.1	1.217	14	3	1	0
Oct	14.1	11.3	0.801	8	1	0	0
Nov	74.3	90.1	1.212	29	34	4	3
Dec	60.6	50.8	0.838	18	16	0	0
Total	591.8	715.9	1.21	221	211	21	10

Source: Hourly rainfall returns for Shawbury, Meteorological Office.

* When rate reached or exceeded 1 mm/hr.

Table 42

Calendar of soil erosion events for the monitored area 1969

Event 1 March 12th

Heavy rainfall caused appreciable run-off from sloping fields of winter wheat. Most of the run-off was concentrated along tractor wheelings and caused confined rill erosion. Splash erosion was widespread on fields of newly drilled spring grain.

Rainfall:

An occluded front was slow moving across southern Britain and brought heavy and prolonged rain to the south and the Midlands.

Claverley 20.3 mm in 14 hours (average rate 1.5 mm/hr.)

Shawbury 20.6 mm in 13.7 hours (average rate 1.5 mm/hr.)

Bridgnorth 29.2 mm, Hilton 24.4 mm, Hatton 22.6 mm, Enville 24 mm.

Event 2 Wind erosion April 1st/2nd

Soil blowing affected the tops and exposed flanks of a number of steeply sloping fields in the Worfe valley between Worfield and Claverley with small patches of spring barley being eroded out of the most exposed sections. On some larger flatter fields in the same area large sheets of sand formed down wind though accumulations against hedgerows

Table 42 continued 1

were small. Strong north-easterly and east winds developed around the eastern margin of a large anticyclone lying to the west of the British Isles. Wind speeds reached an average of 28 knots for several hours with gusts of up to 38 knots. A dry spell of nine days ended on the 27th March and was followed by four days with only 1.6 mm of rain. The ground had become very dry and overnight frost was frequent (March was the coldest since 1962) providing ideal conditions for wind erosion.

Event 3: 25/26 April

Two closely spaced rainfall events caused confined rill erosion along tractor wheelings on several fields of spring grain and sugar beet. The steeper facets of some fields planted to potatoes also eroded with deep rills forming along furrows compacted by tractor and seed-drill wheels. Splash erosion affected a wide range of flat fields including potatoes, sugar beet and spring grain.

Rainfall: A complex depression to the north-west of Ireland moved east and associated fronts brought heavy rain to the Midlands on the 25th and 26th.

Claverley 11.2 mm in 8 hours (average rate 1.4 mm/hr), and 10.5 mm in 7.2 hours (average rate 1.5 mm/hr).

Shawbury 18.3 mm in 11 hours (average rate 1.6 mm/hr).

Bridgnorth 15.7 mm; Hilton 11.4 and 10.2 mm; Enville 11.7 mm and Hatton 11.7 mm.

Events 4 to 6: 3, 5, 6, 24, 26 and 29 May

A series of thunderstorms and heavy periods of rain caused widespread erosion particularly to sugar beet and potato fields

Table 42 continued 2

which had been affected by Event 3. All exposed arable fields were affected by splash erosion. Unconcentrated and concentrated surface soil wash affected gently sloping beet fields. Deep confined rilling removed large quantities of sediment down potato furrows and overtopping of furrows where slope direction changed cut wide shallow channels through furrows.

Rainfall:

Event 4: 3 May

Claverley 12.1 mm in 4 hours (average rate 3 mm/hr).

Shawbury 18.5 mm in 4.3 hours (average rate 4.3 mm/hr).

Event 5: 5/6 May

Claverley 35 mm in 10 hours (average rate 3.5 mm/hr).

Shawbury 35.2 mm in 12.2 hours (average rate 2.8 mm/hr).

(Average for the two stations of 8 hours when rate exceeded 3 mm/hr).

Event 6: 24/26 May

24 Claverley 24.2 mm in 10 hours (average rate 2.4 mm/hr).

24 Shawbury 19.4 mm in 8.3 hours (average rate 2.3 mm/hr).

25 Claverley 14.1 mm in 4 hours (average rate 3.5 mm/hr).

26 Shawbury 21.7 mm in 8.2 hours (average rate 2.6 mm/hr).

Event 7/8: 11 and 16 November

A large, slow moving and complex trough lay from Scandinavia to Britain with minor disturbances crossing the country bringing heavy rain at times, notably on the 11th and 16th. Once again the same pattern was observed of confined rill erosion along wheelings and splash erosion and unconcentrated surface washing on newly drilled winter grain. The most spectacular erosion affected more steeply sloping fields which had been compacted by potato and beet harvesting.

Table 42 continued 3

Other sloping fields prepared by rotovator for winter grain had wide shallow channels which eroded down to the contact with a dense plough pan at which point incised channels developed.

Rainfall:

Claverley 31 mm in 12 hours (average rate 2.6 mm/hr).

Shawbury 18.9 mm in 12.4 hours (average rate 1.5 mm/hr).

Bridgnorth 27.9 mm; Hilton 33.3 mm; Hatton 21.8 mm;

Enville 9.2 mm.

8.4.4 Case Study 4 Erosion events during Autumn 1976

Reference has been made to the exceptional conditions of drought which prevailed in England and Wales from 1975 through to 1976 which the Meteorological Office claims has a return period of once in 500 years. Before the drought ended soil moisture deficits had exceeded 125 mm on arable land in the West Midlands and deep cracks in the sub-soil appeared on medium and fine textured soils.

The drought came to an end during early September when a depression moved south-east across Scotland and associated fronts brought rain to the Midlands on the 8th and 9th. On the 22nd a depression became slow moving to the south-west of the British Isles which brought in a warm and humid southerly airstream until the end of the month with a series of disturbances moving northwards across the country. These gave widespread and heavy outbreaks of rain often accompanied by thunderstorms. Between the 21st and the 29th local stations in the study area received between 135.7 and 145.8 mm, which showed a difference from the average of +71.7 mm and +82 mm respectively. Rainfall for Birmingham in September of 159 mm showed a difference from the average of + 94 mm. The average rainfall rate per hour for Shawbury during these 9 days was 3.3 mm. At a number of stations there were significant increases in the rainfall rate per hour and this accounts for the increased erosion on many sites.

A comparison of hourly rainfall figures for Pershore and Shawbury (see Table 43) shows particularly high values in the former in the two

erosive episodes. However Shawbury had two additional erosive events on the 21st and 22nd (average rates 4.4 and 2.2 mm/hr) followed by four days of rain amounting to 34.7 mm in 13.6 hours, (average 2.5 mm/hr). Rainfall at Pershore during this period was well below these totals.

Table 43

Hourly rainfall for Pershore and Shawbury on 24/25 September 1976

Station Pershore				Station Shawbury			
Date	Hour	mm	Duration (mins.)	Date	Hour	mm	Duration (mins.)
24/9	23	4.9	36	25/9	1	3.1	60
25/9	0	4.3	60		2	2.6	54
	1	8.3	54		3	<u>2.3</u>	<u>36</u>
	2	15.4	60			8.0	2.5
	3	5.3	60			(average 3.2 mm/hr)	
	4	7.4	60		17	3.2	42
	5	<u>11.2</u>	<u>36</u>		18	10.3	60
		56.8	5.1		19	7.2	60
		(average 11.2 mm/hr)			21	1.2	30
	22	4.3	48		22	0.4	12
	23	12.0	60		23	6.4	60
26/9	0	<u>4.7</u>	<u>60</u>		24	<u>10.1</u>	<u>60</u>
		21.0	2.48			38.8	5.4

Average 8.5 mm/hr.

Average 7.2 mm/hr.

The distribution of erosive events in east Shropshire during September was fairly even with Claverley 7 (151 mm), Hatton Grange 8 (169.3 mm), Bridgnorth 7 (182.2 mm) and Enville 7 (182.5 mm).

Widespread damage was caused to exposed arable soils by splash erosion, particularly during the early storms. A large proportion of this detached material was transported during subsequent storms when the rate per hour increased significantly. The extent of the damage might have been greater but for the fact that very dry compacted ground earlier in the month inhibited cultivations for winter grains. Much of the soil erosion damage that was observed during this period was in fields prepared for and drilled with winter grains. Run-off was spectacular from compacted ground where potatoes had been harvested. At Hilton on a recently rotovated plot heavy rains on the 24th yielded 25.4 mm with 18.7 mm falling in three hours with an average intensity of 6.2 mm/hr. On the 25th two thunderstorms yielded a total of 48 mm in 9.7 hours (average intensity 4.9 mm/hr), with 38.1 mm in 5.8 hours (average intensity 6.5 mm/hr) and 20.7 mm in 2.7 hours (average intensity 7.6 mm/hr). The total fall amounted to 83 mm (3.36 inches) and caused extensive erosion to the plot and adjoining fields which is illustrated by Figures 16, 27, 30, 31 - 39.

The return period for major erosive rainfall events such as these exceeds the longest data collection period (89 years) available in east Shropshire.

Summary

1. The results of a ten-year erosion survey of arable soils are analysed for the east Shropshire parishes of Claverley, Rudge and Worfield and these are presented as an example of soil erosion monitoring.
2. This data is set against the background of the changes which have taken place in east Shropshire during the post-war period. The area under study is one of intensive arable agriculture and here the impact of mechanisation has brought about an increase in both farm and field size. Significant changes in land-use, cropping and management practices have tended to produce more simple rotations with a reduction or exclusion of ley grass. The tendency towards continuous arable cropping on some farms, together with some of the changes noted above, has brought an increase in soil structural problems. These have been aggravated by widespread soil compaction caused by an increase in the weight and numbers of farm machinery.
3. These problems of weak soil structure and compaction are emphasised during periods of adverse weather when the risk of soil erosion also increases significantly.
4. One of the principal objectives of the monitoring survey was to establish the frequency of occurrence and the distribution of soil erosion in the study area. The survey shows that out of a total arable hectarage of 4097 for the three parishes approximately 32% (1324 ha) has been affected by erosion during the period 1967-1976.

5. The methods used and the problems encountered in collecting this data are described and individual years are chosen as case studies to show the distribution of erosive events.

6. The selection of the years 1967-1969 has been made to emphasise that soil erosion hazard is not restricted to the occasional abnormal season which may have a long return period. September 1976, was selected as an example of an abnormal month which was characterised by more than three times the average monthly rainfall and by six closely spaced erosive events, each with higher than average rainfall rates per hour. The return period for this combination of events is greater than 89 years (the longest recording time for a key station). These events caused widespread soil erosion with a greater incidence of confined and unconfined gullyng.

Chapter 9

Evaluation of selected field methods used in measuring soil erosion by water on arable land

9. Introduction.

9.1 Laboratory based research into soil erodibility.

9.2 Field based research into soil erodibility using fractional hectare plots.

9.3 Soil erosion research at Hilton, east Shropshire.

9.4 Summary.

Chapter 9

Evaluation of selected field methods used in measuring soil erosion by water on arable land

9. Introduction

There is a large and varied literature which deals with a range of experiments to measure soil erosion using laboratory and field techniques. These vary from simple devices such as splash cups and trays developed by Ellison (1944) to large indoor experimental rainfall run-off facilities 15.3 m long and 9.2 m wide (Mosley 1974), and field plots of various dimensions exposed to natural and simulated rainfall. In this chapter emphasis is placed on a review of the characteristics, function and limitations of measured plots exposed to natural rainfall. The type of laboratory and field methods used will be determined by the objectives of the research programme and by the constraints of available resources.

Two broad areas of experimentation can be recognised and for convenience described under the headings of (a) laboratory based research and (b) field based research using semi-permanent or fixed plots to measure run-off and sediment yield from a range of soils and slopes under different management treatments. Both of these main areas of research were investigated in the United States by Federal and State agencies to measure erosion losses and to assess the effectiveness of various preventative measures. Over 10,000 plot years of basic data from 42 experimental stations were used in a national study by the Agricultural

Research Service (1954) and the main features in the erosion process identified and mathematically enumerated. The mathematical relationships derived from these data were assimilated in the Universal Soil Loss Equation which has been widely adopted as a basic tool in erosion control planning (Wischmeier and Smith 1965). Hayward (1968) calls into question data which has been assembled from some plot studies as he suggests that there are a number of ways in which these data can be biased. He draws attention to the fact that during the fifty years of their use they have never been the subject of critical examination or appraisal. Further reference is made below to these problems and the limitations of some laboratory techniques for measuring soil erodibility.

9.1 Laboratory based research into soil erodibility

Reference has been made in Chapter 4 to a range of fundamental research designed to isolate and measure various important parameters of soil erodibility and the erosivity of rainfall. Soil erodibility results from the interaction of a complex of variables and any attempt to simulate or model these phenomena has inherent problems and limitations. Today it is a relatively simple matter to measure soil loss, run-off and infiltration from a range of artificial plots subjected to simulated rain. Problems can arise when attempts are made to extrapolate data from single parameter experiments to field situations where a different set of factors may operate to invalidate the experimental procedures used and the data derived from them. Mech (1965) considers that the ultimate use of any model or similitude should involve the extrapolation or con-

version of results to the prototype. He contends that too many research workers fail to do this and rely on reporting the results from the model as basic or fundamental work without attempting to extrapolate to field conditions.

There are many advantages claimed in studying the effect of various soil characteristics on erodibility under uniform conditions in the laboratory. It is argued that such studies provide greater precision in monitoring, allow for a greater range of soils to be tested with more control of particular parameters. Bryan (1974) sets out four premises upon which his laboratory testing of soil erodibility was based:-

(a) 'that the soil erosion process in the laboratory would be subject to most of the same controlling factors as in the field (my italics, to emphasise the element of bias here) and therefore, although the magnitude of soil-loss would vary, the relative position of different soils in an erodibility ranking should remain unchanged; (b) that while an index shown to be efficient in the laboratory would not necessarily be so in the field, one shown to be inefficient in the laboratory would be unlikely to prove efficient in the field; (c) that the laboratory test is a simplification of the natural process and that unless the results could be understood and explained, there would be little hope of fully understanding the more complex natural processes; (d) that laboratory testing is a precursor to, not a replacement for field testing.'

These four premises have been quoted in full as they raise issues common to many laboratory based experiments on soil erodibility.

One of the controlling factors which is frequently assumed to be the same as in the field is simulated rainfall.

Meyer (1965) considers that the advantages afforded by simulated rainfall of speed and the ability to replicate the same 'storm' only accrue if the simulator can reproduce, accurately and repeatedly, artificial rain which will have precisely the same effect on the soil as natural rain. However, although drop size, and to a degree the terminal velocity of drops, can be controlled, other rainfall characteristics such as drop temperature, shape impact angle* and the effects of wind, particularly on terminal velocity, are less well-known.

Plot studies at Hilton, east Shropshire, have demonstrated the importance of changes in slope direction relative to rain driven by gusty winds in the amounts of rain catch, splash erosion and sediment yield in run-off produced during a storm.

One particular weakness inherent in most laboratory based experiments on soil erodibility results from the disturbance of the soil samples. In recent years despite the introduction of sophisticated (though expensive) methods for removing large soil columns and monoliths (see Hudson 1974, Wijnsma 1975 and Belford 1979) the bulk of soils which have been used in laboratory 'plot' studies undergo varying degrees of disturbance which in some cases may damage or alter the very properties to be measured. A high proportion of laboratory studies tend to use small soil plots as the cost factor in assembling large rain simulators and moving large 'undisturbed' soil cores is very high. However, erosion in the field is generally associated with run-off from large areas and relatively long

* the shape of the rain drop and its angle at the point of impact on the soil surface.

slopes and this presents a problem which is difficult to simulate even in field based experimental plots. Mosley (1974) used a very large indoor plot 15.3 m long, 9.2 m wide and 2 m deep filled with a silt sand mixture 'which was regarded as homogeneous throughout having characteristics sufficiently (my italics) similar to those of some natural soils in the area to be usefully employed in a study of rill erosion.' Coutts et al (1968) used soil trays 13 x 13 x 4 cm filled with labelled Fe59 clay loam and sandy loam which had been screened through a 5 mm square mesh sieve. Young and Wiersma (1973) constructed 1.52 m x 4.52 m plots 21.6 cm in depth filled with a loam, silt loam and sandy loam, which was tamped to a bulk density of 1.02 g/cm³ to simulate a surface soil which had been ploughed, disced and harrowed. Gabriels et al (1975) separated silt loam aggregates by sieving into two aggregate sizes which were placed in soil pans 30 cm in length.

The interpretation of data derived from small plot studies under simulated rain must be carefully considered in the light of the knowledge that on artificially prepared surfaces micro-processes (micro-rilling and 'sheet' flow) may assume an importance far exceeding that likely to be encountered in arable fields where cultivation practices produce much greater variations in surface roughness, and compaction exerts a marked influence on infiltration and provides preferred routes for surface run-off along wheelings and implement lines.

Another characteristic of many of these experiments is the relatively high intensity-duration values which are used.

As Meyer (1965) observes, storms with high intensity-duration values cause major erosion, and studies using simulators at these more critical rainfall conditions can be expected to severely test the erosion characteristics of most plot treatments. However, unless these very high intensity-duration values are a feature of local rainfall these treatments will tend to mask important changes which can be effected by low intensity storms which are often more frequent events affecting a larger area of soils.

9.2. Field based research into soil erodibility using fractional-hectare plots

Plot studies have been a basic tool of soil erosion research for half a century and although the equipment used has been up-dated, the basic methodology remains essentially unchanged. Apart from the American Agricultural Research Service standard plot 72.5 x 6-ft. (1.83 m x 22 m) which has been widely used, there have been an infinite number of different designs reported in the literature, ranging from micro-plots (1 - 2m²) to field-sized plots 500 m² and more. Plot studies are reviewed by Hayward (1967 and 1968) and details of plot design by Wiltshire (1947), Hudson (1957) and Mutchler (1963).

By far the largest number of experiments have been conducted under natural rainfall. However, since the 1950's portable rain simulators have been widely used on field plots as selected simulated storms can be applied quickly to a range of soils and treatments. This is particularly valuable when evaluating the soil conservation characteristics of newly adopted cropping

and management practices which under natural rainfall studies may require up to twenty years to validate (Meyer 1965). Hayward (1968) reviewed the use of run-off plots for two different but related purposes which he refers to as 'Experimental' and 'Observational' studies. The essential difference between them is that in the former the experimental design is based on the randomised block procedure and in the latter it is based on a sampling procedure. He considers that plot studies in general are a comparatively crude method of hydrological research as they have been frequently characterised by poor experimental design and inadequate analyses of data. He draws attention to the fact that only a few studies used replicated treatments and most of these did not locate them in a random fashion. Hayward emphasises that replication and randomisation of experimentation is needed to establish the differences between treatments. Only then can confidence be placed in the results. He concludes that although plot studies have been useful in improving our understanding of erosion and its prevention much of the data can only be accepted as a qualitative guide and is not considered acceptable for extrapolation.

Some of the equipment used in plot designs is considered below and here emphasis is placed on efficient working plots which do not require the installation of expensive permanent structures which characterise many of the large experimental stations in the U.S.A. and elsewhere. Plot margins which are usually made of wood, metal or concrete are sunk into the ground to a depth of approximately 15 cm, leaving 17 cm above soil level. Run-off is collected down slope via guttering and fed into

storage tanks (see Figure 85 Page 78). There exists a comprehensive literature on plot design, out of which the designs of Garcia^{et al} (1963) and Mutchler (1963) have been selected and modified for use in east Shropshire. Hayward (1968) suggests that while there is no inherent objection to a range of equipment and designs it may not be possible to compare results from dissimilar studies and that comparisons which adjust the results in proportion to the area of each plot may be invalid as important boundary effects are usually ignored.

Boundary and microclimate effects are examples of a number of problems inherent in plot studies which are considered to be one of the sources of bias. When part of a slope facet is enclosed to form a measured plot the natural sequence of run-off is disrupted and consequently the amount of run-off on the measured plot tends to be diminished resulting in an underestimate of soil and water losses. This imbalance may, however, be over rectified by run-off from up slope seeping in under the upper plot margin.

Other sources of error occur when run-off within the plot escapes under the plot margins or overflows the collection device downslope. More frequently significant seepages occur along the soil gutter interface particularly where a concrete sill has been installed parallel to the collection gutter (see Figure 85 Page 78). This section of the plot is most difficult to design, install and maintain and is the area most likely to be damaged by frost heave with consequent loss of run-off. Provision must also be made to facilitate the lowering of the collection trough or gutter to match the lowering

of the soil surface after a period of active erosion on the plot so that the original slope angle is maintained. This can only be done by careful initial levelling which must be repeated at regular intervals during the life of the plot. Border effects interfere with the normal flow of air across the plot and act as down wind traps for soil eroded from the plot surface. This effect can be seen in action during snow drift which builds up both on the inside and outside of the plot perimeter. The most serious problem is wind eroded soil which is blown into the collecting gutter and subsequently washed into the collection tank. These problems can be largely overcome by frequent site visits, particularly after weather events which are anticipated to cause this type of trouble.

Another source of bias particularly in 'Experimental' studies is found in the basic assumption of site homogeneity whereas in 'Observational' studies the equivalent source of bias is found in poor sampling procedure. In the former it is assumed that the measured differences between plots are attributable to the treatment and not to site variables. This assumption may not always be valid (Wischmeier et al 1958). Minor site variations should be segregated into blocks, each with a number of plots so that treatments can be randomly assigned.

No reference is made in the literature of plot studies being used for soil erosion research in the United Kingdom. Work on soil erosion at the National College of Agricultural Engineering, Silso, has involved the measurement in the field of splash erosion and overland flow but without the use of measured plots (Morgan 1978). In Belgium, Bollinne (1978)

uses standard American plots to study the importance of splash and wash on cultivated loamy soils of the Hesbaye area. The Hesbaye station covers an area of 4,500 m² and is divided into three blocks, one of which is planted with sugar beet, another with winter wheat and the third is fallow. Each block comprises four measured plots (4 x 22.13 m) and ^{is} cultivated parallel to slope (6.5°). Splashed soil was collected in funnels 52 mm in diameter (10 to a block) with rot-proof filters. The upper part of the funnel is located at ground level and the apparatus is changed after every rain. The results are expressed in t/ha taking as a basis for the calculations the collecting surface of the funnel and the weight of soil collected. The results represent a cumulative measurement of the quantities of soil moved by splash and cannot be interpreted as the measurement of the depth of soil affected by splash nor as the quantities of soil transported to the bottom of the slope by splash. Data for two years' observations (1974-75) showed that splash loss displaces an average of some ten t/ha yr on the cultivated area, but splash loss is only a few tens kg/ha yr, and soil wash reaches several t/ha yr. These Belgian erosion rates appear to be lower than the observed rates in east Shropshire though in the case of the latter area it is not yet possible to evaluate with precision an annual average rate of erosion based on measured plot data.

9.3 Soil erosion research at Hilton, east Shropshire, using fractional-hectare plots

The aims of the monitoring survey carried out in east Shropshire were to record the incidence, frequency and distribution of soil

erosion on a field to field basis. The survey provided a calendar of erosional events during a ten-year period and the areas of appreciable soil loss were clearly identified. However, the amount of soil loss per hectare could only be qualitatively assessed and then only for a relatively few sites. Although this limitation was an accepted weakness in the research design it was intended to establish a permanent site for erosion research as soon as resources became available.

In April 1976 a one hectare site was rented on a farm at Hilton, Claverley (SO 782 949). Work commenced on the installation of a stock-proof fence and the ploughing of the longest slope facet (see Figure 30 Page 30) in preparation for the first block of plots. A portable meteorological station (M.R.I. pattern) was set up together with an automatic rain gauge (see Page 228 Chapter 8). Site preparations were delayed and made difficult by the exceptional drought during the summer months and the main slope was not rotovated until the end of September when ironically three closely spaced storms caused splash and unconfined rill erosion before the plots could be installed.

This scheme of research as envisaged, entailed the establishment and monitoring of pairs of 50 m² and 100 m² plots to record run-off and sediment yield from sandy fallow soils on slopes of varying percent, length and aspect, exposed to natural and simulated rainfall under a limited range of management treatments. In design, the scheme of work can be classified as an 'Experimental' study with each plot and plot treatment being

replicated.

Two plots were installed to calibrate each of two simple treatments and also to observe how the plots functioned during a year's trial period. The main difficulty experienced entailed the interface between the soil and collection trough or gutter which tended to separate during very cold or very hot weather. There was also the constant threat of run-off leaking along the interface between the soil and collection trough.

Several alternative designs were tried out, none of which solved this problem. Finally the collection trough was separated from the soil interface by a narrow sill of lime-sand mortar which was brought flush against the collection trough. The material used for the latter component was bitumen impregnated fibre sewer pipe (12.7 cm diameter) out of which a 5 cm slot was cut along the length of the pipe, one end of which was sealed. The lower edge of the 5 cm slot was placed flush with the soil surface after a shallow trench had been excavated to accommodate the pipe. The pipe was kept in position by four wooden stakes backed by a mound of soil capped with turf. The mortar was packed below the lip of the pipe slot and carefully levelled. During very cold conditions the interface along the pipe and the mortar separated as anticipated and the crack was filled with joint seal. This now reduces the risk of leakage and allows for expansion-contraction to take place along the interface area. No separation difficulties

have been experienced along the soil-mortar interface.

The collection trough functioned very well and the narrow slot reduced the risk of large amounts of rain being blown in. Run-off collecting in the trough was fed into a 227 litre storage tank which contained a 5 litre graduated reservoir.

Other difficulties experienced included the unwelcome activities of moles and rabbits with the former causing the greatest problems by occasionally burrowing under the plot sill and trough and, more frequently, along the plot margins.

Occasionally rabbits scratched soil onto the sill and into the collection trough. Although the site is very exposed and prone to wind erosion there has only been one occasion when soil was blown into the collection trough. All of these problems can be dealt with by frequent visits to the site.

When completed the plots were rotovated and raked level and surface roughness photographed from a reference point on each plot (vertical photography). During the calibration period the plots were allowed to settle and compact by natural processes. There was a marked increase in the amount of run-off as the plots became more compacted, particularly when the surface became capped. Surface capping took place after an average of 13 hours when the rainfall rate reached or exceeded 1 mm/hr though not necessarily in a single rainfall event. Usually, however, a rainfall event (≥ 10 mm) caused the first noticeable splash erosion and this was marked by an appreciable increase in sediment yield in the collected run-off water. Most of

this sediment appears to have been splashed onto the sill and washed into the collection trough with only minimal amount being derived from surface wash from the plot as a whole.

Once the surface of the plots became capped run-off increased, particularly during prolonged rains, though sediment yield was often only small. This can be partly explained by the fact that although a rainfall of 10 mm or more (but less than 20 mm) fell within a 24-hour period, the rate of rainfall never reached erosive levels of 1 mm/hr. Few large aggregates remained on the surface to be broken down by splash action and it would appear that at this stage the detachable supply of sediment within the restricted area of a plot was reduced by surface sealing. McIntyre (1958) observed during experiments on soil splash using simulated rainfall that surface crusting (sealing) decreased the rate of splash loss. This implies that once the soil surface becomes capped further erosion takes place more slowly. Farres (1978) observed similar phenomena during simulated rainfall experiments on silt loams of the Hamble series.

On the trial plots the slope angle was less than 5° and after the first two rainfall events which caused capping, films and trains of detached sediment were observed on the surface. This material was redistributed by later erosive episodes but the yield of sediment in run-off water was never very high and tended to remain reasonably constant. However, on plots which were installed at a later date on steeper slope facets (10°) there was a greater initial 'flush' of detached sediment during the first two erosive episodes which points

to the combined effects of splash detached soil being transported by surface wash.

Although the expected run-off for a given rainfall event was greater on the more steeply sloping plots, the amount of sediment yield proportionate to run-off was not always greater and on occasions it was less. The latter occurrence can be partly accounted for by the fact that on the less steep plots ($< 5^\circ$) a larger amount of splashed sediment still remained on the surface from the first two events and was available for splash transport in subsequent erosive rains. On the steeper plots a higher proportion of splashed sediment was removed by surface wash and the soil became more effectively sealed until the next major erosive event.

It is acknowledged that the above simplification of a complex set of processes tends to disregard the impact of other physical and biological changes at work on the soil surface. For example, weed growth was a problem on plot B and this could only be controlled by the application of herbicides or by frequent hoeing which resulted in a partial break-up of the surface soil. Possible side effects from the application of sprays on the soil surface are not known. Earthworms were particularly active on some occasions during the spring and early summer and this seemed to be closely related to changes in soil moisture and to an increase in the air and soil temperature. Earthworms produced a large number of surface casts and channels which, together with other organisms, helped to reduce the effects of surface sealing. Worm casts were quickly dissipated by splash action and yielded another source of detached soil for transport by splash and wash action.

A splashed and partially sealed plot surface contained the rounded remains of larger soil aggregates, together with many stones. Frost heave disrupted this seal by lifting both surface and sub-surface stones (contained in the upper 10 cm, but lying beneath the thin layer of surface capping < 5 mm) and by partially breaking down the remaining aggregates. When an erosive rainfall event followed a period of hard frost there was a noticeable increase in the sediment yield of run-off from the steeper plots. Melting snow accompanied by heavy rain (>15 mm in 24 hours) on frozen or partially thawed soil produced appreciable amounts of run-off though sediment yield was below average on the two occasions when this occurred.

By September 1978 a full block of plots was completed, the layout of which is shown in Figure 86 (Page 79). This particular layout was designed on the one hand to evaluate the effect of increased slope (slope angle) and on the other to evaluate the cumulative effect of slope angle and slope length on run-off and soil loss. In order to satisfy the former requirement it was essential that individual plots were located on well defined slope facets. On the particular site this could only be achieved by reducing plot size to 25 m² (10 m x 2.5 m). The cumulative effect of slope length was to be measured on a full length of slope plot 300 m² (60 m x 5 m). Soil loss tends to increase with slope length provided the per cent slope increases or remains constant. Where slope per cent decreases deposition usually takes place. The advantage of the full length plot is that some indication is given of the junction between erosion and deposition along the slope. A guide to the actual amounts of material being moved is obtained from the plots situated on slope facets.

In the calibration period two treatments are allotted to the 25 m² plots. After ploughing, all plots are rotovated. In one set (A), surface roughness is maintained by frequent rotovations. In the second set (B), the surface is permitted to compact by natural processes. It is intended eventually to add a third set (C) where the soil surface is compacted by tractor wheelings as well as by natural compaction. This simulates three field situations in full scale cultivations:

Set A Soil surface after seed bed cultivation
maximum surface roughness and permeability.

Set B Soil surface after natural settling and dispersal
of crumbs and aggregates by splash erosion;
decrease in permeability, surface capping
and increased erosion potential.

Set C Soil surface after combined effects of B,
together with field cultivations (drilling,
spraying and top dressing).

The commencement of the programme in September is intended to simulate field conditions for autumn sown grain and this is followed by a second set in early March to simulate conditions for spring sown grain. When the whole scheme is under way it is envisaged that larger plots 50 m² and 100 m² will be used with one calibration set and one cultivated set in each block (drilled with barley, sugar beet or potatoes).

In conjunction with the monitoring programme the infiltration rate* of each plot is recorded. Infiltration rate is a measure of soil permeability which in turn can be regarded as an indicator of its resistance to erosion. Set A plots represent a

* For method see reference under International Soil Science Society (1967). 283.

control for the other experimental plots. Loss of surface structure can then be attributed to a particular rainfall event or wet period. As the plots are rotated immediately after each event the infiltration rate gives some measure of the degree of splash erosion and subsequent capping. The cumulative effect of a series of such events are measurable in Set B plots. In field trials to date it has been noted that the infiltration rate in Set B plots falls off quite rapidly and then maintains a steady but lower rate. Set C plots will provide a measure of the difference in increased run-off and sedimentation as a result of poor permeability and strong localised compaction associated with vehicular traffic over the soil.

Some marked differences have been noted in the amounts of run-off and sediment yield recorded within the block of plots. These differences are related to wind direction and wind speed during erosive rainfall events and to the degree of exposure or shelter experienced by each plot during specific storms. As the main slope faces due west it lies in the lee of winds from the east. Winds from the N.N.E. and E.S.E. quadrants tend to have a marked effect on the distribution of rain catch among plots on the main slope. Much more work is needed to measure these variables accurately.

No wash erosion has been recorded on the full length plot (300 m²) since September 1976 when 83 mm of rain produced well developed unconfined single rills.

The development of this scheme in its entirety would require

a considerable investment of resources which at present are not available. Some progress has been made, however, with the appointment last year of a full-time research assistant, financed by the Polytechnic, Wolverhampton. Part of the research work outlined above forms the subject matter of a M.Sc. project (designed by the writer) which is now registered at the University of Keele. Plot data collected by the writer has not been presented in this chapter as the M.Sc. thesis will deal with the quantitative aspects of plot run-off and soil loss.

2.4 Summary

1. In the 1930's the run-off plot was adopted in America in place of the watershed as a unit of experimentation to evaluate the factors influencing soil loss and surface water run-off. Since then a great deal of research has gone into ways of determining the relative erodibility of soils. Two broad areas of experimentation have been considered here, namely laboratory based studies using disturbed or simulated soils under simulated rainfall and field based studies using measured plots under natural or simulated rainfall.

2. Laboratory studies became a very important part of soil erosion research since it was possible to provide uniform conditions for evaluating particular parameters which proved difficult or impossible under field conditions. The use of simulated rainfall became an essential part of laboratory erosion research. Selected simulated 'storms' can be applied for a range of plot treatments which is especially

important when evaluating soil conservation characteristics of new cropping and management practices which under natural rainfall plots may require up to twenty years to produce conclusive results.

3. Although a great deal of fundamental research has been accomplished using laboratory studies which range in complexity from studies using small soil plots less than 1 m^2 to large plots $15.3 \text{ m} \times 9.2 \text{ m}$, the weaknesses inherent in all 'controlled' simulated experiments must be clearly recognised for proper interpretation of the results. Natural rainfall is very difficult to simulate, particularly in the form of complex storms as characteristics such as drop temperature, shape, impact angle and the effect of wind on terminal velocity of drops is not fully understood. Likewise the use of disturbed soil samples raises a number of problems in that important soil structural characteristics may be affected which will adversely affect stability and infiltration.

4. The difficulties and dangers of extrapolating data from simulated plots to field conditions must be acknowledged, particularly as data from many field plots under natural rainfall is considered to be biased (Hayward 1968). Observations of micro-processes at work on small plots under high rates of simulated rainfall ($> 100 \text{ mm per hour}$) may not be so significant in the field where conditions of surface roughness, infiltration and rainfall rates are different and can vary greatly throughout the year.

5. Research on field plots has been active since the 1930's and has provided a great store of data which in America has made possible the use of predictive equations such as the Universal Soil Loss Equation. Some authors (Hayward 1967, 1968, Elwell 1978) consider the use of the term 'universal' is questionable and that as this method of predicting soil loss is an empirical one it cannot, therefore, be adapted to areas beyond those for which it was devised.

6. Hayward (1968) classified field plot studies into 'Experimental' and 'Observational' studies, adopting Boughton's division of hydrological research procedures (1968)*. Hayward is critical of the experimental design and data analysis of many plot studies and concludes that much of the data can only be accepted as a qualitative guide and is not considered acceptable for extrapolation.

7. The main sources of bias in plot studies are identified by Hayward as boundary and microclimate effects and the assumption of homogeneity. The lack of replication and randomisation in many studies are further stated weaknesses.

8. No field plot studies on soil erosion have been carried out in the United Kingdom and in Europe reference is made to the work of Bollinne in the Hesbaye area of central Belgium.

9. Finally, reference is made to plot studies at Hilton, east Shropshire, which commenced in 1976. Experimental design is discussed and details of the layout and functioning of 'calibration' plots are described.

* Quoted in Hayward (1968).

Chapter 10

10. Impact of modern agriculture on the soil system and the increasing hazard of soil erosion.

10.1 Introduction.

10.2 Accelerated erosion of arable soils in the
United Kingdom: a summary of evidence.

10.3 Conclusions and recommendations towards a policy
of soil conservation in the United Kingdom.

'Despite the overwhelming evidence of the universal dangers and the universally widespread character of soil erosion, it is still the generally held belief that it is unimportant in Britain.' Sir Dudley Stamp 1943.

10.1 Introduction

In the United Kingdom our perception of accelerated soil erosion has tended to be influenced by the spectacular events which have occurred in other countries, notably the U.S.A., Canada, South America, the U.S.S.R. and Africa and although great strides have been made in combating erosion by the adoption of soil conservation measures, the problem is still very much with us. In 1965 the United States Department of Agriculture's inventory of soil and water conservation needs indicated that conservation measures were required on more than 60 per cent of the cropland (112 million hectares - 267.9 million acres) to reduce erosion losses to an acceptable minimum. During the last two decades renewed soil erosion has been reported in many countries, notably in the prairie provinces of the U.S.S.R. where events in the 1960's showed many similarities to the North American 'Dust Bowl' in the 1930's. Examples of countries affected by new outbreaks of erosion include New Zealand and Brazil. Land development in the last 20 years on the pumice soils of the Central North Island, New Zealand has been followed by gully erosion which appeared to coincide with the first unusually wet season occurring after land development (Selby and Hosking 1973). In Brazil, Barker and Wünsche (1977) describe the agriculture of the Planalto Region of Rio Grande do Sul (the granary of Brazil)

as consisting largely of a simple annual rotation of wheat and soya beans, the hectarage of which has grown in the 1960's at the expense of much of the natural pastureland. The Planalto Region is undulating with long slopes between 5-20%, the rainfall is high, 1500-1900 mm (59-75 inches), and the whole farming region experiences considerable problems of soil erosion.

In Europe soil erosion by wind and water has affected large areas of land and Bennett (1960) estimates that between 60 and 80 per cent of the cultivated land in the central and southern provinces of Spain has been seriously to severely eroded. Only in 1955 did a soil conservation programme get underway. Southern Europe is still badly affected by soil erosion which has devastated areas of sloping land (see Figure 87 Page 80). The writer has seen many sites in Haute Provence, Var, Vaucluse, Gard and Herault, where the effects of past erosion are very evident with some slopes being completely denuded of soil. The age of these features was difficult to ascertain. However, there was abundant evidence that erosion was still very active on these slopes and in adjoining vineyards (see Figure 88 Page 81). Soil erosion has always been a problem in vineyards grown on sloping terrain and today this risk is heightened by compaction from a range of machinery which is now widely used in viticulture. Re-alignment and enlargement of holdings has also brought problems, particularly where field amalgamation has increased the length of slope.

Chisci (1979) describes the erosion of clay soils in the

Italian Apeninnes by intermittent but violent rainstorms. The winter cereal sowing time is the most critical period when intensive rainfall may destroy soil mechanical structure very quickly on the surface causing run-off and severe rill and inter-rill erosion. Another peculiar aspect of degradation affecting clay soils is a process described by Chisci as soliflussion. This is a common occurrence after a long period of rainfall when an entire layer of soil may become completely saturated by water. On arable land soliflussion may result from saturated surface soil sliding over the compact layer (plough sole) formed by ploughing. The risk of soil erosion is increased by the common practice of up and down hill cultivation.

The areas of Europe affected by wind erosion have already been referred to in Chapter 6 (Page 157). In many of these areas, as in parts of central and southern Europe, modernisation of agriculture has been slow when compared to England and the U.S.A. Bennett considers that over much of Europe division of land among heirs has proved an obstacle to good farm management, including the control of erosion. However, increased mechanisation brings with it the attendant problem of soil compaction and where up and down hill cultivation practices are common the risk of greater run-off and erosion. The full impact of these changes in the last two decades have not yet been fully analysed.

Watson (1979) observes that because of improved systems of production yields of cereals, sugar beet, potatoes and other crops in the E.E.C. are increasing more rapidly than the demand

for them. The significance of this situation, Watson contends, will mean that in the long run farmers will concentrate on those soils which give the best yield with less profitable areas being no longer cultivated. He considers that there has been a distinct trend in the E.E.C. toward larger farms and a decrease in the labour force, a pattern of events which was under way in the 1950's in the United Kingdom. In the decade 1960-1970 the amount of cultivated land in the E.E.C. fell by 3.8%, a trend which Watson considers will almost certainly increase over the next fifteen years as it has been estimated that the land area under cultivation (in the former 6 members of the E.E.C.) will fall by between nine and thirteen million hectares and move to other uses, notably recreation and grazing.

It can be concluded from these observations that the pressure on the better land and soils must inevitably increase, with the consequent risk of renewed erosion unless new agricultural techniques and management strategies are adopted. By contrast developing countries are faced with increased pressure from rapidly growing populations and limited soil and economic resources to increase food production. Rapid deforestation in Latin America, Africa and Asia is seen as a quick and cheap solution to these problems with income being derived from timber, followed by the establishment of extensive agriculture and cattle raising. The forest resources in developing countries are estimated by the World Bank to exceed 1,000 million ha and currently they are being cleared at the rate of 15-20 million ha per annum. At this rate the reserves could disappear within sixty years (Donaldson 1978 quoted by Watson). Despite the dangers inherent in this type of land exploitation

some of the developing countries may be able to develop farming systems using modern tillage techniques which will enable them to avoid its worst consequences (Watson *ibid*). One fundamental problem entails the recognition of the fact that changes in land use, technology or management practices may have a long term detrimental effect on the soil system which, once initiated, may be difficult to reverse or, at worst, be irreversible. This is basically a problem of perception. Saarinen (1966) observes that failure to accurately perceive the drought hazard has been the focal problem on the Great Plains since farmers from humid areas first settled there in the late nineteenth century. Whilst much has been written in recent years in the United Kingdom about the problem of the impact of modern agriculture on the soil system, most commentators fail to acknowledge that the risk of soil erosion can be a natural extension of these problems, particularly in adverse seasons. This highlights a fundamental problem of perception.

10.2 Accelerated erosion of arable soils in the United Kingdom: a summary of evidence

As erosion by wind and water poses a potential threat to all exposed soil surfaces, particularly in intensively cultivated areas, it is necessary to consider the question of the extent to which soil erosion constitutes a threat to the present and future productivity of arable soils in the United Kingdom. Although much has been written in the United Kingdom about the current interrelated problems in arable areas of declining levels of soil organic matter, loss of structure and increasing

soil compaction, surprisingly few writers acknowledge a relationship between these problems and a natural extension of them - particularly in adverse seasons - SOIL EROSION. Cultivation during the adverse season of 1968-69 caused serious soil structural problems in many parts of England and was marked by reductions in the yields of many crops. Soil erosion by water (splash erosion, soil wash, rill and gully erosion) and by wind was widespread in the West Midlands and wind erosion affected large areas of arable land in central and eastern England.

In 1969 the Rt. Hon. Cledwyn Hughes, the Minister of Agriculture, expressed concern 'that we should be well informed about any effect which modern farming methods may have in the long term on the fertility and structure of the soil.' In 1970 there followed the Strutt report, 'Modern Farming and the Soil', which states that as far as the nutrient fertility of our soils is concerned there is no great problem resulting from modern farming methods, though structural problems were evident in a range of 'unstable' soils and this resulted directly from modern farming methods. Part of this report examines the causes and effects of soil structural problems and offers a series of recommendations to help rectify them. The problem of wind erosion is examined but only in relation to eastern England and regrettably no mention is made of the present and potential hazard of water erosion on arable soils.

This report and others tend to subscribe to the view that accelerated erosion of arable soils rarely occurs in the United Kingdom outside of areas of the east Midlands and

eastern England where wind erosion can be a hazard during spring and early summer cultivations. Erosion of arable soils by water, however, is generally considered to be very localised, spasmodic, and as such does not constitute a problem, although no comprehensive study has been made to substantiate this view. Evidence from a number of areas in the United Kingdom seems to suggest that soil erosion by rainfall and run-off is a more widespread and frequent event than is generally accepted and this is certainly borne out by a decade of soil erosion monitoring in the West Midlands by the writer. Although much of the data here relates to sandy soils it demonstrates that significant amounts of soil erosion can be effected by rain falling at much lower intensities and for shorter durations than is experienced in many parts of the U.S.A. where soil erosion is a serious problem. By analogy with the West Midlands there are many areas of the United Kingdom with similar soils, terrain and land use to warrant a closer inspection of the problem. Apart from sandy soils there are extensive areas in Lowland Britain which are characterised by silty soils which suffer from varying degrees of instability under continued arable use and these problems can be exacerbated during periods of adverse weather. Soil Survey Memoirs and Records report surface structural problems affecting a wide array of soils which in some cases have led to soil wash and rill erosion. Instances of water erosion of arable soils in Scotland are quoted by Glentworth (1954), Glentworth and Muir (1963) and Ragg (1960, 1973). Water erosion of arable land in England is reviewed by Douglas (1970) and referred to by a number of writers; Low (1963, 1972), Mackney and Burnham (1966), Hodgson and Palmer (1971), Whitfield (1971), Evans

and Morgan (1974), Morgan (1974, 1977), Catt, King and Weir (1974), Evans and Northcliff (1977), and in Wales, Lea (1975).

When due consideration is given to the many interrelated factors which influence soil erosion by water on a particular site, the erosive forces of rainfall and run-off, the susceptibility of the soil to erosion, the length, gradient and shape of the site, the type of crop being grown, its stage of development and cultivation methods used, two factors appear most frequently to act as a catalyst - namely the extent of soil compaction and the presence of up and down slope cultivation. Of the total number of sites in the West Midlands (600+) where water erosion has been recorded by the writer, soil compaction and down slope cultivation lines were major contributory factors in over 95% of the cases. It is apparent, therefore, that there are two divergent schools of thought in the United Kingdom over the question of soil erosion. The 'official' view subscribed to by the Ministry of Agriculture is one which acknowledges the existence of a limited wind erosion hazard and accepts this to be essentially a local rather than a national problem. An alternative view to this is held by a number of research workers who believe that soil erosion is more widespread and occurs more frequently than is generally believed and it is now a cause for concern and action. The object of this section is to present this alternative point of view.

How then does this apparent contradiction arise? One reason that can be advanced is the assumption that there are a number of factors which tend to minimise the risk of soil erosion in the United Kingdom. Central to the argument is the belief

that the principles and practice of British farming and the very nature of our agricultural landscape tend to insure against any potential erosion hazard, and that our humid climate which rarely produces extremes of weather is seldom likely to endanger agriculture. These ideas might have prompted Sir Daniel Hall to write in 1903 'that the extent of erosion in the United Kingdom is very limited and must be regarded rather as exceptional than as a normal occurrence', and this may well have been the case at the time of writing.

Since then a revolution has taken place in British agriculture and profound and lasting changes have been effected in soil and crop management. In the arable areas a new agricultural landscape is emerging, brought about by the removal of miles of hedgerows and the enlargement of fields to accommodate an ever-extending range of machinery. The traditional link between arable cash crops and livestock is now much less important than formerly and with changes in these enterprises the area of ley grass has decreased and in some areas has ceased to play an important role in the arable rotation. A reduction in the numbers of stock carried and in the hectarage of short-term grass has been a characteristic of many farming enterprises which have tended to become simpler and more specialised.

The intensification of arable cropping has been accompanied by a reduction in the levels of organic matter and a deterioration in soil structure. These changes lower the resistance of some soils to the effects of natural compaction resulting

from rain drop impact (splash erosion) and induced compaction from machinery. The difficulties of maintaining soil structure are increased by compaction caused by farm machinery which has become progressively heavier since the last war and research has shown that when heavily laden wheels run over cultivated soils, bulk density increases can be detected to the depth of ploughing. The values for bulk density and air-filled porosity which have been measured in the crop root zone following compaction suggest that adverse crop responses are likely to result, especially during periods of high soil moisture content (Soane 1970). However, the problem of poor crop responses as a result of compaction is small in comparison to the potential danger of accelerated run-off through compaction, which can occur even on gently sloping sites (2-3 degrees) during periods of heavy rainfall. Whereas compaction problems can be rectified by subsequent cultivations the effects of marked erosion episodes (see Figure 37 Page 35) are more serious, wide ranging and long lasting. The most graphic examples of this problem have been seen in the West Midlands on land sown to sugar beet when two erosion episodes occurred in one season during the early stages of crop growth and during and after harvesting, causing widespread rill and gully erosion.

The preponderance of low intensity rainfall is considered to be one of the major factors which minimise the risk of soil erosion in the United Kingdom. There is also the implication (though rainfall intensities per hour are rarely stated) that erosion only occurs during periods of high intensity rainfall and as many of these events tend to be infrequent and short-

lived, the erosive effect is very localised. Davies, Eagle and Finney (1972) contend that by the standards of continental climates the rainfall (of the British Isles) is almost always comparatively gentle, '. . . and surges of run-off water, which in the U.S.A. can gully a field to depths of more than one foot in a single storm are practically unknown (in the British Isles) and there is no serious risk of erosion except on steep slopes.' They further state 'that there is no reason to believe that the British climate is likely to change radically, and it can be concluded that the risk of water erosion is not likely to get worse in the future . . . as at present only very infrequent erosion is likely to occur on sloping land in sandy areas.'

The key issue here is not whether the British climate is likely to change in the future but whether we fully comprehend the small aberrations in our present pattern of weather and the adverse effects which they can exert on agriculture particularly during periods of maximum field activity. Instances of surges of run-off water during storms which gully fields below the Ap horizon (plough horizon) and indeed into the B and C horizons, are not uncommon in the West Midlands even on gently and moderately sloping land ($2-7^{\circ}$) and have been reported elsewhere in the United Kingdom (see Figure 36 Page 34). Today there is a greater chance of low intensity rainfall being potentially more erosive because of the combined effects of low soil organic levels, loss of structure and increased compaction, which in turn lead to reduced water infiltration into the soil and consequently the risk of ponding or run-off. The effects of run-off are increased where fields have been enlarged and slope length and water catchment increased. The enlargement of fields in which continuous arable cropping is practised

has also increased the risk of wind erosion on susceptible soils. The full impact of these changes is not realised until an adverse season is experienced as exemplified by 1968-69 and more recently, 1976.

Herein lies a major problem in the perception of soil erosion hazard in the United Kingdom for usually only the most dramatic instances of wind and water erosion tend to be recorded and the reports in most cases stem from chance sightings of the phenomena where it occurs close to routeways. A corollary of this is that the extent of erosion from a particular rainfall or severe blow is often underestimated as detailed surveys are rarely carried out to ascertain the full extent of the area affected. Also, the cumulative erosive effect of less spectacular episodes tends to be overlooked. Unless a given area is examined on a field to field basis after erosive events no reliable estimate can be made of the area affected and damage by splash, soil wash and incipient rilling can be quickly eradicated by subsequent cultivations. Evidence of gully erosion and depositional sequences by wind and water do persist for longer periods of time.

Reference to the occurrence of soil erosion in the United Kingdom made by writers at home and abroad can present a misleading picture. Bennett (1960) referring to fragmentation of land holdings in relation to erosion describes England as having 'numerous small parcels of land, but the gentleness of the rains and the numerous substantial hedges between fields

tend to hold erosion to a minimum.' Hudson (1967) in a paper entitled, 'Why don't we have soil erosion in England?' concludes 'that approximately 5% of the annual rainfall would fall at intensities greater than the critical threshold figure of 1 inch per hour (25.4 mm/hr) below which kinetic energy is insufficient for splash erosion to occur' (C.F. the 1 mm/hr which causes splash erosion in the West Midlands). He observes, however, that 'in general the amount of erosion in this country is of a lower order of magnitude compared with that which is normal in the tropics and sub-tropics.'

Any attempt at this stage to map the distribution of soil erosion in the United Kingdom must be essentially tentative as the data available is still fragmentary. Apart from a limited number of papers dealing specifically with soil erosion, the researcher must rely on data from soil survey memoirs and records, which only covers approximately 20% of the country, mostly in lowland situations. Whereas it is possible through these reports to identify and locate some of the areas affected by erosion it is more difficult to obtain details of frequency of occurrence and quantities of eroded material as these are rarely referred to in soil survey publications. However, if weakly structured soils are known to erode when under continuous arable cropping in one area, it is reasonable to assume that they may well be at risk in other areas where land forms, rainfall and management practices are broadly similar and this is particularly so in adverse seasons.

Another factor which should be considered is the difference

in the perception of erosion between one field surveyor and another. Surveyor A might perceive soil erosion in terms of dramatic events and tend to ignore minor events. Should the field time required to complete a soil survey of 100 km - 200 km² coincide with a period of little or no erosive activity in the area reference to erosion in the report might be minimal despite the fact that some of the soils are known to have unstable structures under continuous arable and are liable to erode in other areas. Surveyor B, having witnessed erosion episodes on particular soil series in one area, may be consciously looking for evidence of erosion in other areas.

The chances of detecting soil erosion, particularly by water, tend to be minimised by a number of factors, one is access, as a large part of our arable land is still relatively inaccessible, especially if the researcher is relying upon chance sightings of erosion from roadways. This disadvantage can be partly offset by using aerial photography but unless this is specially flown for erosion survey work most of the available sorties at the scale of 1:10560 are of limited value. There are also significant differences between the chance recording of wind and water erosion. When wind erosion occurs on arable soils its effects are often spectacular both during and after the event and in a severe blow with thousands of hectares affected it is likely that a large number of observers will witness the event over many miles and see the aftermath of drifted soil against hedgerows, in ditches and over roads. Herein lies a significant difference between wind and water erosion as the latter is rarely observed in the making and with the possible exception of the more dramatic examples of gully erosion, the effects are not always easily

recognised in the field, as evidence can be quickly eradicated by cultivation and partially masked by crop growth.

10.3 Conclusions and recommendations towards a policy of soil conservation in the United Kingdom

There is now sufficient evidence to suggest that our rather complacent approach to the question of soil erosion in the United Kingdom should be replaced by a more positive one of adopting conservation measures to protect our arable soils before erosion becomes a major problem. The question of what constitutes acceptable levels of soil erosion on arable soils will remain unanswered until a programme of erosion monitoring at regional and national levels is initiated and some assessment made of the extent of the problem. Ideally this should include experimental work on a range of soils which are known to be unstable when in continuous arable cropping so some estimate can be obtained of the erosion rates likely to occur on various sites under different cropping sequences and management practices.

Good progress has been made in the United States and Canada to encourage farmers to adopt soil conservation measures. An integrated campaign of publicity and education has been mounted by Federal and State agencies with emphasis placed on the theme that soil erosion costs money and the farmers' profitability is most at risk. Official policy in the United Kingdom is, by contrast, too complacent. It may be argued that the serious nature of America's erosion problem

merited such concerted action by the Government. However, the problem in 'official circles' in the United Kingdom is one of perception: a failure to understand that the time to initiate conservation measures is before soil erosion becomes a major problem. There remains a preoccupation with ways of increasing the yield of crops as increased yield means increased profitability. The environmental risks of such policies are not always considered or fully appreciated. Undeniably, modern farming is a business and profitability is an economic fact of life. However, as Watson (1979) observes, the E.E.C. countries are already over-producing grain, potatoes, sugar beet and some other crops. Against this background what should be the considered priorities for the policy makers in the United Kingdom? In his presidential address entitled, 'Priorities for British Soil Science', Cooke (1979) acknowledges the warnings that yields from crops and stock may reach a plateau but regards the warnings 'as a challenge to research workers and particularly to soil scientists to develop their work so that new technologies needed for further advances may be established.' 'Better scientific control in agriculture depends on predictions which must be made from a knowledge of the components of a system and the materials used.' One component of this system - the soil - is under considerable stress from modern farming methods and Cooke fails to observe that the combined effects of continuous arable, compaction and erosion might account for the levelling off of crop yields, despite record levels of nutrient input.

However, Russell (1975) observes 'we are all realizing more

and more how often yields are now limited by the physical condition of the soil rather than by its nutrient status, and how often poor physical conditions may set back the crop through their effect on soil organisms.' Davies (1970) avers that farmers will need to devote more thought to the effect of their systems of farming on the soil, which in most cases is their basic material.'

In practical terms many farmers are unaware of the long-term implications of soil washing and blowing in respect of farm profitability, the social costs generated by increased silting of waterways and drainage channels, and the pollution of water supplies by washed-off fertilizer. There is a dearth of information and guidance from the Ministry in the entire area of soil conservation measures and practices.

Basic conservation measures which can be employed, include the avoidance of wholesale removal of hedgerows, particularly where there is a potential risk of wind erosion. The subsidy paid for hedgerow removal and field realignment should be more judiciously administered. The removal of hedgerows subdividing long slopes should be kept to a minimum and, where removal has taken place, cultivation and strip cropping parallel to the contour will help to reduce the effects of run-off.

Up-and-down-slope cultivation should be avoided wherever possible, even on gentle slopes and, where it is practised, the adoption of some device on tractors (e.g. one small tine mounted behind each rear wheel to break up the surface pattern of wheelings) would help in reducing surface compaction and run-off

which is concentrated along wheel tracks. Soils which are susceptible to structural damage, when exposed to heavy rainfall, or are liable to wind erosion, should not be left fallow for longer periods than necessary, and field operations should be kept to the minimum when the upper layers of the soil are too moist.

All the available evidence suggests that the intensification of arable cropping will continue in the 1980's and beyond, and it is feared that this will be accompanied by an extension of the soil structural problems which will, in turn, increase the risk of soil erosion, particularly in unfavourable seasons. Hopefully, management techniques will be adopted which will continue to increase the productivity of the land and at the same time conserve soil resources. One of the most promising soil conservation developments in the last decade has been the no-tillage (direct drilling) method of crop production which Lessiter (1978) estimates is now used to produce some 3.2 million hectares of crops, mostly grains - in the United States. The advantages claimed for this system are discussed in Chapter 1 Page 26. The introduction of effective herbicides in the 1950's which reduced the weed problem, paved the way for the successful introduction of direct drilling. Cannell and Finney (1973) quote Dennings' estimate of about 400,000 ha of cereals which are grown in the U.K. after some form of minimal cultivations. Direct drilling of winter cereals into stubble rose by 76% from 1976 to 1977 while direct drilling of winter cereals into grass rose by 32%. Spring cereals direct drilled into stubble rose by 50% during the same period. In 1977 an I.C.I. survey showed

some 204,049 ha of crops were direct drilled in the United Kingdom. Allen (1975) describes direct drilling of sugar beet into 'blow sands' and 'blow fen' soils in eastern England. In a pilot scheme on about 40 hectares, rye stubble was desiccated with paraquat and was direct drilled with sugar beet in spring 1975 following a method now used commercially by the Dutch on their very light soils. This technique might help overcome the problem of wind erosion on these highly erodible soils. Pidgeon and Ragg (1979) consider that in Scotland farmers (in the east) are beginning to reconsider direct drilling in an attempt to control wind erosion and the avoidance of 'puffy' seed beds on sandy soils.

Although still in its infancy, this method offers the dual advantages of erosion control and timeliness of planting as well as increasing farm productivity, which must appeal to farmers and conservationists alike. In a recent review and provisional classification of soil suitability for continuous cereal direct drilling in the United Kingdom, Cannell et al (1978) proposed two climatic categories. The driest or most favourable area is defined as where the mean date of return to field capacity (R.F.C.) is after 1st November. The wetter category has R.F.C. date earlier than 1st November and demands careful management under any tillage system. The authors recognise three categories of soil suitability for continuous direct drilling compared to ploughing and these are summarised in Table 44. The advantages to be gained from direct drilling of reduced erosion risk can be offset by increased soil compaction on some soils of low bearing strength and this is an

Table 44

Provisional classification of soil suitability for continuous cereal direct drilling in the United Kingdom

Category 1: Suitable soils

Expected yields: High probability of similar or better yields from direct drilling compared with traditional cultivation for both winter and spring crops.

Soil type: includes chalk and limestone soils, well-drained loamy soils, coarse sandy and loamy soils (organic matter >2%) and some humic sands, loams, clays and peat if well drained.

Site factors: include the absence of spring lines and depressions where surface flooding occurs. Soil physical conditions and drainage are generally good and management relatively easy under any tillage system.

Category 2: Less suitable soils

Expected yields: Yield of winter cereals is likely to be similar after direct drilling compared to conventional cultivation. For spring crops - high risk of moderate yield reductions with direct drilling.

Soil type: This category contains the better structured, moderately well-drained and imperfectly drained clay soils and weakly structured imperfectly drained loamy soils (Stagnogleys) where water tables can be partially controlled by field drainage.

Site factors: Interactions between climate and soil type are particularly important for soils in this category where impeded drainage is their major physical limitation. Where waterlogging problems are evident all Category 2 soils are downgraded to Category 3. In drier districts direct drilling is perhaps at its most advantageous on heavier soils which usually present management problems with traditional cultivations.

Category 3: Least suitable soils

Expected yields: High risk of yield reductions (at present) especially for spring cereals.

Soil type: includes poorly drained and weakly structured clay loam and clay soils. Sandy and silty soils liable to slaking and over-compaction are unsuitable as rooting may be restricted by compaction.

Table 44 (continued)

Site factors: Alluvial soils liable to flooding and sites where spring lines or other drainage problems are not satisfactorily controlled are included.

Source: Cannell et al 1978 P. 306-11.

important factor in determining soil suitability for direct drilling.

Apart from the problem of compaction, the restriction of root growth and lower yields on some soils, other limiting factors have been recognised, particularly the control of perennial grass weeds. As with the adoption of any new system, initial management problems may be an important limiting factor, particularly in adverse seasons.

British agriculture has a vast store of management expertise and technical know-how with the backing of a number of famous research establishments, each with distinguished records. British agriculture is a success story, as Cooke (1979) rightly claims. This excellence must not be tarnished by an over-complacent approach to soil conservation. The eighties will be a testing time for agriculture, particularly in areas of intensive arable cultivation. A sound policy of soil conservation is based on the early adoption of preventative measures. Clear guidelines on soil conservation techniques should be available to the farming community as part of the agricultural advisory service programme. There is a need for more information at regional and national levels of the areal

extent, nature and frequency of erosion hazard on arable soils. The infrastructure already exists for the collection and dissemination of data and this is diagrammatically presented in Table 45. Regional Centres and Experimental Husbandry Farms could undertake a limited range of plot experiments on local soils to ascertain run-off and soil loss under fallow, cereals, beet and potatoes. It is feasible that some of these experiments could be integrated into existing field programmes. Soil erosion hazard could be monitored within the regions. Of particular interest and value would be monitoring experiments based at Rothamsted and Woburn Experimental Farm, where data on soils and crop performance spans a century. Here the recording of erosive episodes which affect experimental plots would be a useful start.

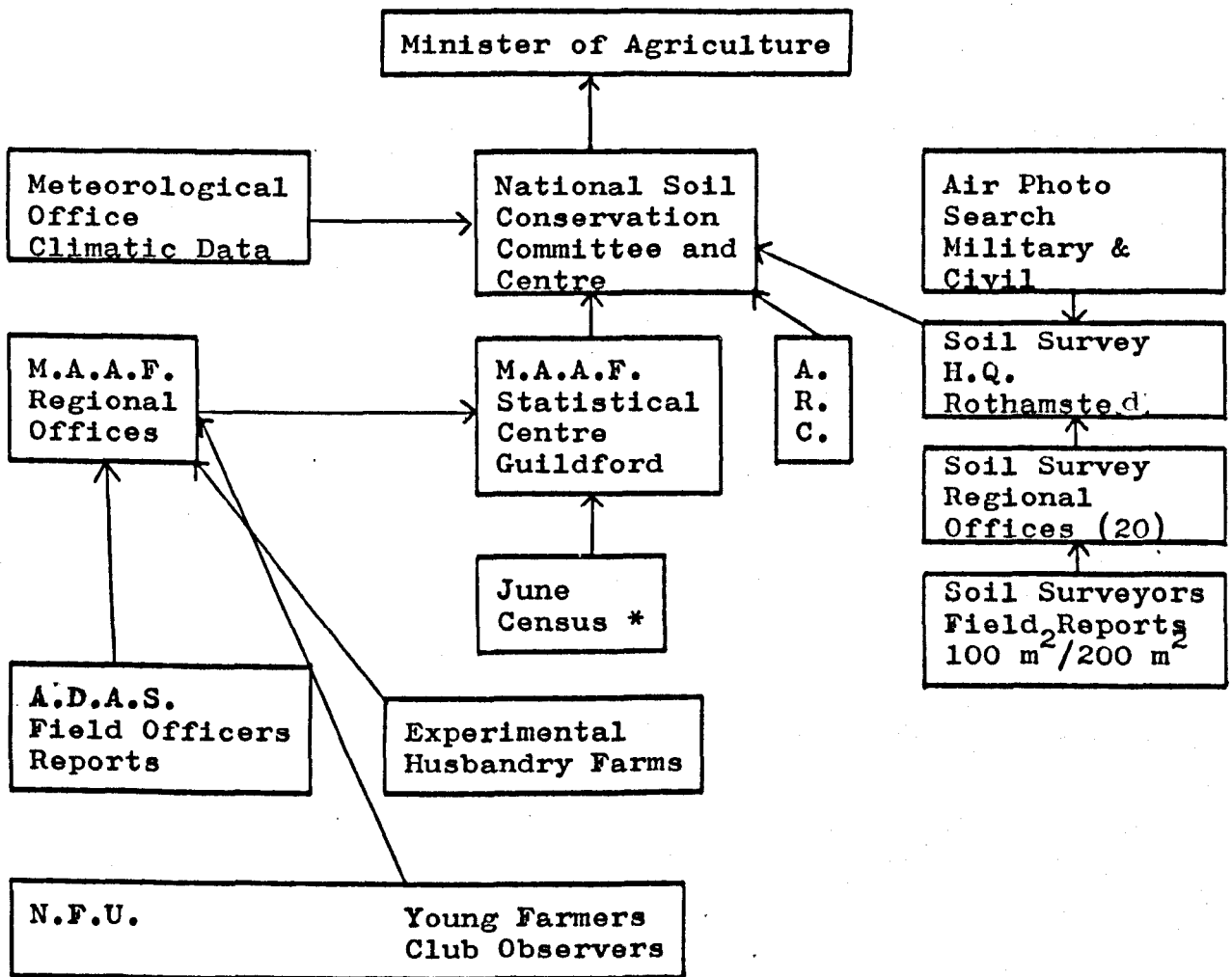
A two-tier programme is envisaged with the first part being essentially fact finding to assess the extent of the soil erosion problem and whether further investigative work is required. The second part of the programme would establish the acceptable levels of soil loss on particular soil series under various systems of cropping and management. The programme should be initiated and co-ordinated by a National Soil Conservation Committee with clearly defined terms of reference and made up from a multi-disciplinary team of soil scientists, agriculturalists and representatives from commercial and farming interests. The Committee would report directly to the Minister.

'Let it not be thought that because in the British Isles the depletion of land by soil erosion is seldom spectacular, it is of little moment to the farmer and gardener.'

Brade-Birks 1944.

Table 45

Flow diagram of data sources and data acquisition for a
National Soil Conservation Committee: a first approximation



* June Census questionnaire (additional data requested).

1. Estimate of farm hectarage affected by erosion during year.
2. Type of erosion - wind, soil washing.
3. Type of damage - categories (a) Soil loss (off farm)
(b) Soil redistribution on farm
4. Type of crops affected.
5. Dates of erosion to correlate with meteorological data and details of cultivations.

REFERENCES

- AGRICULTURAL ADVISORY COUNCIL
1970 Modern Farming and the Soil
Ministry of Agriculture, Fisheries
and Food London 119 pp
- AHMAN R. 1975 Wind Erosion in Southern Scania
Svensk Geografiska Arsbok 50
232-240
- ALBRIGHT W.D. 1939 The Menace of Water Erosion in
the Peace
Scientific Agriculture
Vol. XIX No.5 241-247
- ALLEN H.P. 1975 Direct Drilling of Sugar Beet
into 'Blow' Sands and 'Blow'
Fen Soils in eastern England
Outlook on Agriculture
Vol.8 215
- ARCHER J.R., WILKINSON B.
1969 Survey of poor soil and crop
conditions in Lincolnshire and
Nottingham 1969
National Agricultural Advisory
Service East Midlands Region 8
- ARMBRUST D.V., CHEPIL W.S.,
SIDDOWAY F.H. 1964 Effects of ridges on erosion of
soil by wind Proc. Soil
Science Society America Vol.28
557-560
- AVERY B. 1964 The Soils and Land Use of the
District around Aylesbury and
Hemel Hempstead
Soil Survey, Harpenden 216 pp
- AVERY B.W. 1973 Soil Classification on the
Soil Survey of England and Wales
Journal of Soil Science 24
324-38
- BAKOWSKI B. 1964 Meteorological Factors of the
occurrence of wind erosion in
light soils in the Laskowice,
Olawskie and environs
ZESZ. Problem. Postep. Nauk
Rol 50b 383-388
Experimental Station,
Laskowice, Poland
- BARKER M.R., WÜNSCHE W.A. 1977 Plantio Direto in Rio Grande do Sul
Brasil Outlook on Agriculture 9(3)
114-120

- BARNETT A.P., ROGERS J.S.,
HALLIDAY J.R., DOOLEY A.E. 1965
Soil Erodibility Factors for
selected soils in Georgia and
South Carolina
Transactions American Society
Agricultural Engineers Vol.8
393-395
- BAUR A.J. (ed) 1952
Soil and Water Conservation
glossary. Journal of Soil and
Water Conservation 7 41-52,
93-104, 144-156
- BAVER L.D., GARDINER W.H.,
GARDINER W.R. 1972
Soil Physics 4th Ed.
J. Wiley, New York 498 pp
- BAZELEY 1921
The Extent of the English Forest
in the 13th Century
Trans. Roy. Hist. Soc. Ser. Vol.4
140
- BEASLEY R.P. 1972
Erosion and Sediment Pollution
Control
Iowa State University Press,
Ames, Iowa 320 pp
- BELFORD R.K. 1979
Collection and Evaluation of
Large Monoliths
Journal of Soil Science 30
363-373
- BENNETT H.A. 1926
Some comparisons of the properties
of humid tropical and humid
temperate American soils
Soil Science 21 349-375
- BENNETT H.H. 1939
Soil Conservation
McGraw Hill, New York 402 pp
- BENNETT H.H. 1941
Thirty Years of Vertical Farming
in Soil Conservation Service
Bulletin 101
Department of Agriculture,
Washington
- BENNETT H.H. 1960
Soil Erosion in Spain
Geographical Review Vol.50 59-72
- BERTRAND A.R., SOR K. 1962
Effects of Rainfall Intensity on
Soil Structure and Migration of
Colloidal Materials in Soils
Soil Science Society America
Proc. 26 297-300

- BEST A.C. 1950 The size distribution of raindrops
Quart. Journal Royal Meteorological
Society Vol.76 Part 16 16-36
- BIBBY J.S., MACKNEY D. 1975 Land Use Capability Classification
Technical Monograph No.1
Soil Survey, Harpenden
- BLANCHARD D.C. 1950 Behaviour of water drops at
terminal velocity
Trans. American Geophysical
Union 31 836
- BLANCHARD D.C. 1953 Raindrop size distribution in
Hawaiian rains
Journal of Meteorology Vol.10
457-473
- BLEASDALE A. 1963 The distribution of exceptionally
heavy daily falls of rain in the
United Kingdom 1836-1960
Journal of Institute of Water
Engineering Vol.17 Part 1 45-55
- BLEASDALE A. 1974 British Rainfall 1968
Meteorological Office
HMSO London 231 pp
- BODALAY I., MATE F., SZUCS L.
1976 Wind erosion in the Bacska
loess ridge Hungary
Agrokemia es Talajtan 25 96
- BOLLINNE A. 1978 Study of the importance of
splash and wash on cultivated
loamy soils of Hesbaye (Belgium)
Earth Surface Processes Vol.3
71-84
- BORSY Z. 1975 Recent results of wind erosion
studies in Hungarian blown sand
areas Foldrajzi Ertesito 23.2
227-236
- BRADY-BIRKS G.S. 1944 Good Soil
English Universities Press 245pp
- BROWNING G.M., PARISH C.L.,
GLASS J.A. 1947 A method for determining the
use and limitation of Rotation
and Conservation Practices in
control of Soil Erosion in Iowa
American Society Agronomy
Journal 39 65-73
- BRYAN R.B. 1968 The development, use and
efficiency of indices of soil
erodibility Geoderma 25-26

- BRYAN R.B. 1974 A simulated rainfall test for the prediction of soil erodibility
Zeitschrift Fur Geomorphologie 21
138-150
- BRYAN R.B. 1977 Assessment of soil erodibility: New approaches and directions
Chap.5 in Erosion: Research Techniques, Erodibility and Sediment Delivery Ed. Toy T.J.
Geo Abstracts Ltd. Norwich 86 pp
- BULLOCK P. 1974 Soils in Yorkshire III
Soil Survey Record No.16
Sheets SE 67/74
(Escrick and Barmby Moor)
Soil Survey Harpenden
- BUTZER K.W. 1974 Accelerated Soil Erosion: a problem of man-land relationships in Perspectives on Environment
Ed. by I.R. Manners and M.W.M. Kesell, Association of American Geographers Publication No.13
- CANADA DEPARTMENT OF AGRICULTURE RESEARCH BRANCH 1961 Soil Erosion by Water
Publication 1083
Information Division Ottawa 30 pp
- CANADA DEPARTMENT OF AGRICULTURE 1966 Soil Erosion by Wind
Publication 1266
Information Division Ottawa 26 pp
- CANNELL, R.Q., DAVIES D.B., MACKNEY D., PIDGEON J.D. 1978 Provisional Classification of Soil Suitability for Continuous Cereal Direct Drilling in the United Kingdom
Outlook on Agriculture 9
306-311
- CANNELL R.Q., FINNEY J.R. 1973 Effects of direct drilling and reduced cultivation on soil conditions for root growth
Outlook on Agriculture
Vol.7 No.4 143
- CATT J.A., KING D.W. and WEIR A.H. 1974 The Soils of Woburn Experimental Farm 1. Great Hill, Road Piece and Butt Close in:
Rothamsted Report for 1974 Part 2
Harpenden 5-28

- CATT J.A., WEIR A.H.,
KING D.W., LE RICHE H.H.,
PRUDEN G. and NORRISH R.E.
1976
- CHEPIL W.S. 1945
- CHEPIL W.S. 1956
- CHEPIL W.S. 1957
- CHEPIL W.S. 1958
- CHEPIL W.S., MILNE R.A. 1941
- CHEPIL W.S., SIDDOWAY F.H.,
ARMBRUST D.V. 1964
- CHEPIL W.S. and WOODRUFF N.P.
1963
- CHISCI G.C. 1979
- CLARK J.A. 1942
- CLAYDEN B. 1964
- CLAYDEN B. 1971
- The Soils of Woburn Experimental
Farm II, Lansome, Whitehorse,
and School Field in
Rothamsted Report for 1976 Part 2
Harpenden 5-32
- Dynamics of wind erosion II
Initiation of soil movement
Soil Science 60 397-411
- The influence of moisture on
erodibility of soil by wind
Soil Science Society America
Proc 20 288-292
- Width of field strips to control
wind erosion Technical Bulletin
92 Kansas Agricultural Experimental
Station, Manhattan, Kansas 65 pp
- Soil conditions that influence
wind erosion
US Dept. Agricultural Technical
Bulletin 1185 70 pp
- Wind erosion of soil in relation
to roughness of surface
Soil Science 52 417-433
- Wind erodibility of knolly terrain
Journal of soil and water conser-
vation 179-181
- The Physics of Wind Erosion and
its control
Advances in Agronomy 15
211-302
- The management of clay soils on
hilly land: a model for a
Mediterranean environment
Outlook on Agriculture Vol.10.1
5-12
- Prince Edward Island Soils and
Control Methods for Soil Erosion
Scientific Agriculture Vol.23
223-228
- Soils of the Middle Teign
Valley District of Devon
Rothamsted Experimental Station
Harpenden 73
- Soils of the Exeter District
Soil Survey Harpenden 254 pp

- COOKE G.W. 1979
Some priorities for
British Soil Science
Journal of Soil Science
Vol. 30.2 187-214
- CORBETT W.M. and TATLER W.
1970
Soils in Norfolk
Soil Survey Record No.1
Sheet TM49 (Beccles North)
Soil Survey Harpenden
- CORBETT W.M. 1973
Breckland Forest Soils
Soil Survey Special Survey No.7
Soil Survey Harpenden
- COUTTS J.R.H., KANDIL M.F.,
NOWLAND J.L. and TINSLEY J.
1968 a
Use of Radioactive ^{59}Fe for
tracing Soil Particle Movement
Part 1. Field Studies of
Splash Erosion
Journal of Soil Science Vol.19.2
312-324
- COUTTS J.R.H., KANDIL M.F.
and TINSLEY J. 1968b
Use of Radioactive ^{59}Fe for
tracing Soil Particle Movement
Part 2. Laboratory studies
of labelling and splash
displacement
Journal of Soil Science Vol.19.2
325-341
- CROMPTON A. and MATTHEWS B.
1969
Soils of the Leeds District
Soil Survey Harpenden 221 pp
- CROSSLEY A.F., LOFTHOUSE N.
1964
The distribution of severe
thunderstorms over Great Britain
Weather Vol.19 172-177
- DANIEL H.A., ELWELL H.M.,
HARPER H.J. 1938
Nutrient losses from soils by
water erosion
Soil Science Society America
Proc.3. 230-233
- DAVIES A.J. 1975
Farming in the 1970's in
Soil Physical Conditions and
Crop Production
Technical Bulletin 29
Ministry of Agriculture, Fisheries
and Food H.M.S.O. 505 pp
- DAVIES D.B., EAGLE D.J.,
FINNEY J.B. 1972
Soil Management 226
Farming Press Ltd., Ipswich 226 pp
- DAVIES D.B. and HARROD M.F.
1970
Processes and Control of Wind
Erosion
N.A.A.S. Quart. Review Vol.88 139

- DELANY A.C., ZENCHELSKY S.
1975
The organic component of wind erosion - generated soil-derived Aerosol
Soil Science Vol.121 No.3
146-155
- DIXON R.M., PETERSON A.E.
1971
Water infiltration control: a channel system concept
Soil Science Society America Proc. 35 968-973
- DOUGLAS I. 1970
Page 58 in The Role of Water in Agriculture, Taylor J.A. (Ed.) Pergamon Oxford 230 pp
- DULEY F.L., HAYS O.E. 1932
The effect of degree of slope on run-off and soil erosion
Journal of Agricultural Research 45
349-360
- DULEY F.L., KELLY L.L. 1939
Effect of soil type, slope and surface conditions on intake of water
Nebraska Agricultural Experimental Station Research Bulletin 112 16
- EHLERS W. 1975
Observations on Earthworm Channels and infiltration on tilled and untilled loess soil
Soil Science Vol.119 No.3 242-249
- EKERN P.C. 1953
Problems of raindrop erosion
Agricultural engineering St Joseph Michigan Vol.34 23-25
- EKERN P.C., MUCKENHIRN R.J.
1947
Water drop impact as a force in transporting sand
Soil Science Society America Proc. Vol.12 443-444
- ELLISON W.D. 1944
Studies of raindrop erosion
Agricultural Engineering 25 181-182
- ELLISON W.D. 1947
Soil Erosion Studies
Agricultural Engineering 28 145
- ELWELL H.A. 1978
Modelling Soil Losses in South Africa
Journal of Agricultural Engineering Research 23.2 117-127
- EVANS R. 1971
The Need for Soil Conservation
Area Vol.3 No.1 20-23
Institute of British Geographers

- EVANS R., MORGAN R.P.C. 1974 Water Erosion of Arable Land Area Vol.6 No.3 221-225
Institute of British Geographers
- EVANS R., NORTHCLIFF S. 1977 Soil Erosion in North Norfolk Journal of Agricultural Science Cambridge 90 185-192
- F.A.O. 1960 Soil erosion by wind
Rome 101 pp
- FARRES P. 1978 The role of time and aggregate size in the crusting process Earth surface processes Vol.3 243-254
- FINDLAY D.C. 1976 Soils of the Southern Cotswolds and Surrounding Country
Soil Survey Harpenden 252 pp
- FRANKLIN T.B. 1948 A History of Agriculture
G. Bell & Sons, London 239 pp
- FREE G.R. 1952 Soil Movement by Raindrops Agriculture Engineering Vol.33 491-6
- FURNESS R.R. 1971 Soils in Cheshire I Soil Survey Report No.5 Sheet SJ 65 (Crewe West)
Soil Survey Harpenden
- FURNESS R.R. and KING S.J. 1973 Soils in Cheshire II Soil Survey Report No.17 Sheet SJ 37 (Ellesmere Port)
Soil Survey Harpenden
- GABRIELS D., PAUWELS J.M., DE BOODT M. 1975 The slope gradient as it affects the amount and size distribution of soil loss material from run-off on silt loam aggregates MEDELINGEN FAC. LANDBROUW RUKUNW GENT. Vol.40 1333-1338
- GARCIA G., HICKEY W.C. and DARTIGNAC E.J. 1963 An Inexpensive Run-off Plot
Research note RM12
Forest Service, United States Department of Agriculture
- GARD L.E., McKIBBEN G.E. 1973 'No-till' Crop Production Proving a Most Promising Conservation Measure. Outlook on Agriculture Vol.7 Part 4 149-154

- GLENTWORTH R. 1954 The Soils of the Country around Banff, Huntly and Turriff
Memoir of the Soil Survey of Great Britain
Soil Survey Harpenden 239 pp
- GLENTWORTH R. and MUIR J.W. 1963 The Soils of the Country around Aberdeen, Inverurie and Fraserburgh
Memoir of the Soil Survey of Great Britain
Soil Survey Harpenden 204 pp
- GRAY H.L. 1915 English Field Systems
Harvard and Oxford 275 pp
- GREAT PLAINS COMMITTEE 1936 The Future of the Great Plains
U.S. Government Printing Office, Washington 95 pp
- GUNN R., KINZER G.D. 1949 Terminal velocity of water droplets in stagnant air
Journal of Meteorology 6 243
- HALL A.D. (Sir) 1903 The Soil
John Murray London 322 pp
- HALL B.R. and FOLLAND C.J. 1970 Soils of Lancashire
Soil Survey Bulletin No.5
Soil Survey Harpenden 179 pp
- HARRIS R.F., CHESTERS G., ALLEN O.N. 1966 Dynamics of Soil Aggregation
Advances in Agronomy 18 107-160
- HARROD T.R. 1971 Soils in Devon I
Soil Survey Record No.9
Sheet ST 10 (Honiton)
Soil Survey Harpenden
- HARROLD L.L., TRIPLETT G.B., YOUKER R.E. 1967 Soil loss from conventional tillage and no-tillage watersheds 1964-1966
Rep Ohio Agricultural Experimental Station 52 (2) 22
- HAYS O.E., PALMER V.J. 1936 Soil and Water Conservation Investigations at La Crosse
Soil and Water Conservation Progress Report 1932-1935
La Crosse, Wisconsin
- HAYWARD J.A. 1967 Plots for evaluating the catchment characteristics affecting soil loss
Review of plot studies 2
New Zealand Journal of Hydrology 6 (2) 120-137

- HAYWARD J.A. 1968 A critique of soil-loss plot studies New Zealand Agricultural Engineering Institute Research Report 2 Lincoln College
- HINMAN W.C., BISAL F. 1973 Percolation rate as affected by the interaction of freezing and drying processes of soils Soil Science Vol.115 No.2 102-106
- HODGE C.A.H. and SEALE R.S. 1966 The Soils of the District around Cambridge Soil Survey Harpenden 183 pp
- HODGSON J.M. 1967 Soils of the West Sussex Coastal Plain Soil Survey Harpenden 148 pp
- HODSON J.M. 1972 Soils of the Ludlow District Soil Survey Harpenden 139 pp
- HODGSON J.M., PALMER R.C. 1971 Soils in Herefordshire I Sheet 5053 (Hereford South) Soil Survey Record No.2 Soil Survey, Harpenden
- HOLLIS J.M. 1978 Soils in Salop I Soil Survey Record No.49 Sheet SO 79E/89W (Claverley) Soil Survey, Harpenden
- HOLLIS J.M., HODGSON J.M. 1974 Soils in Worcestershire I Soil Survey Record No.18 Sheet SO 87 Kidderminster Soil Survey, Harpenden
- HOOPER M. 1970 Dating Hedges Area No.4 63-65 Institute of British Geographers
- HORTON R.E. 1945 Erosional development of streams and their drainage basins Geological Society of America Bulletin 56 275-370
- HOWELL E.J. 1941 The Land of Britain Part 66 Shropshire Land Utilization Survey London 285
- HUDSON J.C. 1974 Use of large soil monoliths in the study of soil (plant relationships) Tropical Agriculture (Trinidad) 51 304-12

- HUDSON N.W. 1957
The design of field experiments
in soil erosion
Journal of Agricultural
Engineering Research 2.1 56-67
- HUDSON N.W. 1967
Why don't we have soil erosion in
England in Proceeding of
Agricultural Engineering Symposium
Paper 5/B/42 Cribb J.A.C. Ed.
- HUDSON N. 1971
Soil Conservation
B.T. Batsford Ltd. London 320 pp
- INTERNATIONAL SOIL SCIENCE
SOCIETY 1967
West European Methods for
Soil Structure Determination
Chap. V Page 137
- JACKS G.V., WHITE R.O. 1939
The Rape of the Earth
Faber London 275 pp
- JACKSON M.C. 1974
Largest two-hour falls of rain in
the British Isles
Weather Vol 29 No.2 71-73
- JARVIS R.A. 1968
Soils of the Reading District
Soil Survey Harpenden 150 pp
- JARVIS R.A. 1973
Soils in Yorkshire II
Soil Survey Record No.12
Sheet SE60 (Armthorpe)
Soil Survey, Harpenden
- JOHNSON P.A. 1975
Soils in Nottinghamshire II
Soil Survey Record No.26
Sheet SK 85 (Newark on Trent)
Soil Survey, Harpenden
- JONES R.J.A. 1975
Soils in Staffordshire II
SJ 82 (Eccleshall)
Soil Survey Record No.31
Soil Survey, Harpenden
- KINNEL P.I.A. 1968
An acoustic impact rainfall
recorder
Postgraduate Cert. Dissertation
National College of Agricultural
Engineering, Silsoe
- KNOTTNERUS D.J.C.,
PEERLKAMP P.K. 1972
Wind Erosion. What can be done
about it?
Bedryfontwikkeling 3.2
175-179
- KOWAL J.M., KIJEWSKI W.,
KASSAM A.H. 1973
A simple device for analysing
the energy load and intensity
of rainstorms
Agricultural Meteorology (12)
271-280

- LAMB H. 1978 Probable maximum precipitation in Great Britain
Letters to the Editor in Weather Vol 33 No.8 323
- LAWS J.O. 1940 Recent studies in raindrops and erosion
Agricultural Engineering 21 No 11
431-433
- LAWS H. 1941 Measurement of fall - velocity of water droplets and raindrops
Transactions of the American Geophysical Union 22: 709
- LAWS J.O., PARSONS D.A. 1943 Relation of drop-size to intensity
Trans American Geophysical Union Part 2 452-460
- LEA J.W. 1975 Soils in Powys 1
Soil Survey Record No.28
Sheet SO 09 (Caersws)
Soil Survey, Harpenden
- LESSITER F. 1978 Less Tillage is Catching on
No-Till Farmer 3. 4-5
- LOW A.J. 1963 Page 55-59 in Crop Production in a weed-free environment
Symposium of the British Weed Control Council Vol.2
- LOW A.J. 1972 The Effect of Cultivation on the Structure and other Physical Characteristics of Grassland and Arable Soils
Journal of Soil Science Vol.23 No.4
363-380
- LOWDERMILK W.C. 1930 Influence of Forest Litter on Run-off Percolation and Erosion
American Journal of Forestry 28(4) 474-491

- LUMKES L.M. VELDE H.A. 1974 Protection from wind erosion - minimum cultivation techniques on soils susceptible to in Proclamations 12 British Weed Control Conference Vol 3
- MACKNEY D. BURNHAM C.P. 1964 Soils of the West Midlands Bulletin No.2
Soil Survey Harpenden 111 pp.
- MACKNEY D. BURNHAM C.P. 1966 Soils of the Church Stretton District of Shropshire
Soil Survey Harpenden 247 pp.
- MATTHEWSB. 1971 Soils in Yorkshire I
Soil Survey Record No.6
Sheet SE 65 (York East)
Soil Survey, Harpenden
- McCLURE W.R. PHILLIPS S.H.
HERRON J.W. 1968 No-tillage experiences in Kentucky
University of Kentucky paper 68-144
Lexington, Kentucky
- McINTYRE D.S. 1958 Soil splash and the formation of surface crusts formed by rain-drop impact Soil Science 85
261-266
- MECH S.J. 1965 Limitations of simulated rainfall as a research tool
Transactions of American Society of Agricultural Engineers 8.1 66 and 75
- MEYER L.D. 1965 Simulation of rainfall for soil erosion research
Transactions of American Society of Agricultural Engineers 8.1 63-65
- MIDDLETON H.E. 1930 Properties of soils which influence SOIl erosion U.S. Department of Agriculture Technical Bulletin 178 1-16.
- MIHARA Y. 1952 Rain drops and soil erosion
National Institute of Agricultural Science Tokio Japan 1 48-51
Summary translation
- MINISTRY OF AGRICULTURE 1954 A Survey of the Agriculture of the Sand Lands Bulletin No.163 HMSO 48 pp.
- MOLDENHAUER W. LONG D.C. 1964 Influence of rainfall energy on soil loss and infiltration
1. Effect over a range of texture.
Soil Science Society America Proc. 28 813-817

- MOLDENLAUER W.C. LOVELY W.G. SWANSON N.P. CURRENCE H.D. 1971 Effects of low grades and tillage systems on soil and water losses
Journal of Soil and Water Conservation Vol 2 193-195
- MORGAN R.P.C. 1974 Nature Provides Man Erodes
Geographical Magazine Vol 46 No 10 528
- MORGAN R.P.C. 1977 Soil erosion in the United Kingdom: field studies in the Silsoe area 1973-1975 Occasional paper No.4
National College of Agricultural Engineering, Silsoe
- MORGAN R.P.C. 1978 Field Studies of Rainsplash Erosion Earth Surface Processes Vol 3 295-299
- MOSLEY M.P. 1974 Experimental study of Rill Erosion Transactions American Society Agricultural Engineering Vol 17 909-913 and 916
- MUSGRAVE G.W. 1947 The quantitative evaluation of factors in water erosion: a first approximation
Journal of Soil and Water Conservation 2 133-138
- MUTCHLER C.K. 1963 Run-off plot design and installation for soil erosion studies United States Agricultural Research Service ARS 41-79 27 pp.
- MUTCHLER C.K. 1971 Splash amounts from water drop impact on a smooth surface Water resources research 7 195-200
- MUTCHLER C.K. and YOUNG R.A. 1975 Soil displacement by raindrops in present and perspective technology for predicting sediment yields and sources Agricultural research Service 4Q U.S. Dept of Agriculture 113-117
- PALMER R.S. 1963 The influence of a thin water layer on waterdrop impact forces Int. Association Scientific Hydrology 65 141-148
- PALMER R.C. 1972 Soils in Herefordshire III S.O. 34 (Staunton on Wye) Soil Survey Record No.11 Soil Survey, Harpenden
- PHILLIPS S.H. YOUNG H.M. 1973 No-tillage Farming Reiman, Milwaukee, Wisconsin 220 pp.

- PIDGEON J.D. RAGG J.M. 1979 Soil, Climatic and Management
Options for Direct Drilling Cereals
in Scotland
Outlook on Agriculture Vol 10 No.1
49-55
- POLLARD E. MILLAR A. 1968 Wind Erosion in the East Anglian
Fens Weather Vol 23 No 10 415-417
- RADLEY J. SIMMS C. 1967 Wind Erosion in East Yorkshire
Nature Vol 216 20-22
- RAGG J.M. 1960 The Soils of the Country around
Kelso and Lauder Macaulay Inst.
of Soil Research Aberdeen 96
- RAGG J.M. 1973 Factors in Soil Formation in:
The Organic Resources of Scotland
Ed. Tivy J.
Oliver & Boyd Edinburgh 227 pp.
- REED A.H. 1972 Soils and Land Use in the East
Shropshire Parishes of Claverley,
Rudge and Worfield Unpublished
M.Sc. thesis University of Keele
- REEVE M.J. 1975 Soils in Derbyshire II
Soil Survey Record No 27
Sheet SK 32E/42 W (Melbourne)
Soil Survey Harpenden
- REEVE M.J. 1976 Soils in Nottinghamshire III
Soil Survey Record No.33
Sheet SK 57 (Worksop)
Soil Survey Harpenden
- REYNOLDS G. 1978 Maximum Precipitation in
Great Britain Weather Vol 33 No 5
162-166
- RIODL O. 1969 Wind erosion in Czechoslovakia
and its control
Acta University Agriculture
BRNO (Fac Silv) 38 169-193
- ROCQUE J. 1752 Actual Survey of the County of
Salop Salop County Archives,
Shrewsbury
- ROBINSON D.N. 1968 Soil erosion by wind in Lincolnshire
March 1968 East Midland Geographer
4(6) 351-62
- ROBSON J.D. GEORGE H. 1971 Soils in Nottinghamshire I
Soil Survey Record No.8
Sheet SK66 (Ollerton)
Soil Survey Harpenden

- ROBSON J.D., GEORGE H. and
HEAVEN F.W. 1974 Soils in Lincolnshire I
Soil Survey Record No.22
Sheet TF 16 (Woodhall Spa)
Soil Survey Harpenden
- ROGERS W.S., GREENHAM D.W.P.
1948 Soil Management with Special
Reference to Fruit Plantations
Journal of the Royal Agricultural
Society Vol.109 194-211
- ROSE C.W. 1958 Effects of rainfall and soil
factors on soil detachment and
the rate of water penetration into
soil Ph.D. thesis, University of
London
- ROWLEY T. 1972 The Shropshire Landscape
Hodder and Stoughton, London 272 pp
- ROYAL SOCIETY 1977 Scientific Aspects of the 1975-6
Drought in England and Wales
Royal Society, London 133 pp
- RUDEFORTH C.C. 1974 Soils in Dyfed II
Soil Survey Record No.24
Sheets SM 90/91
Pembroke/Haverford West
Soil Survey, Harpenden
- RUSSELL E.W. 1975 Opening address in
Soil Physical Conditions and
Crop Production
Technical Bulletin 29
Ministry of Agriculture, Fisheries
and Food H.M.S.O. 505 pp
- SAARINEN T.F. 1966 Perception of Drought Hazard
on the Great Plains Research
papers Dept. of Geography
University of Chicago 106 1-23
- SALTER P.J. 1967 Effects of PFA on the moisture
characteristics of soils
Nature 213 1157
- SEALE R.S. 1975 1. Soils of the Ely District
Soil Survey Harpenden 253 pp
- SEALE R.S. 1975 2. Soils of the Chatteris district of
Cambridgeshire Sheet TL 38
Special Survey No.9
Soil Survey Harpenden
- SELBY MJ., HOSKING P.J. 1973 The Erodibility of Pumice Soils
of the North Island, New Zealand
Journal of Hydrology (N.Z.)
Vol.12 No.1 32-56

- SHAW E.M. 1962 A decade of rainfall at Keele (1952-1961)
North Staffs Journal of Field Studies Vol 5.28
- SHROPSHIRE COUNTY RECORDS Commissioners' Awards for Enclosing Lands 1773-1891
Interim Report of the Clerk and Deputy Clerk of the County Council, Shrewsbury, Salop
- SKRODZKI M. 1972 Present-day water and wind erosion of soils in N.E. Poland
Geographic Polonica No.23
77-91
- SMITH D.D. 1941 Interpretation of Soil Conservation Data for Field Use
Agricultural Engineer 22 173-175
- SMITH L.P. 1954 Humidities in the Lee of Hill Masses Meteorological Magazine
Vol.83 No.979 1-3
- SMITH R.T. 1975 in The Effect of Man on the Landscape: the Highland Zone
Early Agriculture and Soil Degradation 27-37 Research Report No.11 The Council for British Archaeology
- SMITH D.D., WISCHMEIER W.H. 1962 Rainfall Erosion
Advances in Agronomy 14 109-148
- SMITH D.D., WISCHMEIER W.H. 1957 Factors affecting Sheet and Rill Erosion American Geophysical Union
Trans: 38 889,896
- SNEESBY N.J. 1953 Wind erosion and the value of shelter belts Agriculture 60
263-271
- SOANE B.D. 1970 The effects of traffic and implements on soil compaction
Journal and Proceedings of the Institute of Agricultural Engineers
Vol.25 Part 3 115, 125
- SOIL CONSERVATION SERVICE
U.S. DEPARTMENT OF AGRICULTURE
1948 Erosion Survey of Arkansas, Louisiana, Oklahoma and Texas
United States Government Printing Office, Washington 105 pp
- SOIL SURVEY HANDBOOK 1976 Technical monograph No.5
Ed. Hodgson J.M.
Soil Survey Harpenden

- SOR K., BERTAND A.R. 1962 Effects of Rainfall Energy on Permeability of Soils Soil Science Society America Proc 26 293, 297
- SPENCE M.T. 1955 Wind Erosion in the Fens Metecrological Magazine 84 304-307
- SPENCE M.T. 1957 Soil blowing in the Fens 1956 Meteorological Magazine 86 21-22
- STALLINGS J.H. 1957 Soil Conservation Prentice Hall, Englewood Cliffs, New Jersey 350 pp
- STAMP L.D. 1943 The Land of Britain: Kent No.85 Land Utilization Survey Report H.M.S.O.
- STAMP D. 1955 Man and the Land Collins, London 272 pp
- SYLVESTER D. 1969 The Rural Landscape of the Welsh Borderland Macmillan, London 548 pp
- TACKETT J.L., PEARSON R.W. 1965 Some characteristics of soil crusts formed by simulated rainfall Soil Science Vol.99.6 407, 413
- TASK COMMITTEE 1965 Wind Erosion and Transportation in Sediment Transportation Mechanics Progress Report Journal of the Hydraulics Division 261-287
- TAYLOR H.M., HENDERSON D.W. 1959 Some effects of organic additives on compressibility of yolo silt loam soil Soil Science 88 101, 106
- THOMAS T.M. 1956 Gully erosion in the Brecon Beacons area, South Wales Geography 41 99-107
- THOMAS T.M. 1965 Sheet erosion induced by sheep in the Pumlumon (Plynlimon) area, mid-Wales in Rates of Erosion and Weathering in the British Isles Institute of British Geographers Geomorphological Symposium 11-4
- THOMPSON J.R. 1970 Soil Erosion in the Detroit Metropolitan Area Journal of Soil and Water Conservation Vol.25 8-10

- TOY T.J. 1977
 Introduction to the Erosion Process
 in Erosion, Research Techniques
 Toy J.T. (Ed.) 7-18
 Geo. Abstracts Ltd. Norwich 86 pp
- UNITED STATES
 DEPARTMENT OF AGRICULTURE 1907
Soil Erosion Survey Report
 Miscellaneous Papers
 U.S. Government Printing Office
 Washington D.C.
- UNITED STATES
 DEPARTMENT OF AGRICULTURE 1934
Soil Conservation
Reconnaissance Survey
 Miscellaneous Papers
 U.S. Government Printing Office
 Washington D.C.
- UNITED STATES
 DEPARTMENT OF AGRICULTURE 1948
Soil and Water Conservation Needs
 U.S. Government Printing Office,
 Washington D.C.
- UNITED STATES DEPARTMENT
 OF AGRICULTURE 1954
 Agricultural Research Service
Misc. Papers
 U.S. Government Printing Office,
 Washington D.C.
- UNITED STATES DEPARTMENT
 OF AGRICULTURE 1965
Soil and Water Conservation needs -
A National Inventory
 Misc. publ. 971
 U.S. Government Printing Office,
 Washington D.C.
- VAN DOREN C.A. and BARTELLI
 L.J. 1956
A Method of forecasting Soil Loss
Agricultural Engineering 37 335-341

- WATSON G.A. 1979
Management of soil under adverse conditions Outlook on Agriculture
Vol.10.1 p 2-4
- WHITFIELD W.A.D. 1971
Soils in Herefordshire II
SO 52 (Ross on Wye)
Soil Survey Record No.3
Soil Survey Harpenden
- WHITFIELD W.A.D. 1974
Soils in Warwickshire I
SP 36 (Leamington Spa)
Soil Survey Record No.19
Soil Survey Harpenden
- WHITFIELD W.A.D., BEARD G.R.
1975
Soils in Warwickshire II
SP 05 (Alcester)
Soil Survey Record No.25
Soil Survey Harpenden
- WIJNSMA M. 1975
The collection of undisturbed soil
columns for Lysimeters Nota 891
Institut Voor Cultuurtechniek en
Waterhuishouding, Wageningen
- WILKINSON B., BROUGHTON W.,
PARKER-SUTTON J. 1968
Survey of wind erosion on sandy
soils in the east Midlands
Experimental Husbandry No.18
Ministry of Agriculture H.M.S.O.
53-59

- WILTSHIRE C.R. 1947 Run-off plots and standard run-off and soil loss measuring equipment used by the New South Wales Soil Conservation Service Journal of Soil Conservation Service N.S. Wales 3 171-178
- WISCHMEIER W.H. 1959 A Rainfall Erosion Index for a Universal Soil Loss Equation Soil Science Society, America Proc. 23 246-249
- WISCHMEIER W.H. 1960 Cropping-Management Factor Evaluations for a Universal Soil Loss Equation Soil Science Society, America Proc. 24 322-326
- WISCHMEIER W.H. 1962 Rainfall Erosion Potential Agricultural Engineering 43.4 212-215, 225
- WISCHMEIER W.H. 1974 New Developments in Estimating Water Erosion in Land Use: Persuasion or Regulation 179, 186 Soil Conservation Society, America
- WISCHMEIER W.H. 1976 Use and Mis-use of the Universal Soil Loss Equation Journal of Soil and Water Conservation Vol 31 5-9
- WISCHMEIER W.H. 1977 Soil Erodibility by Rainfall and Run-off Chap 4 in Erosion, Research Techniques Toy E.J. (Ed.) 45-56 Geo Abstracts Ltd. Norwich 86 pp.
- WISCHMEIER W.H. JOHNSON C.B. and CROSS B.V. 1971 A Soil Erodibility Nomograph for Farmland and Construction Sites Journal of Soil and Water Conservation Vol 26 189-193
- WISCHMEIER W.H. MANNERING J.V. 1969 Relationship of soil properties to its erodibility Soil Science Society America Proc 33 131-137
- WISCHMEIER W.H. SMITH D.D. 1958 Rainfall energy and its relationship to soil loss American Geophysical Union Trans 39 285-291
- WISCHMEIER W.H. and SMITH D.D. 1961 A Universal Soil-loss Estimating Equation to Guide Conservation Farm Planning 7th Congress International Soil Science Society Transactions VI Paper 2 418-425

- WISCHMEIER W.H. and SMITH D.D. 1965 Predicting Rainfall - Erosion Losses from Cropland East of the Rocky Mountains
Agricultural Handbook 282
Agricultural Research Service,
U.S. Dept. of Agriculture 114 pp.
- WITTMUS H.D. SWANSON N.P. 1964 Till-planted corn reduced soil losses Agricultural Engineering ST Joseph Michigan 45 256-257
- WOODBURN R. 1948 The effect of structural conditions on soil detachment by raindrop action Agricultural Engineering 29 154-156
- WOODRUFF N.P. SIDDOWAY F.H. 1965 A wind erosion equation Proc. Soil Science Society America 29.5 602-608
- WOLLNY E. 1877 Der einfluss der pflanzen decke und beschattung auf die physikalischen eigenschaften un die fruchtbarkeit des bodens
Berlin
- YATES E.M. 1965 Dark Age and Mediaeval Settlement on the Edge of Wastes and Forest Field Studies Vol 2 148-153
- YOUNG A. 1785 A Tour of Shropshire
Annals of Agriculture Vol IV 138
- YOUNG H.M. 1973 No-tillage farming in the United States - its Profit and Potential Outlook on Agriculture Part 4 143-148
- YOUNG R.A. and WIERSMA J.L. 1973 The role of rainfall impact in soil detachment and transport Water Resources Research 9: 1629-1636
- ZINGG A.W. 1940 Degree and Length of Land Slope as it Affects Soil Loss in Run-off
Agricultural Engineer 21.1 59-64
- ZHIRKOV K.F. 1964 Dust storms in the Steppes of Western Siberia and Kazakhstan
Soviet Geography Vol 5 33-41

Accelerated erosion of arable soils in the United Kingdom by rainfall and run-off

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On more than six hundred sites in the UK West Midlands, where water erosion was recorded by the writer during the years 1967–76, soil compaction and down-slope cultivation lines were identified as major contributory factors in over 95% of cases. Such cultivations should be avoided where possible, susceptible soils should not be left fallow longer than necessary, and field operations should be kept to the minimum when the upper layers of the soil are too moist.

Accelerated or man-induced soil erosion is most spectacularly evidenced in countries such as the USA, Canada, South America, the USSR and Africa. In 1965 the United States Department of Agriculture's inventory of soil and water conservation needs indicated that conservation measures were required on more than 60% of the cropland (112 million hectares = 267.9 million acres) to reduce erosion losses to an acceptable minimum. During the past two decades renewed soil erosion has been reported in, among others, the prairie territories of the USSR (where events in the 1960s showed many similarities to the North American 'Dust Bowl' in the 1930s), New Zealand (Selby & Hosking 1973) and Brazil (Barker & Wünsche 1977). In the United Kingdom, instances of water erosion of arable soils in Scotland are quoted by Glentworth (1954), Glentworth & Muir (1963) and Ragg (1960, 1973). Water erosion of arable land in England is reviewed by Douglas (1969) and referred to by a number of writers; Low (1963, 1972), Mackney & Burnham (1966), Hodgson & Palmer (1971), Whitfield (1971), Evans & Morgan (1974), Morgan (1974, 1975), Catt, King & Weir (1975), Evans & Northcliff (1977), and, in Wales, Lea (1975).

When due consideration is given to the many inter-related factors which influence soil erosion by water on a particular site, the erosive forces of rainfall and run-off, the susceptibility of the soil to erosion, the length, gradient and shape of the site, the type of crop being grown, its stage of development and cultivation methods used, two factors appear most frequently: the extent of soil compaction and the presence of up-and-down slope cultivation. On more than six hundred sites in the West Midlands where water erosion has been recorded by the writer, soil compaction and down-slope cultivation lines were major contributory factors in over 95% of the cases. A number of research workers believe that soil erosion in the UK is widespread, occurs more frequently than is generally believed and is now cause for concern and action.

Over the years, the intensification of arable cropping has been accompanied by a reduction in the levels of organic matter and a deterioration in soil structure. These changes lower the resistance of some soils to the effects of natural compaction resulting from raindrop impact (splash erosion) and induced compaction from machinery. The difficulties of maintaining soil structure are increased by compaction caused by farm machinery which has become progressively heavier in the last 30 years, and research has shown that, when heavily laden wheels run over cultivated soils, bulk density increases can be detected to the depth of ploughing. The values for bulk density and air-filled porosity which have been measured in the crop root zone following compaction

suggest that adverse crop responses are likely to result, especially during periods of high soil moisture content (Soane 1970). However, the problem of poor crop responses as a result of compaction is small in comparison to the potential danger of accelerated run-off through compaction, which can occur even on gently sloping sites (2–3 degrees) during periods of heavy rainfall. Whereas compaction problems can be rectified by subsequent cultivations, the effects of marked erosion episodes are more serious, wide ranging and long-lasting. The most graphic examples of this problem have been seen in the West Midlands on land sown to sugar beet when two erosion episodes occurred in one season during the early stages of crop growth and during and after harvesting.

The preponderance of low-intensity rainfall is considered to be one of the major factors which minimise the risk of soil erosion in the United Kingdom. There is also the implication that erosion only occurs during periods of high intensity rainfall and, as many of these events tend to be infrequent and short-lived, the erosive effect is very localised. Davies, Eagle & Finney (1972) contend that, by the standards of continental climates, the rainfall of the British Isles is almost always comparatively gentle... "and surges of run-off water, which in the USA can gully a field to depths of more than one foot in a single storm are practically unknown (in the British Isles) and there is no serious risk of erosion except on steep slopes". They further state "that there is no reason to believe that the British climate is likely to change radically, and it can be concluded that the risk of water erosion is not likely to get worse in the future... as at present only very infrequent erosion is likely to occur on sloping land on sandy areas".

The issue, however, is not whether the British climate is likely to change in the future but whether the small aberrations in the present pattern of weather and the adverse effects which they can exert on agriculture are fully understood. Instances of surges of run-off water during storms which gully fields below the Ap horizon (plough horizon) and indeed into the B and C horizons, are not uncommon in the West Midlands even on gently and moderately sloping land (2–7°) and have been reported elsewhere in the United Kingdom. Currently there is a greater chance of low-intensity rainfall being potentially more erosive because of the combined effects of low soil organic levels, loss of structure and increased compaction, which in turn lead to reduced water infiltration into the soil and, consequently, the risk of ponding or run-off. The effects of run-off are increased where fields have been enlarged and slope length and water catchment increased. The enlargement of fields in which continuous arable cropping is practised has also increased the risk of wind erosion on susceptible soils. The full impact of these changes is not realised until an

adverse season is experienced such as that of 1968–69 and more recently, 1976. The evidence to substantiate the view that soil erosion by water is more widespread in lowland Britain is derived from a number of areas in general and from the West Midlands in particular.

Soil erosion in the West Midlands

Although there was substantial evidence of erosion on the Clee Hills, Cannock Chase and on some common land used as amenity areas, the most widespread incidence of erosion was found on agricultural land. A survey carried out during the period 1966–1970 recorded evidence of erosion, predominantly by rainfall and run-off, in Herefordshire, Staffordshire, Shropshire, Warwickshire and Worcestershire where the soils were sandy or silty in texture and the terrain was characterised by gentle or moderate slopes (2–7°). Wind also affected a large area of sandy textured soils, particularly of the Newport, Bridgnorth and Crannymoor series; reference is made to soil erosion on these series and others within the region in a number of Soil Survey Reports. Mackney & Burnham (1966) report soil erosion in the Church Stretton district of Shropshire affecting soils of the Munslow series (silt loams) on sloping land of 3–11° during periods of heavy rain in the spring and summer. Hodgson (1972) refers to spectacular erosion affecting Munslow soils during heavy spring or summer rains on fallow or partially covered soils, and widespread erosion of soils of the Bromyard (fine silty) and Eardiston series (fine and very fine sandy loams). Hodgson & Palmer (1971) describe erosion by rainfall and run-off on the Eardiston series and Munslow series to the south of Hereford, recording both sheet and gully erosion affecting Bromyard series (silt loam) and the Ross series (sandy loam). Whitfield (1971) describes serious rill erosion on soils of the Ross, Eardiston and Sellack series (sandy loam–loam) of the Ross-on-Wye area of Herefordshire. Palmer (1972) again cites soils of the Eardiston and Bromyard series as being prone to sheet and gully erosion when sloping land is cultivated and capping is considered to be a serious problem on silt loams of the Dove series. Hollis & Hodgson (1974) refer to spectacular gully erosion occurring on the fine sandy loams of the Bromsgrove series near Kidderminster (Worcestershire). These soils are liable to blow and are considered to be very susceptible to both water and wind erosion. Whitfield (1974) and Whitfield & Beard (1975) describe nine soil series near Leamington Spa and Alcester in Warwickshire which are affected by loss of structure and “capping” and a further five series which have a high risk of structural damage. Jones (1975) describes soils in the Eccleshall district of Staffordshire, cites erosion of the Bridgnorth and Wick series (sandy loams) and considers that four other series (Bromsgrove, Newport, Arrow and Ollerton—all sandy loams) have minor erosion hazards on slopes and are affected by weak structure, slaking and capping.

Although in each year of the survey erosion was observed on new as well as on known sites, by far the greatest amount occurred during the 1968–69 period and again in 1976 when it could be described as ubiquitous in the West Midlands. Bleasdale (1974) considers 1968 to be an outstanding year for multiple events with exceptionally heavy and widespread rainfall, and he regards that year as unique during more than 100 years of well-

documented rainfall history. The record-breaking drought of 1976 was followed by a very wet autumn when the combined England and Wales rainfall of 313 mm for September and October together exceeded the previous highest since 1727 of 310 mm in 1903 (Royal Society 1977). During the spring and early summer of 1968 there were some marked dry spells with strong winds which caused severe wind erosion in Eastern England and, to a lesser degree, in parts of the West Midlands.

During the West Midland survey, attention was focused on an area of approximately 800 square kilometres, broadly delineated as East Shropshire, lying west of Wolverhampton and reaching to the Severn Valley at Bridgnorth (Figure 1). Newport and Kinver respectively locate the northern and southern extremities. The arable parts of this area proved to be particularly susceptible to erosion by wind and water.

A smaller area of approximately 280 square kilometres was selected in East Shropshire and three “arable” parishes, namely Claverley, Rudge and Worfield, were chosen for an erosion monitoring case study. Though much of the land is below 150 metres it is well dissected and the steeper slopes are associated with the valley sides of the River Severn and its tributaries and with outcrops of Triassic and Carboniferous rocks which form low ridges and plateaux. Undulating land characterises much of the Severn-Worfe lowland which is predominantly below 91 metres and this is one of the areas largely affected by soil erosion. Sandy textured soils (loamy



Figure 1 Location area studied, East Shropshire, West Midlands.

sands, sandy loams) with varying amounts of stones predominate in this area overlying sandy clay and silty clay till, sands and gravels and outcrops of Triassic and Carboniferous rocks. Over much of this area the average annual rainfall is some 693 mm (27 inches) with totals for individual years ranging from 558 mm (22 inches) to 1,016 mm (40 inches) and, in seven years out of ten, there is a soil moisture deficit of over 100 mm per annum. A wide variety of crops are grown, with grain, sugar beet and potatoes being important.

A conservative estimate of the total area affected by erosion during 1967–1976 (Table 1) probably represents an underestimate of total erosion, for it proved impossible, on some occasions, to monitor the entire area after closely-spaced erosive rainfall events. Of the total arable area of each parish 27%, 17% and 38% respectively was affected by both wind and water erosion. These data were compiled by summing the area of all the fields eroded in each parish during the stated period. As the actual removal of soil by erosion affected less than the total area of some fields, the figures quoted represent a qualitative statement of the area *affected by* erosion rather than the total area of eroded soil. These figures reveal only part of the erosion story as they represent one erosion event per field during the decade. For example, a proportion of fields was eroded on at least one occasion in each year of the survey, and some registered even higher totals of up to twenty occasions during the decade. Examples of the latter may be found on the moderate to strongly sloping land (4–11°) of the Worfe valley and its tributaries, particularly in fields which are in continuous arable cropping.

Monitoring of soil erosion and the analysis of rainfall records (daily and autographic data) have revealed that falls of rain at intensities sufficient to cause erosion are not uncommon and are usually well-distributed throughout the year. The question of what constitutes erosive rainfall in terms of intensity and duration needs to be considered in the context of arable soils and, in particular, soil, site and management factors which tend to affect run-off. In general terms rain which falls at a rate greater than the infiltration capacity of the soil is considered to be potentially erosive, particularly on sloping sites. The infiltration rate of an arable soil is influenced by a number of factors which include soil



Figure 2 Sheet and incipient rill erosion along tractor wheelings running parallel to slope. Sugar beet, slope 4°, sandy loam. Rainfall 12.2 mm (11 May 1967), 26.9 mm (12 May 1967). Average rate 1.5 mm per hour. Parish of Claverley.

texture, degree of surface and sub-surface compaction, the amount of cover afforded by crops and crop residues, antecedent moisture and methods of cultivation. Soils which are characterised by weak structure and continuous arable cropping are particularly prone to damage by splash erosion which results in surface sealing and 'capping'. The impact of falling rain-drops pulverises and disperses weakly structured soil aggregates and leads to the suspension of fine particles in the water which causes a reduction in porosity when they enter the soil interstices. Such action results in a closer packing of particles and the formation of a thin crust or cap when the soil surface dries out.

Observations of erosion episodes in East Shropshire on compacted sandy and silty loams and loamy sands indicate that the threshold level of intensity at which rainfall becomes erosive is reached at 1 mm per hour or more and is usually associated with rainfall totals reaching or exceeding 10 mm. A 10 mm rainfall in five hours is sufficient to cause splash erosion and initiate sheet erosion with pockets of coarse sand trapped in the depressions made by tractor wheelings. Where cultivation lines run in the direction of slope, run-off water is channelled along tractor wheelings, and incipient rills develop (Figure 2). Initially, no reason could be advanced for the apparent haphazard development of small rills which, at this stage, were contained within the wheel depression. Some wheelings showed more rill development than others, even on the same section of a long, straight slope. In some sets of wheelings the lug pattern remained intact while in others it was virtually destroyed. Closer inspection revealed that well-developed rills were associated with tractor wheelings moving in a down-slope direction, which left behind lug imprints with a 'V' pattern, whereas less-developed rills were associated with tractor wheelings moving up-slope leaving a lug pattern in the form of an inverted 'V' (Figures 3, 4). The down-slope 'V' pattern provides a ready-made channel, as one arm of the V is shorter, leaving a 3 cm gap at the apex of the V through which run-off water can

Table 1
East Shropshire Parishes – Claverley, Rudge, Worfield
Total area affected by accelerated erosion (1967–76) based on parish agricultural statistics for 1969

Parish	Total hectares crops and grass	Total hectares arable	Total hectares eroded	Wind erosion	Water erosion
1 Claverley	2952	1780	492 (27%)	12%	88%
2 Rudge	483	296	50 (17%)	6%	94%
3 Worfield	3247	2021	782 (38%)	33%	67%



Figure 3 Tractor wheelings and beet seed drill tracks in loamy sand. The right-hand wheeling with the eroded "V" shaped lug pattern (and incipient rilling) was made by a tractor wheel moving down-hill during sowing. The left-hand wheeling has been made subsequently by a tractor moving uphill producing a lug pattern in the form of an inverted "V". Metre rule for scale.



Figure 4 Tractor wheelings and beet seed drill tracks in loamy sand, the surface of which has been affected by splash erosion. The lug imprints which "V" downhill postdate the beet seed drill tracks and are associated with subsequent spraying operations.

concentrate; whereas, the inverted 'V' pattern tends to have the opposite effect, dissipating water movement and deflecting it to the side of the track.

Most soil erosion events have taken place when rainfall totals have reached or exceeded 10 mm. Analysis of daily rainfall records (manual gauges) for local stations with over 35 years of data provides a useful insight into the number of occasions per annum when daily totals reached or exceeded 10 mm, though this does not imply that all these events were erosive. Rather, it enables some comparison to be made with autographic data which is available for shorter periods, but where intensity and duration periods are known for each 10 mm fall. Daily rainfall figures for one station, Hatton Grange (SJ 766 043), near Shifnal, East Shropshire (80 metres AMSL, annual average rainfall 692 mm, recording period 1900–1978) show that during the recording period 10 mm falls or more occurred on average of 16 occasions per annum with high and low values for individual years of 30 and 6 respectively. Throughout the entire recording period there are peaks for May (100), July (120), August (123), October (117). In any year an increase in the number of rainfall events (10 mm) will add appreciably to the risk of soil erosion, particularly during spring and early summer on exposed or partially exposed soils. An increase in the number of rainfall events in the autumn and early winter increases the risk of soil erosion on compacted beet and potato fields and can cause serious damage to land prepared for, or sown to, winter grain. Autographic gauges show that, in many of these 10 mm events, rain falls as short but fairly intense showers.

A number of fixed plot experiments were carried out in 1975 on a farm with a marked erosion problem in an attempt to assess threshold values for the erosion of compacted and uncompacted fallow sandy soils. Preparation for new plots commenced in June 1976 with the ploughing of a 9° slope, 60 metres long and 10 metres wide. This plot was rotovated for the first time towards the end of September 1976, producing a friable and spongy surface which contained a lot of partially-decomposed pieces of turf. Prior to ploughing, the slope had been in grass for six years and the organic matter content was 5–6% (loss on ignition). It is important to note that there were no wheelings visible or apparent

signs of compaction, though penetrometer readings indicated the presence of a plough pan. Although sections of the slope are stony very few were apparent on the surface of the soil. Heavy rains associated with a thunderstorm commenced on the evening of the 24th and continued into the 26th, with a succession of storms yielding between 2.5 and 7.6 mm/hr. The total fall amounted to 83 mm (3.26 inches) and caused extensive erosion in East Shropshire. The newly rotovated plots eroded and a network of well-defined rills appeared 8–13 cm deep and 9–15 cm wide, terminating in small fans of coarse sand and grit. No estimate can be given of the amount of material deposited in the fans as they were dissipated into long grass at the lower margin of the plot, but it is estimated that the soil surface settled 9–10 cm (natural compaction); most of the small soil aggregates appeared to have been dispersed and abundant washed stones were apparent on the surface of the plot.

In adjoining fields these storms produced more spectacular erosion with well defined deep gullies and huge overlapping fans (Figures 6, 7). In one field of 6.64 hectares with a convex-concave slope of 7° and the largest section above this sloping 2 to 3°, large gullies developed along tractor wheelings which ran parallel to the slope over the entire length of the field. The largest gullies ranged from 1–1.5 metres deep and 1.5–2 metres wide and developed headward on the steepest section of the slope excavating beds of rythmites and sand and gravel. Large overlapping fans developed against the hedgerow and one section 120 metres wide averaging 20 metres long with an average depth of 20 cm gave a total of approximately 480 m³ of material. The bulk density of coarse-textured soils is in the range of 1.3–1.8 and, taking the average figure of 1.55, this would yield 744 tonnes (or 112 tonnes per hectare). Another large fan associated with a single deep gully (Figure 8) measured 48 metres by 20 metres with an average depth of 20 cm. It is estimated that the fan contained 192 m³ or 297.6 tonnes, equivalent to 44.8 tonnes per hectare. The two fans represent material equivalent to approximately 156 tonnes per hectare. Even so it is difficult to estimate the gross tonnages of material moved, as large quantities were swept through the hedge into the field below and either deposited as fans, or as deltas into the flooded



Figure 5 Severe rill and gully erosion affecting a 14.8 hectare (36.8 acre) field prepared and part sown to winter barley. Formerly two fields – tree marks line of one field boundary. Soil is stony sandy loam/loamy sand. Slope in foreground 10°, background 2–3° 24–26 September 1976. Parish of Worfield.

stream, or carried away entirely. Estimates of materials left behind would indicate another 60 tonnes per hectare of eroded soil. Intermittent erosion continued on this field and a subsequent storm in November 1976 yielded 9.8 mm in 2 hours with 7.8 mm falling in one hour and renewed gullying and deposition. Eventually, in February 1977, a bulldozer was used to fill in the gullies and now the steeper sections of the field have been grassed over. Sheet and rill erosion has occurred on this field every year during the survey and, in July 1977, parts of the field were again badly affected by gully erosion.

Many other instances of serious gullying could be quoted resulting from the storms of September 1976. During the survey period over 50 sites were recorded, with gullies excavating either the B or C horizon of soils (see Figure 5). Erosion sequences, which involve extensive rilling or gully development, bring about a significant redistribution of soil material which is of considerable agricultural significance. On the steeper slopes erosion removes soil at a much faster rate than it can be renewed and eventually results in shallower soils. Down-slope deposition can result in more fertile soils receiving an overwash of subsoil materials such as coarse sand. Large quantities of fine sand, silt and clay together with organic matter can be washed out and transported into the drainage system and are lost forever from the eroded fields. As gully erosion is not uncommon in the West Midlands and is reported by other workers in England (Evans & Northcliff 1977, Foster 1977, Morris 1942,

Cole 1910) there is a need for a closer examination during soil surveys of the characteristics and potential erodibility of sub-soil materials on moderate to steep slopes utilized for arable agriculture, as all such slopes are potentially at risk.

It is debatable whether this area of East Shropshire has a unique combination of factors which leads to erosion hazard or whether this particular monitoring technique, if applied to other areas with similar sandy soils, landforms, cropping sequences and management practices would also point to the presence of soil erosion.

Water erosion of arable soils elsewhere in the United Kingdom

Other parts of the United Kingdom are affected by water erosion. Evans & Morgan (1974) describe spectacular erosion near Balsham in south Cambridgeshire on shallow loamy soils of the Swaffham Prior association on slopes of 4–5° planted with beans and sugar beet. An estimated 3.3 tonnes/hectare of soil was deposited during a thunderstorm which yielded 7.4 mm of rain over Cambridge 13 km



Figure 6 Severe gully erosion at Hilton. Loamy sand over sand. Large single gully 1.5 m deep, average width 1 metre. Parish of Worfield 24–26 September 1976.



Figure 7 Severe gully erosion at Hilton and base-of-slope fans. Figure 6 is located at right-hand side of field.

to the north-west. Further erosion was noted near Abington, Cambridgeshire on slopes of less than 2° on compacted ground sown to turnips. Morgan (1974) refers to sheet and rill erosion in the Silsoe area of mid-Bedfordshire on sandy loams derived from the Lower Greensand (Cottenham, Flitwick and Oak Series) when 17.7 mm of rain fell in 30 minutes causing some minor roads to be partially blocked with sediment. Catt *et al.* (1974) describe soil erosion affecting soils of the Cottenham series (Brown sand on Lower Greensand) and the Stackyard series (Brown earth on sandy colluvium) at Woburn Farm, when exposed to heavy rain. One example quoted occurred during a storm in May 1973 when over 50 mm rain fell in an hour, causing severe sheet erosion in a field of potatoes (slope $1-3^\circ$) with several centimetres of surface soil and many young potato plants being washed out. The inherent erodibility of the soils on the Lower Greensand when exposed to heavy rain and the influence of surface and sub-surface compaction by heavy machinery are considered by the authors to be causal factors.

Douglas (1970) cites a number of examples of soil erosion by water ranging from small gullies 0.35 m deep in winter wheat on chalk near Horncastle, Lincolnshire (April 1939) to 4 m deep gullies which developed in a crop of young turnips growing on the slope of a drumlin near Blaydon, Co Durham following a thunderstorm on 22 June 1941, when almost 80 mm of rain fell in 2 hours. Rogers and Greenham (1948) described erosion caused by a heavy storm in a young plantation on sandy soil at East Malling and also at Larkfield, Kent. They comment on the siting of fruit plantations on hillsides in order to lessen risk of frost damage, and how this has made soil erosion a more serious problem. Low (1963) reports erosion of silty loam soils on a newly-planted apple orchard at Jealott's Hill Research Station, when the first winter's rain produced many tons of washed soil down slope (concentrated along cultivation lines paralleling the slope) which necessitated the use of a bulldozer to return the material back up-slope. He also refers to rill erosion in sandy loams of the Berkhamsted series and sheet erosion in the Hildenborough series at Fernhurst, Sussex (Low 1972).

In a survey of poor soil and crop conditions in Lincolnshire and Nottinghamshire, Archer and Wilkinson (1969) refer to sheet or gully erosion, on undulating

ground, causing damage to small seedlings, particularly sugar beet. In the Ollerton district of Nottinghamshire, sandy soils of the Newport series cover an area of 3990 hectares (9859 acres) and some 40% of the survey area (Robson & George 1971). The soils are prone to wind erosion with severe blows resulting in the loss of fine earth and abrasive damage to seedlings being expected once every five years. However, Robson and George consider that the cumulative effect of annual rainwash (mean annual rainfall 640 mm, 25 inches) on arable land may reduce the productivity of Newport soils more than the dramatic but rarer blows. South of Derby in the Melbourne area, Reeve

(1975) records erosion affecting the Worcester series (clay loam) after heavy spring rain, and the same thing on strongly sloping land which carries the shallow phase of the Rivington series (coarse loamy) which is prone to erosion when intense rain follows compaction resulting from spring harvesting of horticultural crops.

Clayden (1964, 1971) refers to soils in Devon around the middle Teign valley and the Exeter districts where arable cultivation on moderate to strongly-sloping ground with a long tradition of barley growing has led to a moderate degree of soil erosion. He also considers sheet and gully erosion to be a hazard on virtually all the cultivated land around Exeter, and that erosion is likely to be more serious where steep slopes are cultivated. In another part of Devon, near Honiton, erosion is considered to be a hazard on sloping sites used for intensive arable cropping on soils of the Bridgnorth series (Harrod 1971).

Any attempt at this stage to map the distribution of soil erosion in the United Kingdom must be tentative as the data available are still fragmentary. Apart from a limited number of papers dealing specifically with soil erosion, the researcher must rely on data from soil survey memoirs and records, which only cover a relatively small part of Britain. Whereas it is possible to identify and locate some of the areas affected by erosion, it is more difficult to obtain details of frequency of occurrence and quantities of eroded material as these are rarely referred to in soil survey publications. However, if weakly-structured soils are known to erode when under continuous arable cropping in one area, it is reasonable to assume that they may well be at risk in other areas where land forms, rainfall and management are broadly similar, and this is particularly so in adverse seasons. The chances of detecting soil erosion particularly by water tend to be minimised by a number of factors. One is access, as much arable land in the UK is still relatively inaccessible, especially if the researcher is relying upon chance sightings of erosion from roadways. This disadvantage can be partly offset by using aerial photography but, unless this is specially flown for erosion survey work, most of the available sorties at the scale of 1:10560 are of limited value.

There are also significant differences between the chance recording of wind and water erosion. When wind erosion occurs on arable soils its effects are often

spectacular, both during and after the event and, in a severe blow with thousands of hectares affected, it is likely that a large number of observers will witness the event over many miles and see the aftermath of drifted soil against hedgerows, in ditches and over roads. Herein lies a significant difference between wind and water erosion as the latter is rarely observed in the making and, with the possible exception of the more dramatic examples of gully erosion, the effects are not always easily recognised in the field, as evidence can be quickly eradicated by cultivation and partially masked by crop growth.

There is now sufficient evidence to suggest that the rather complacent approach to the question of soil erosion in the United Kingdom should be replaced by a more positive one of adopting conservation measures to protect arable soils before erosion becomes a major problem. The question of what constitutes acceptable levels of soil erosion on arable soils will remain unanswered until a programme of erosion-monitoring at regional and national levels is initiated and some assessment made of the extent of the problem. Ideally this should include experimental work on a range of soils which are known to be unstable when in continuous arable cropping, so that some estimate could be obtained of the erosion rates likely to occur on various sites under different cropping sequences and management practices.

In practical terms many farmers are unaware of the long-term implications of soil washing and blowing in respect of farm profitability, the social costs generated by increased silting of waterways and drainage channels, and the pollution of water supplies by washed-off fertilizer.

Basic conservation measures which can be employed, include the avoidance of wholesale removal of hedgerows, particularly where there is a potential risk of wind erosion. The removal of hedgerows subdividing long slopes should be kept to a minimum and, where removal has taken place, cultivation and strip cropping parallel to the contour will help to reduce the effects of run-off. Up-and-down-slope cultivation should be avoided wherever possible, even on gentle slopes and, where it is practised, the adoption of some device on tractors (e.g. one small tine mounted behind each rear wheel to break up the surface of wheelings) would help in reducing surface compaction and run-off which is concentrated along wheel tracks. Soils which are susceptible to structural damage, when exposed to heavy rainfall, or are liable to wind erosion should not be left fallow for longer periods than necessary, and field operations should be kept to the minimum when the upper layers of the soil are too moist.

All the available evidence suggests that the intensification of arable cropping will continue in the 1980s and beyond, and it is feared that this will be accompanied by an extension of soil structural problems which will, in turn, increase the risk of soil erosion, particularly in



Figure 8 Large single gully at Hilton 2.5 metres wide 1.5 metres deep. Large fan can be seen at base of slope. Ranging pole as scale.

unfavourable seasons. Hopefully, management techniques will be adopted which will continue to increase the productivity of the land and at the same time conserve soil resources.

One of the most promising soil conservation developments in the last decade has been the no-tillage (direct drilling) method of crop production which Young (1973) estimated was then used to produce some 2 million hectares of crops, mostly grains—in the United States*. Young lists the physical advantages of no-tillage as including: reduction of wind and water erosion, conservation of soil moisture and maintenance and improvement of soil structure. Of the various economic advantages which accrues he cites the new cropping combinations made possible on many farms previously limited to less diversity of cropping because of erosion risks, and the opportunity to grow high value row crops on land previously considered as usable only for pasture or hay because of wind or water erosion hazards.

The introduction of effective herbicides in the 1950s which reduced the weed problem, paved the way for the successful introduction of direct drilling. Cannell and Finney (1973) quote Denning's estimate of about 400,000 ha of cereals which were then grown in the UK after some form of minimal cultivation. Direct drilling then only accounted for about 55,000 ha of which about one third were cereals, but this area has grown significantly in the last few years†. Allen (1975) describes direct drilling of sugar beet into 'blow sands' and 'blow fen' soils in Eastern England. In a pilot scheme on about 40 hectares, rye stubble was desiccated with paraquat and was direct drilled with sugar beet in spring 1975 following a method now used commercially by the Dutch on their very light soils.

Although still in its infancy this method offers the dual advantages of erosion control and timeliness of planting as well as increasing farm productivity, which must appeal to farmers and conservationists alike.

*Estimate for 1978 is 3.2 million ha (Lessiter 1978).

†An ICI survey showed some 204,049 ha of crops were direct-drilled in the UK in 1977.

References

- Allen H P (1975) *Outl. Agric.* 8, 215
- Archer J R, Wilkinson B (1969) *Survey of poor soil and crop conditions in Lincolnshire and Nottingham 1969*. NAAS, East Midlands Region. p. 8
- Barker M R, Wünsche W A (1977) *Outl. Agric.* 9 (3), 114
- Bleasdale (1974) *British Rainfall 1968*. Meteorological Office, HMSO, London, p. 223
- Cannell R Q, Finney J R (1973) *Outl. Agric.* 7, 184
- Catt J A, King D W, Weir A H (1971) *Rothamsted Exp. Stn Rep for 1974*, Part 2. p. 23
- Clayden B (1964) *Soils of the Middle Teign Valley District of Devon*. Rothamsted Exp. Stn, Harpenden. p. 73
- Clayden B (1971) *Soils of the Exeter District*. Rothamsted Exp. Stn, Harpenden. p. 212
- Cole E M (1910) *Naturalist*. p. 255
- Davies D B, Eagle D J, Finney J B (1972) *Soil management*. Farming Press Ltd, Ipswich, UK. p. 226
- Douglas I (1969) P. 58 in *The role of water in agriculture*. Taylor J A (Ed) Pergamon Press, Oxford
- Evans R, Morgan R P C (1974) *AREA* Institute of British Geographers. 6 (3), 221
- Evans R, Northcliff S (1977) *J. agric. Sci. Camb.* 1978. 90, 185
- Foster S W (1977) An example of gullying on arable land on the Yorkshire Wolds. Univ. of Hull (unpublished)
- Glentworth R (1954) *The soils of the country around Banff, Huntley and Turriff*. Macaulay Inst. for Soil Research, Aberdeen. p. 122
- Glentworth R, Muir J W (1963) *The soils of the country around Aberdeen, Inverurie, and Fraserburgh*. Macaulay Inst. for Soil Research, Aberdeen. Pp. 104 and 178
- Harrod T R (1971) *Soils in Devon I*. Soil Survey Record No 9, Sheet ST 10 (Honiton). Rothamsted Exp. Stn, Harpenden. p. 30
- Hodgson J M (1972) *Soils of the Ludlow District*. Rothamsted Exp. Stn, Harpenden. p. 50
- Hodgson J M, Palmer R C (1971) *Soils in Herefordshire I*. Soil Survey Record No 2. Rothamsted Exp. Stn, Harpenden. p. 25
- Hollis J M, Hodgson J M (1974) *Soils in Worcestershire I*. Soil Survey Record No 18. Sheet S.O. 87 Kidderminster. Rothamsted Exp. Stn, Harpenden. p. 38
- Jones R J A (1975) *Soils in Staffordshire II*. Soil Survey, Record No 31. Sheet S.J. 82 Eccleshall. Rothamsted Exp. Stn, Harpenden. p. 120
- Lea J W (1975) *Soils in Powys I*. Soil Survey Record No 28. Harpenden. p. 71
- Low A J (1963) P. 55 in *Crop production in a weed free environment*. Blackwell Scientific Publications Ltd, Oxford
- Low A J (1972) *J. soil Sci.* 23 (4), 363
- Mackney D, Burnham C P (1966) *Soils of the Church Stretton District of Shropshire*. Rothamsted Exp. Stn, Harpenden. p. 85
- Morgan R P C (1974) *Geogr. Mag. Lond.* 47, 528
- Morgan R P C (1975) *Geogr. Mag. Lond.* 47, 360
- Morris F G (1942) *Geogr. J.* 100, 257
- Palmer R C (1972) *Soils in Herefordshire III*. Soil Survey Record No 11. Sheet S.O. 34 Staunton on Wye. Rothamsted Exp. Stn, Harpenden. p. 56
- Ragg J M (1960) *The soils of the country around Kelso and Lauder*. Macaulay Inst. of Soil Research, Aberdeen. p. 96
- Ragg J M (1973) P. 48 in *The organic resources of Scotland*. Tivy J (Ed). Oliver & Boyd, Edinburgh
- Reeve M J (1975) *Soils in Derbyshire II*. Soil Survey Record No 27. Sheet S.K. 32E/42W Melbourne. Rothamsted Exp. Stn, Harpenden. p. 28.
- Robson J D, George H (1971) *Soils in Nottinghamshire I*. Soil Survey Record No 8. Sheet S.K. 66. Ollerton. Rothamsted Exp. Stn, Harpenden. p. 26
- Rogers W S, Greenham D W P (1948) *J. R. agric. Soc.* 109, 194
- Selby M J, Hosking P J (1973) *J. Hydrol. N.Z.* 12 (1), 32
- Soane B D (1970) *J. Proc. Instn agric. Engrs.* 25, Part 1-3, 115
- The Royal Society (1977) Scientific aspects of the 1975-6 drought in England & Wales. A meeting for discussion on 28 October 1977
- USDA (1965) *Soil and water conservation needs—a national inventory*. Misc. publ. 971, Washington
- Whitfield W A D (1971) *Soils in Herefordshire II*. Soil Survey Record No 3. Rothamsted Exp. Stn, Harpenden. p. 44
- Whitfield W A D (1974) *Soils in Warwickshire I*. Soil Survey Record No 19. Sheet S.P. 36 Leamington Spa. Rothamsted Exp. Stn, Harpenden. p. 86
- Whitfield W A D, Beard G R (1975) *Soils in Warwickshire II*. Soil Survey Record No 25. Sheet S.P.05 Alcester. Rothamsted Exp. Stn, Harpenden. p. 96
- Young H M (1973) *Outl. Agric.* 7, 143