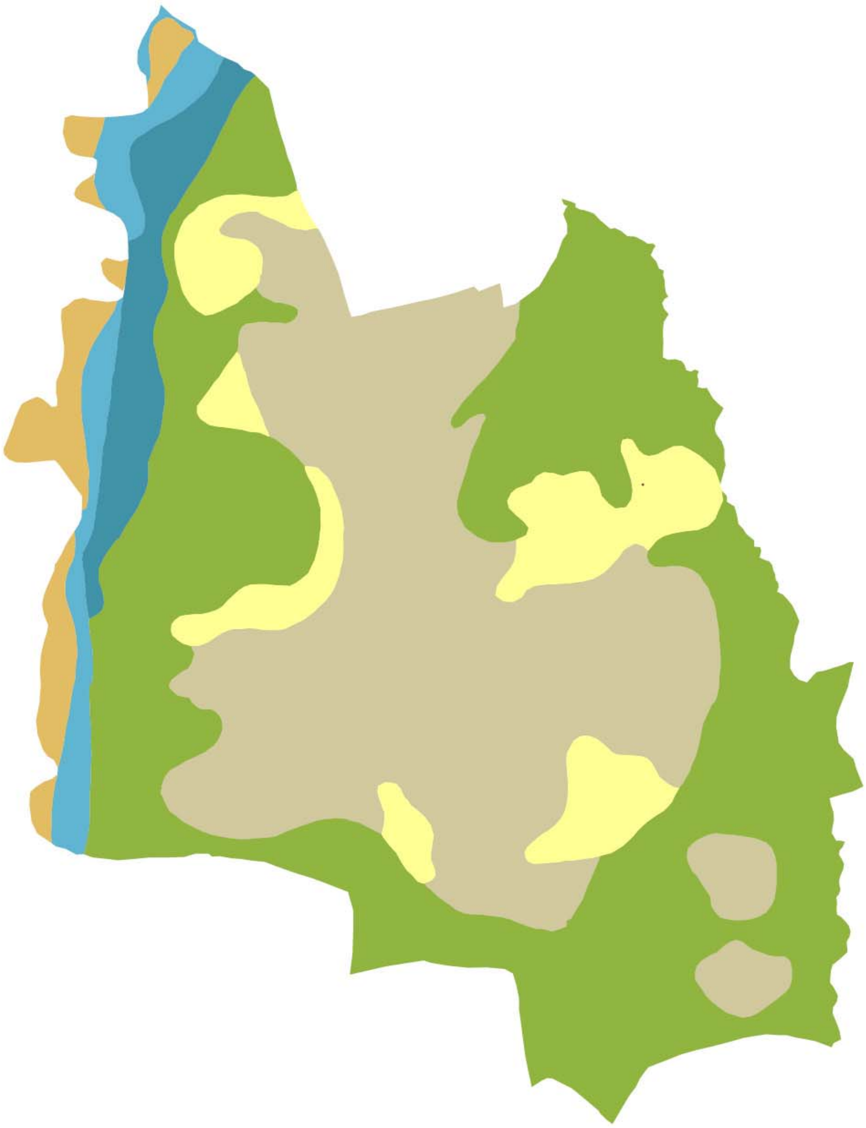
Harrod, T. R. and Hogan, D. V. 2008. The soils of North Wyke and Rowden. *Soil Survey of England and Wales.* pp. 1-54.

THE SOILS OF NORTH WYKE AND ROWDEN

By T.R.Harrod and D.V.Hogan (2008)

Revised edition of original report by T.R. Harrod,
Soil Survey of England and Wales (1981)



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PREFACE

A soil survey of North Wyke was begun in 1954 for Fisons Ltd by the Soil Survey of England and Wales (C.J. Tapp and D.C. Findlay) and completed in 1957 by Findlay and B. Clayden. However, equivalent detailed information was not available for Rowden and Falcadon Moors until T.R. Harrod's (1981) report, when both blocks of land came under Grassland Research Institute management. Additionally during those intervening years, ideas on the classification of soils and their use had developed, several detailed surveys on comparable soils had been made in Devon, and a survey of the geology of the Okehampton area was published. Consequently the 1981 report, while incorporating the original soil survey, involved some updating of it, together with interpretations for practical applications of the primary soil information. Armstrong *et al.* (1984) provide some history of the land at Rowden, and give details of the experimental design and drainage works carried out in the summer of 1982 for a grassland drainage economics study. The drained plots were moled immediately after installation of the underdrainage. For comparison, the most recent drainage improvement works, including re-moling, undertaken at Rowden are described by Hatch and Hawkins (2007).

Since 1981, IGER North Wyke (becoming North Wyke Research in 2008) has established itself nationally and internationally as a research centre for pastoral land use systems, with the emphasis changing from predominantly agricultural production to one of more multi-functional land use taking account of wider environmental, social and economic considerations. In consequence it has become particularly important to optimise awareness and understanding of the soils of North Wyke as a vital primary natural resource.

The period since 1981 has also seen publication of the results of a national soil mapping programme, with consequent additional development of ideas on soil taxonomy and interpretation. Developments in information technology have changed methods of handling soil information and ways of presenting interpretations, though much field-based expertise has been lost as senior soil scientists and soil surveyors reach the end of their careers and are not being replaced in any number. This report has been produced in electronic format to facilitate its availability via appropriate channels. The soil maps have been digitised on the GIS at North Wyke to enable the future handling and analysis of these in conjunctions with other related spatial datasets.

1. INTRODUCTION

Chapter 1 of this report deals with the environmental background of the soils, briefly considering physiography, geology and climate. In Chapter 2 the soils are considered in detail with descriptions of profiles and their properties and their occurrence as map units. Relationships between soils and land use are described in Chapter 3, while Chapter 4 deals with the national context of the soils found at North Wyk, using information held on the national soils database (Land Information System) by the National Soils Resources Institute at the University of Cranfield. Additional information on these soils and their land use more specifically elsewhere in Devon is given in Clayden 1965 and 1971, Harrod 1976 and 1981.

1.1 Situation, relief and drainage

North Wyke is about 7km to the north of Dartmoor, midway between the villages of South and North Tawton in an area of dissected plateau country with summit levels about 200 m 0.D. drained by streams flowing northward from Dartmoor, notably the Okement and Taw, with their tributaries. North Wyke is sited on a spur projecting to the north from Dartmoor between the Taw and a right-bank tributary which joins the main river at Taw Mill. Most of the farm occupies the northern end of the spur which is separated from the main part of the feature by a saddle along the line of Cocktree Throat.

The highest point within the farm boundary is a little over 180 m O.D. near the farm buildings, from there the ground slopes gently (about 3-5^0) northwards to the lowest point (126 m) at Pecketsford

Bridge; in the opposite direction, slopes are a little more pronounced. The steepest slopes, in the order of 10^0, are facing east and west where the convex upper slopes drop away rapidly into concave lower slopes and thence to the flatter fields in the valleys. As a result of these radiating slopes only about a quarter of the total area, i.e between the farm buildings and Cocktree Throat, has a favourable southerly aspect. The western boundary of North Wyke is formed by the River Taw which has reached a mature stage of development and meanders through a narrow flood plain about 400m wide. With the exception of a small meander terrace a little higher than the present flood plain no higher-level terraces are present.

The land at Rowden comprises part of a ridge centred near Beacon Cross. From this minor summit, the ground slopes away gently, mostly 2-5^o, relief being more subdued than at North Wyke.

1.2 Geology

Both North Wyke and Rowden are underlain by the Carboniferous Crackington Formation, a part of what geologists have long called 'Cu1m Measures'. The Crackington Formation comprises clay shales (locally known as 'shillot') with thin subsidiary sandstone bands. The shales which may be somewhat cleaved, are dark grey or black, but weather pale brown or buff. When waterlogged they break down readily to form clay, the clay minerals being predominantly illitic. Sandstone bands in the Crackington Formation probably comprise about a quarter of the sequence but are rarely thicker than 30-40 cm. As a whole the Carboniferous dips to the north and is affected by folds with east-west axes. The restricted number of local exposures, mainly in the river bed, indicate steep, near vertical dips, with some overturning. As over much of Devon *in situ* rocks are largely mantled with Head of varying (0.5-3 m) thickness. This is rock waste of local origin resulting from protracted frost working and solifluction during the Pleistocene.

A very small igneous dyke runs east north-east to west south-west across the ridge at North Wyke itself, the outcrop being partly picked out by quarried ground. The rock is altered by weathering from its original state (lamprophyre, a medium grained, intermediate igneous rock), and is not of account as a soil parent material here.

The valley of the Taw is floored by Recent deposits of gravel and sandy alluvium. The gravels consist mainly of grey or black, fine-grained sandstones, some hard metamorphic rocks probably from the Dartmoor aureole, and a minor amount of well-rounded granite cobbles, noticeably more weathered than the finer-grained rocks. The alluvium, where it forms levees, near the river banks, is a deep sandy loam containing mica and much clean, angular sand, typical of granite-derived material. Further away from the stream heavier textured alluvium is probably more locally derived from the Culm.

1.3 Climate

The climatic weather station at the farm (NGR SX 659983 - No. 8836) has been collecting data since 1960 and has been part of the Meteorological Office network since 1982. Long-term records quoted here use mean values for the 40 year period 1961-2000, together with some more recent information for the period 2001-2007.

1.3.1 Rainfall

The mean annual rainfall recorded is 1055.7m with monthly distribution shown in Table 1

Table 1 Mean monthly rainfall (mm) at North Wyke (1961-2000)

J	F	M	A	M	J	J	A	S	O	N	D
130	95	84	68	64	58	53	68	81	105	117	133

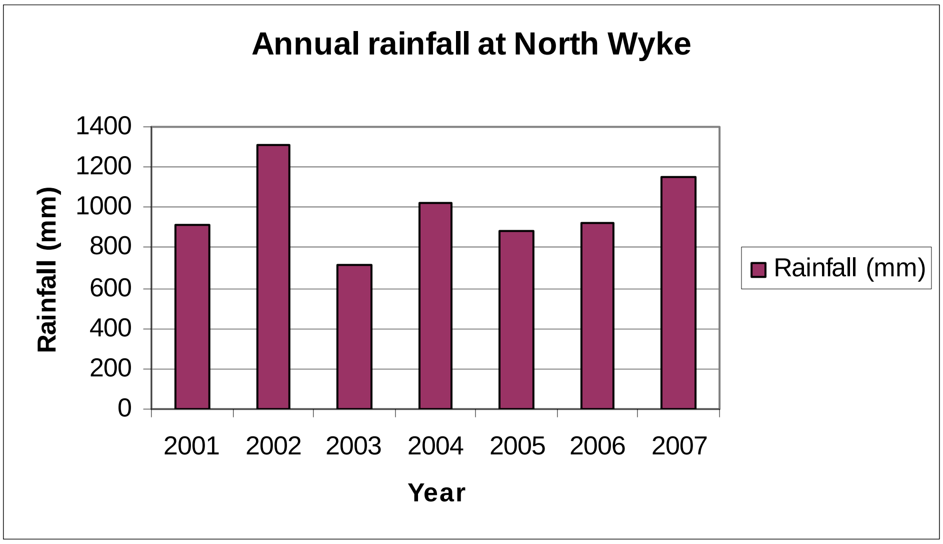
This shows a marked October to December maximum, and spring to early summer minimum, characteristic of the south west of England. Mean excess winter rainfall at North Wyke is 562 mm.

Only a small proportion of total rainfall is likely to be derived from convectional rain and the average number of days with thunder for the year is only ten (MAFF 1975). In the wettest four months there are likely to be 20 rain days (per month) whereas the average figure for June is 12. Yearly totals show a wide variation between the extremes of 1452.2 mm and 781.6 mm recorded for the period 1961-2000. However, the dominant factor is the excessive rainfall in early winter months. On average North Wyke has about 3 days a year in which the rainfall exceeds 25 mm.

In an average year a soil moisture deficit exists at North Wyke from the early April to mid October, with a maximum average deficit of about 181 mm at the end of August. For about 200 days a year field capacity or wetter conditions are predicted. However, when interpreting such data it important to bear in mind that meteorological calculations of soil moisture deficit and field capacity are based on models which assume free soil drainage. In practice at North Wyke, given the predominance of soils with impeded natural drainage, for a period of over 200 days in most years, soil conditions are such that soil structure and consequent capacity for infiltration are at risk of degradation by grazing or landwork, and the land is considered unsuitable for stocking and traffic.

Mean annual rainfall totals for the more recent period 2001-2007 are shown in Figure 1. Even this relatively short period of time shows considerable inter-annual variation between 1314.6 mm (2002) and 711.8 mm (2003)

Figure 1 Mean annual rainfall (mm) at North Wyke (2001-2007)



1.3.2 Temperature

W hile temperatures (MAFF 1976) are sufficient to sustain plant growth for an average of about 280 days a year, the grazing season is restricted to about 180 days, largely due to the heavy autumnal rainfall. Mean monthly temperatures at North Wyke are shown in Table 2.

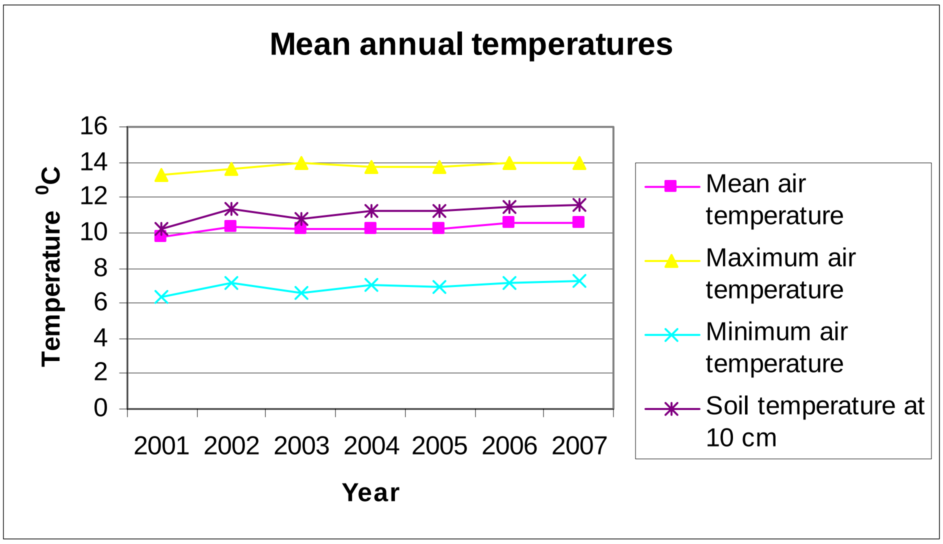
Table 2 Mean monthly temperatures (^{o}C) at North Wyke (1961-2000)

J	F	M	A	M	J	J	A	S	O	N	D	Year
4.6	4.5	6.1	7.8	10.7	13.5	15.5	15.4	13.4	10.7	7.4	5.6	9.6

The first screen/air frost may be expected in November, and the last after April, so that about 180 days are liable to frost, although usually only 30 days a year have air frost. On about two occasions a year the air frost persists throughout the day. Ground frost is far more frequent than air frost and can be expected on still clear nights in the spring and autumn. Air drainage probably makes the lower slopes of the farm particularly liable to frost.

More recent data (Figure 2) for the period 2001-2007 indicate a slight general rise in both air and soil (10 cm depth) temperatures.

Figure 2 Mean annual temperatures (^{0}C) at North Wyke (2001-2007)



1.3.3 Sunshine

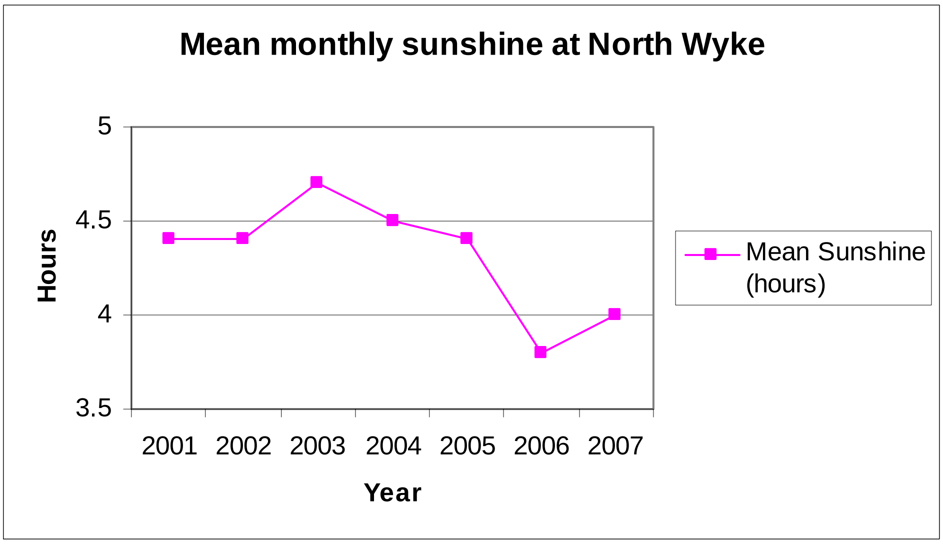
North Wyke is located approximately midway between the coasts of north Cornwall and south-east Devon. Bright sunshine at North Wyke is reduced by its inland position compared with more coastal locations. Data in Table 3 compare hours of bright sunshine recorded at North Wyke with those at Bude, some 30 miles to the west, though over a different duration of time. Maps of sunshine records (http://www.metoffice.gov.uk/climate/uk/averages) indicate the drier coastal effect to be narrower along the Atlantic compared with the English Channel coast, probably due to a combination of greater lapse rates with more rapid development of cloud in the west and the rain shadow effect of Dartmoor in the east. It can be seen that the main differences occur in spring and autumn.

Table 3 Mean daily hours of bright sunshine each month at North Wyke (1961-2000) and Bude (1971-2000)

Location	J	F	M	A	M	J	J	A	S	O	N	D	Year
N.Wyke	1.6	2.3	3.3	5.0	6.1	6.3	6.2	5.5	4.3	3.1	2.2	1.6	3.9
Bude	1.8	2.7	3.7	5.9	6.9	6.1	6.3	6.2	5.1	3.6	2.3	1.6	4.3

More recent data for North Wyke (Figure 3) indicate an overall decline in mean monthly duration of sunshine for the period 2001-2007, though considerable variation (between 3.8 and 4.7 hours) occurs from year to year.

Figure 3 Mean monthly hours of bright sunshine at North Wyke (2001-2007)



2. THE SOILS

2.1 Methods of survey and classification

Wherever possible, the survey of North Wyke (Findlay and Clayden 1957) was conducted by means of auger borings on a paced grid at a frequency of about 4 borings to an acre. In woodland and scrub, borings were less frequent and their distribution was more related to surface features than to a fixed grid. In mapping Rowden, observations were at National Grid 100m intersections supplemented by "free" checks wherever soil, slope or vegetation indicated the likelihood of a change. In addition, further observations were made at North Wyke to characterise some aspects of the units described in the earlier survey. This enabled amalgamation of several of Findlay and Clayden's units without alteration of mapped boundaries.

The soil classification used in this account is that used by the Soil Survey of England and Wales and its successor bodies the Soil Survey and Land Research Centre and more latterly the National Soil Resources Institute. The first stage, described by Avery (1973 and 1980), uses soil profile characteristics (distinguishing soil morphological properties and assemblages of horizons) as the basis for progressive subdivision of profile classes into *major groups*, *groups*, and *subgroups*). In the second stage, following Clayden and Hollis (1984), *soil series* are identified as divisions of Avery's subgroups differentiated by lithological characteristics, notably texture and parent material. Soil series are conventionally named after places where they were first identified or commonly occur. Within series, *phases* can relate to minor differences in soil profile morphology or site conditions.

Prior to the undertaking of the National Soil Map project [1979-83], soil surveying in this country had proceeded with detailed mapping of various areas, each more or less isolated from one another. Although rigorous definition of soil profile attributes, such as texture and structure, along with higher taxonomic categories (Avery, 1980), was applied, the same was not so for parent material or lithology. Indeed, following a long history of strong geological influence, geological age of parent material often remained as part of the definition of the basic unit of study, the *soil series*. Consequently essentially similar soils, for example typical brown earths on shaly or slaty parent material, had, by the 1970s, at least three separate series names in different parts of the country, namely Dunsford, Denbigh and Highweek series.

With the onset of the national mapping project, the rationalisation of definitions for parent materials and lithology was instigated by Clayden and Hollis (1984). They stressed the importance of parent material and lithological properties that affect the soil profile's character, with considerations of geological age being largely abandoned. Applying Clayden and Hollis's differentiations to Avery's (1980) classification has provided robust definition of each soil series. However many of the well-established local soil series names previously used overlapped, as in the example of Dunsford, Denbigh and Highweek. In such cases a rule of 'primogeniture' was adopted, with Denbigh taking precedence. Similarly most soils previously described by Harrod, (1981) at North Wyke as Tedburn series, are renamed Hallsworth.

Despite numerous attempts over the last century, no universally accepted classification of soils exists. Among the more widely applied are the USDA's Soil Taxonomy (1992) and the United Nations FAO (1990). While the system of Avery (1980) and Clayden and Hollis (1984) is used in this account, it may be helpful for researchers to identify approximate classification correlations of the soils of North Wyke and Rowden within those other systems (Table 4).

Table 4 Classification of the soils of North Wyke and nearby research locations, according to different systems

Soil series	Avery (1980)	FAO	USDA
North Wyke and Rowden			
Denbigh	Typical brown earths	Stagni-eutric cambisol	Dystric eutrochrept
Halstow	Typical non-calcareous pelosols	Stagni-vertic cambisol	Aeric haplaquept
Hallsworth	Pelo-stagnogley soils	Stagni-vertic cambisol	Typic haplaquept
Teign	Typical ranker-like alluvial soils	Eutric regosol	Typic udorthent
Blithe	Typical alluvial gley soils	Gleyi-eutric fluvisol	Typic fluvaquent
Fladbury	Pelo-alluvial gley soils	Gleyi-eutric fluvisol	Vertic fluvaquent
Nearby research locations (de Bathe, Den Brook and Drewston)			
Crediton	Typical brown earths	Dystric cambisol	Dystric eutrochrept
Moretonhampstead	Typical brown podzolic soils	Dystric cambisol	Typic haplorthod
Laployd	Humic gley soils	Humic gleysol	Histic umaquept

In soil mapping, the object is to delineate *map units* conforming as far as possible to single soil series. However, because of geomorphological, hydrological and pedological complexities affecting the natural soil mantle, at scales too small to be represented by mapping, varying proportions of differing series may have to be included in mapped delineations. As part of the natural landscape, a soil map unit's composition is more analogous to features such as natural vegetation associations, rather than to pure stands, as with agricultural crops. Soil map units are the basis of the following descriptions since they approximate to the natural distribution of the soils at North Wyke and Rowden, as indicated on the soil map (Figure 4). Each map unit has a symbol, as shown in Table 5, and on the map, a colour which matches the equivalent soil association on the national soil map (Soil Survey of England and Wales, 1983). It should be noted that boundaries shown on this map often represent gradual changes, though abrupt changes can occur, as between the soils in river alluvium and those on adjoining slopes.

Figure 4 Soil map of North Wyke and Rowden

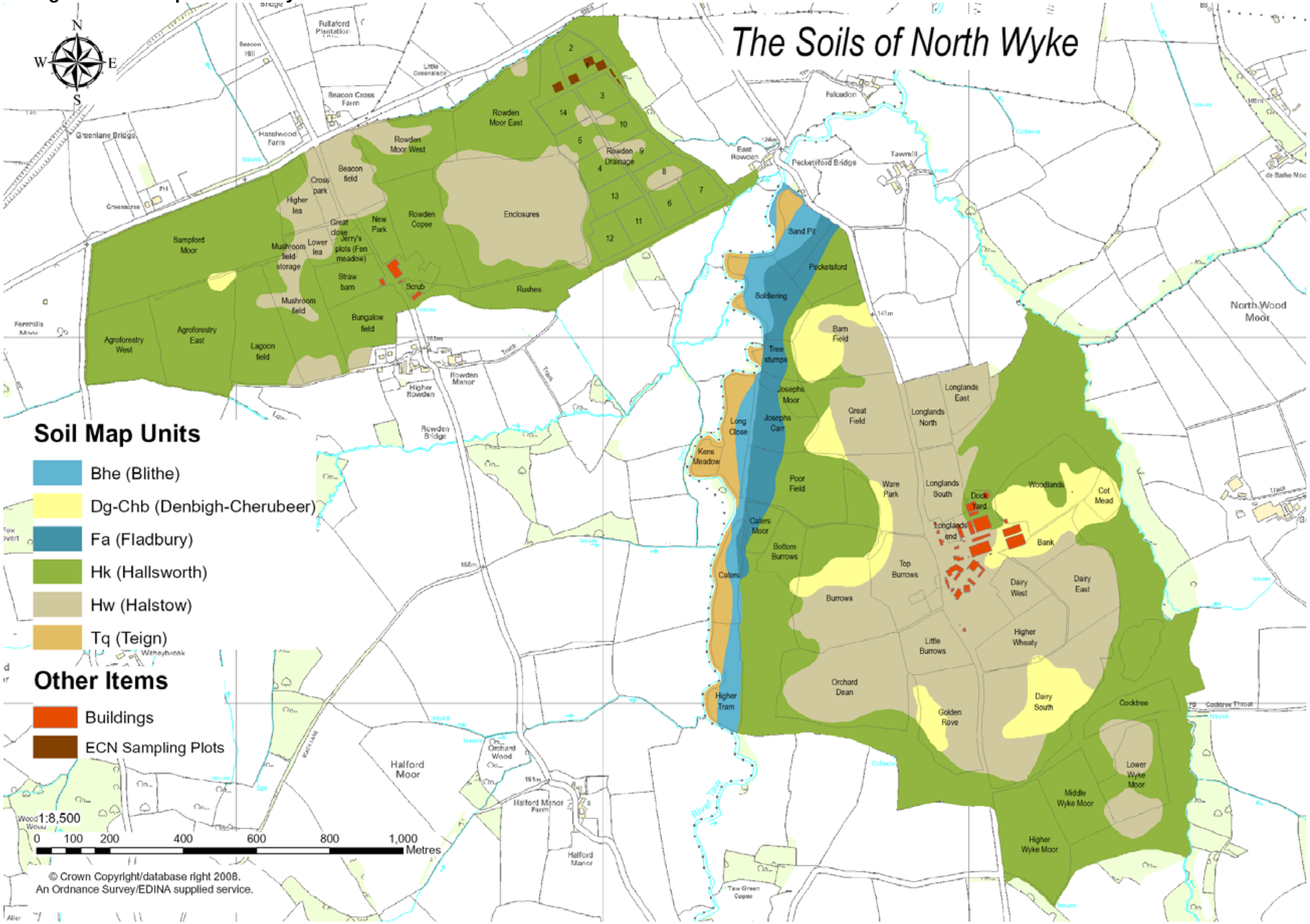


Table 5 Important properties of the soils

Series	Subgroup/lithology	Typical profile features	Map unit (map symbol)
Denbigh	A fine loamy typical brown earth in Head from clay shale	1. Clay loam 2. Brown throughout 3. Shaly at depth	Denbigh - also includes some Cherubeer series (Dg-Chb)
Cherubeer	A fine loamy over clayey stagnogleyic brown earth in Head from clay shale	1. Clay loam over clay at about 40 cm 2. Brownish colours 3. Mottled below 40 cm	------------------------------
Halstow	A clayey typical non-calcareous pelosol in Head from clay shale	1. Clayey throughout 2. Brownish colours 3. Mottled below 40 cm	Halstow - also includes some Cherubeer series and Hallsworth, less gleyed phase (Hw)
Hallsworth	A clayey pelo-stagnogley soil in head from clay shale	1. Clayey throughout 2. Greyish colours 3. Mottled throughout	Hallsworth (Hk)
Teign	A loamy typical ranker-like alluvial soil	1. Loamy 2. Gravel by 30 cm 3. Brown colours	Teign (Tq)
Blithe	A loamy over clayey typical alluvial gley soil	1. Loamy over clayey at about 40 cm 2. Mottled throughout 3. Grey colours below 30 cm	Blithe (Bhe)
Fladbury	A clayey pelo-alluvial gley soil	1. Clayey throughout 2. Grey or bluish colours 3. Stony	Fladbury (Fa)

Six map units have been recognised, important soil properties being summarised in Table 5. Over the Carboniferous rocks, the hydrological sequence of Halstow-Dunsford-Tedburn series as described by Clayden in 1965 (now called Halstow-Denbigh-Hallsworth) is represented here by the following map units: Denbigh soils (map unit Dg-Chb) are of restricted extent, mostly on steeper ground. Much of the ridge crest and flanks at North Wyke and ridge crests at Rowden carry Halstow soils (map unit Hw). Gentle, usually low lying slopes have Hallsworth soils (map unit Hk). Soil formation in this sequence is largely controlled by hydrological conditions. On the wettest, gentle slopes of the Hallsworth map unit, release of clay from the Carboniferous shales has been most intense to produce coarsely structured and impermeable subsoils, which are also found in the Halstow map unit. Only on the usually stronger slopes of the Denbigh map unit are the soils finely structured, permeable and without indications of serious waterlogging.

Along the Taw floodplain the alluvium is coarsest on the natural levees close to the river, becoming heavier in backlands away from the river channel. This reflects a sedimentary sequence typical of most floodplains, though here the clays deposited in the backlands close to the shale hills may have been supplemented by overwashing of clayey material from upslope. On the coarse alluvium the Teign map unit (Tq) has free draining loamy soils over gravel at varying depth. The Blithe map unit (Bhe) is loamy over clayey and affected by groundwater, the influence of which is most strongly marked in the clayey soils of the Fladbury map unit (Fa).

In the map unit descriptions which follow, representative soil profiles are described and laboratory analyses given. Three profiles of Denbigh, Halstow and Hallsworth series (SX69/5467, /5883, /5684) were described in 1977 using the terminology of Hodgson *et al* (1976), which differs slightly from the system of Soil Survey Staff (1960), used in 1957. Minor differences in terminology and style are apparent. The Soil Survey’s system of numbering profile descriptions is a modification of the National Grid Reference. The first 4 characters denote the 10 km grid square (*eg* SX69), with a slash separating the final 4, which are the 100 m grid reference *within* that 10 km square.

Analyses accompanying profiles described before 1976 used 50 µm as the boundary between silt and sand-sized particles; later analyses employed 60 µm. In determining organic matter contents, the earlier analyses give values for *loss on ignition.* Water bound in the crystal lattice of the clay fraction, amounting to about 10% of that fraction's mass, is driven off on ignition. If this proportion of the clay content is subtracted from *the loss on ignition* value, the remainder represents the amount of organic matter. Later analyses determine *organic carbon*; multiplying this value by 1.72 gives a measure of organic matter content.

2.2 Denbigh map unit (Dg-Chb on soil map)

This map unit comprises stony, loamy typical brown earths of the Denbigh series and related stagnogleyic brown earths of the Cherubeer series. These soi1s, often on relatively strong slopes, are characterised by brown, permeab1e, loamy surface and subsurface horizons, usually with fine blocky or subangu1ar blocky structure. In the Denbigh series this passes at depth to stony sha1y Head or to sha1e, with any gleying confined below 70cm. The Cherubeer series becomes clayey and gleyed between 40 and 70cm. Distribution of Cherubeer profiles in the map unit is not always predictable but gives rise to relative wet spots in the map unit, particularly in flatter sites. The map unit includes areas mapped as *soil H* by Findlay and C1ayden (1957) and their stony phase, *soil I*, in Woodlands Field, that is, north of the track running north-east from North Wyke. The polygons of these soils formed on gentler slopes, notably in Great Field, north west of North Wyke itself, probably owe their development to local folding in the underlying shales. This is likely to have caused minor metamorphic hardening and consequent resistance to clay production on weathering.

The example profiles are SX69/5467 (Denbigh series), a well documented profile from nearby Taw Green, and SX69/5785 (Cherubeer series) from Ware Park, North Wyke. The Denbigh series is permeable with rapid natural drainage; confirmed by the very large air capacity percentage (drainable porosity) in the subsoil of the Taw Green profile, these soils being waterlogged only at very wet times. Available water is moderate, reducing where stone content increases in the subsoil, indicating that shallow stony examples of the Denbigh series are susceptible to drought. In the example profile, surface retained water capacity (water held after drainage) is large, but may reflect under-stocking since surface bulk density is only moderate. In a Denbigh profile near Chu1m1eigh (Harrod 1981) retained water and moisture content at the plastic limit at the surface were similar. The Cherubeer series, having an impermeable subsoil, suffers some drainage impedence.

Profile SX 69/5467 Denbigh series

Note: The brightly coloured subsoil (Bw) can be a field indicator of a podzolic B horizon, the presence of which would qualify the soil profile as a typical brown podzolic soil (Manod series). However the iron chemistry suggests it is more likely to qualify as a brown earth (Avery 1980), supported by the negative sodium fluoride (NaF) test for reactive hydroxyl-aluminium (allophane) (Hodgson 1976).

Horizon (cm)	Description
0-11 Ahg	Dark yellowish brown (10YR 3/4) silty clay loam; common prominent very fine yellowish red (5YR 4/6) mottles with sharp edges; a few small subangular and tabular micaceous sandstone and shale stones; moderately developed fine subangular blocky with dark yellowish brown (10YR 3/4) faces; low packing density; very porous, very fine fissures; fine macropores; moderately firm soil strength; moderately weak ped strength; slightly sticky; very plastic; abundant very fine fibrous roots; abrupt smooth boundary.
11-32 AB	Dark reddish brown (5-7.5YR 3/4) clay loam; common medium subangular and tabular micaceous sandstone and shale stones; moderately developed fine subangular blocky

	with dark reddish brown (5YR 3/4) faces; medium packing density; slightly porous, very fine fissures; fine macropores; moderately weak soil strength; moderately weak ped strength; moderately sticky; very plastic; many very fine fibrous roots; abrupt wavy boundary.
32-61 Bw	Strong brown (7.5YR 5/6) but slightly lower chroma; clay loam; many small angular clay shale stones and some sandstone pieces; moist; moderately developed fine subangular blocky with strong brown (7.5YR 5/6) faces; medium packing density; slightly porous, very fine fissures; very fine macropores; moderately weak soil strength; very sticky; very plastic; common very fine fibrous roots; clear wavy boundary; negative NaF test.
61-84 BC	Brown (7.5YR 5/4) clay loam; abundant small angular clay shale stones; very moist; a few very fine fibrous roots; non-calcareous; gradual irregular boundary; horizon occurs as pockets between Bw and Cr.
84-140 Cr	Black (N 2/0) soft laminated clay shale with common discontinuous prominent brown (7.5YR 5/4) fine earth coats on partings.

Analyses

Horizon Depth (cm)	Ahg 0-11	AB 11-32	Bw 32-61	BC 61-84
Sand 600 µm-2 mm %	5	9	13	27
Sand 200-600 µum %	5	4	7	13
Sand 60-200 µm %	8	7	5	7
Silt 2-60 µm %	50	49	43	32
Clay <2 µm %	32	31	32	21
Organic carbon %	4.6	1.8		0.9
pH in water (1:2.5)	5.0	5.7	6.2	6.2
pH in 0.01M $CaCl_2$	4.5	4.8	5.3	5.4
Pyrophosphate ext.				
Fe %	0.57	0.25	0.29	0.14
Al %	0.18	0.13	0.15	0.10
C %	1.21	0.53	0.32	0.18
Residual dithionite Fe %	2.24	2.24	3.50	3.50
Fe + Al as % of clay	2.34	1.22	1.37	1.14
Bulk density gcm^{-3}	0.91	1.18	1.29	
Gamma probe density gcm^{-3}		1.37	1.58	
Total pore space % by vol	65.8	55.3	51.4	
Available water % by vol	25.0	13.2	8.6	
Air capacity % by vol	19.4	25.3	28.1	
Retained water % by vol	46.4	30.0	23.3	

Micromorphology (thin sections at 40-46 and 50-56 cm)

1. *Clay coats and intrapedal clay concentrations*: common (2-4%) fine void ferriargillans at 40-46 cm and few (< 1%) fine at 50-56 cm; common (2-3%) fine intrapedal concentrations at 40-46 cm and few (<1%) at 50-56 cm.
2. *Other coats*: None
3~ *Nodules and segregations*: few irregular distinct clear and diffuse segregations at 40-46 cm; (interpreted as weathered ‘ghosts’ of rock fragments rather than gleyed phenomena). No nodules.
4. *Mineralogy and weathering*: Sand and gravel-size particles of quartz, moderately weathered shale, micaceous fine and medium sandstone and siltstone.
5. *Plasmic fabric*: Mixture of skel-insepic (40%) and in-masepic (60%) at 40-46cm; ma-skel-insepic at 50-56cm.

6. *Other observations*: Large number of smooth edged voids (probably associated with faunal activity), vughs, channels, chambers and skew-planes.

Profile SX69/5785 (Cherubeer series)

Horizon (cm)	Description
0-17 Ap	Brown (8.5 YR 5/3) clay loam with very slight root mottle in top 5 cm; stony; numerous small grit fragments; fine to medium subangu1ar blocky; peds with many fine pores; friable; moderate organic matter; numerous roots; only just moist; earthworms seen; merging boundary
17-38 Bw	Brown to reddish brown (6 YR 5/4) clay loam; stony with grit fragments up to 10 cm diameter; fine to medium subangular blocky; finely porous; friable; moderate to low organic matter; numerous roots; just moist; merging boundary
38-60 2B(g)	Over-all colour of yellow-brown to brownish yellow (10 YR 6/6) clay loam made up of 7.5 YR 6/6 and 10 YR 7/4-6/4 on structure faces; no definite grey faces or grey interiors to peds, stony; large subangu1ar blocky tending to prismatic; numerous pinholes in peds; friab1e to rather compact; low organic matter; occasional fine roots; just moist.

Analyses

Horizon Depth (cm)	Ap 5-10	Bw 25-30	2B(g) 55-60
Sand 50 µm-2 mm %	31	27	21
Silt 2-50 µm %	47	43	35
Clay <2 µm %	22	30	44
Loss on ignition %	8.6	6.3	5.1
pH	6.1	6.5	6.3
C.E.C. (me/100 g)	14.4	11.4	7.7

2.3 Halstow map unit (Hw on soil map)

This is the soil of the ridge crests and gently convex flanks where clayey subsoils are present beneath ungleyed or relatively weakly gleyed subsurface horizons. In addition to typical non-calcareous pelosols of the Halstow series there are many profiles of the less gleyed phase of the Hallsworth series, some loamy surface-water gley soils and Cherubeer series (described under map unit 1). Halstow soils have brownish clay loam or silty clay loam A horizons in which mottling, due to compaction by stock and traffic, is commonplace under pasture. The B horizon is clayey with marked gleying confined below 40 cm. At depth clay content declines as the weathering shale is approached. The 1ess gleyed phase of the Hallsworth series differs in having a strongly gleyed subsurface horizon above 40 cm, although often the A horizon can be brownish. Surface horizons of both soils may have fine subangular blocky structure but the clayey subsoils usually display prismatic structure which is often of a coarse size. In a minority of profiles clay release from the shale has been less marked, B horizon texture being marginal to clay loam. This is often the case where profiles tend to be shallower, with shale found within 45 cm of the surface, as on some convex sites. This map unit comprises soils E, F and G of Findlay and Clayden's survey of North Wyke.

Example profiles are SX69/5883 (Halstow series) from Burrow's West, North Wyke, SX69/5885 (Hallsworth series less gleyed phase) from Ware Park, SX69/5788 from Great Field and SX 69/5787 from Ware Park.

These soils have unusually low cation exchange capacity (C.E.C.) relative to clay content. This is partly an expression of the micaceous nature of the clay minerals and partly of the relatively

coarse size and therefore small surface area of the clay, (the proportions of fine clay in the Halstow
analyses is representative of these soils but is small by comparison with many clay soils in this country). The very limited shrink-swell potential of these soils is a further consequence of these properties.

The soils of this map unit are waterlogged for considerable periods of the year. Their impermeable nature is confirmed by the very small air capacity (drainable pores), the high density of the Bg (41-73cm) of the Halstow profile (SX69/ 5883), and by the very slow hydraulic conductivity, which was measured for this soil type near Chu1mleigh (Harrod 1981), where a Ha1stow profile had comparable retained water capacity (water held after drainage has ceased) and a surface plastic limit of 32 per cent. Available water is large or moderately large, but much is held at high suctions.

Profile SX69/5883 Halstow series

Horizon (cm)	Description
0-21 Ap	Brown (l0YR 5/3) silty clay loam with common prominent very fine reddish brown (5YR 4/4) mottles with sharp edges; common small subangular micaceous sandstone stones; moderately developed coarse subangular blocky with brown (10YR5/3) faces; medium packing density; slightly porous, very fine fissures; fine macropores; moderately firm soil strength, moderately firm ped strength; moderately sticky; very plastic; abundant very fine fibrous roots; clear smooth boundary.
21-41 Bw(g)	Yellowish brown (10 YR5/4) silty clay with many prominent very fine strong brown (7.5YR5/6) mottles with sharp edges; common medium subangu1ar and tabular micaceous sandstone stones also very small soft shale fragments; moderately developed very coarse prismatic with pale brown (10YR 6/3) faces; medium packing density; slightly porous, very fine fissures; fine macropores; very firm soil strength; very firm ped strength; moderately sticky; very plastic; many very fine fibrous roots; clear smooth boundary.
41-73 Bg	Light grey (N 7/0) silty clay with very many prominent medium strong brown (7.5YR 5/6) mottles with sharp edges; stoneless with few small subangular and tabular micaceous sandstone stones; very strongly developed very coarse prismatic with light grey to grey (10YR 6/1) faces; medium packing density; very slightly porous; very fine fissures; very fine macropores; very firm soil strength; very firm ped strength; moderately sticky; very plastic; common very fine fibrous roots; gradual smooth boundary.
73-93 BCg	Light grey to grey (N6/0) c1ay with common prominent medium strong brown (7.5YR 5/8) mottles with clear edges; abundant small subrounded and platy clay shale stones with sub-parallel alignment often close to horizontal with occasional crumbly sandstone fragments; massive; high packing density; very slightly porous, very fine macropores; moderately firm soil strength; moderately sticky; very plastic; common very fine fibrous roots; gradual smooth boundary.
93-150 Cr	Black (N2/0) soft laminated clay shale with interstitial fine earth of brown (7.5YR 5/4) with thin bands of strong brown (7.5YR 5/8) and light grey (N 7/0); crumbly sandstone fragments occupy about 10%; roots extend to 100 cm.

Analyses

Horizon	Ap	Bw(g)	Bg	BCg

Depth (cm)	0-21	21-41	41-73	73-93
Sand 600µm-2 mm %	5	4	2	16
Sand 200-600 µm %	5	4	2	10
Sand 60-200 µm %	12	8	4	6
Silt 2-60 µm %	47	46	45	40
Clay <2 µm %	31	38	47	28
Fine clay <0.2µm%	9	10	11	5
Fine clay as % of total clay	29	26	23	18
Organic carbon %	2.9	0.6		0.4
pH in water (1:2.5)	5.0	7.1	7.2	7.1
pH in 0.01M $CaCl_2$	4.7	6.4	6.5	6.4
CEC (me/100 g)	20.3	10.7		8.6
Percent saturation	50	75		80
Bulk density gcm^{-3}	1.04	1.36	1.42	1.51
Gamma probe density gcm^{-3}	1.06	1.36	1.38	1.8
Total pore space % by vol	61.4	48.7	46.3	42.9
Available water % by vol	27.8	16.8	15.7	16.5
Air capacity % by vol	12.1	11.1	1.2	0
Retained water % by vol	49.3	37.6	45.0	43.0

Micromorphology (thin section at 50-55 cm)
1. *Clay coatings and intrapedal concentrations*: Few (<1%) fine void ferriargillans.
2. *Other coats*: None.
3. *Nodules and segregations*: No nodules. Very many prominent clear and diffuse ferruginous segregations.
4. *Mineralogy and weathering*: Strongly weathered shale fragments occur as 'ghosts' in the matrix. Other large fragments are of strongly weathered siltstone and micaceous sandstone. Sand sized quartz particles also occur concentrated in patches (ghosts of sandstone).
5. *Plasmic fabric*: Ma-vo-skel-insepic.

Profile SX69/5885 Hallsworth series, less gleyed phase

Horizon (cm)	Description
0-15 Ag	Brown (l0YR5/3) clay loam, with slight greying of faces and abundant rusty mottles on roots; numerous small stones; fine to medium subangular blocky; porosity mainly due to roots, peds compact and relatively non-porous; friable; moderate organic matter indicated by light colour of horizon; roots numerous; only just moist; occasional earthworms ; clear boundary.
15-30 Bg1	Brown (10YR 5/3-6/4) clay with brownish grey (10YR 6/2-6/1) on faces and yellowish brown (10YR 5/6-6/6) mottles, brightest around weathering shale and redder blotching of yellowish red (5YR 4/8); stony with abundant small shaly and grit fragments; large angular blocky tending to prismatic; peds dense but many fissures developed, compact with silty feel when smoothed out; low organic matter; few worm tracks, fairly numerous to few grass roots, markedly less than above; just moist; merging boundary.
30-45 Bg2	Greyer colour more predominant, structure faces entirely light grey (10YR 6/1) interiors blotched with yellow brown (l0YR 5/6-5/8) and reddish yellow (5 YR 5/8-6/6); rotting stone fragments are strong brown to yellow brown when broken; clay with sandier patches associated with rotting stones; stony; strongly prismatic; very occasional roots; just moist.

Analyses

Horizon Depth (cm)	Ag 5-10	Bg1 20-25	Bg2 36-40
Sand 50 µm-2 mm %	31	29	19
Silt 2-50 µm %	43	29	31
Clay <2 µm %	26	42	50
Loss on ignition %	9.1	5.1	5.4
pH	6.8	6.6	6.8
C.E.C. (me/100 g)	13.2	7.5	8.9

Profile SX69/5788 Unnamed stagnogley
Note: This soil profile is similar to the Tedburn series but has a lower clay content (*ie* <35 percent clay); the soil is too shallow over shale to qualify as Cegin series

Horizon (cm)	Description
0-32 Ap	Brown (7.5 YR 4/2) clay loam with s1ight mottle on surface roots; stony with fragments of grit throughout; crumb and fine to medium subangular blocky; porous; friable; moderate organic matter; numerous roots; just moist.
32-66 Bg	Pale yellow-brown (10 YR 7/3 to 2.5 Y 8/4) and light grey (2.5 Y7/2) silty clay loam to clay, with strong brown (7.5 YR 5/6) blotching, especially around weathering shale fragments; very stony, abundant fragments of shale, strong brown to yellow brown when broken; compact to indurated; occasional roots; just moist.
66+ C	Weathering shale in strong brown silty clay matrix.

Analyses

Horizon Depth (cm)	Ag 5-13	Bg1 23-30	Bg2 45-56
Sand 50 µm-2 mm %	22	25	20
Silt 2-50 µm %	46	41	46
Clay <2 µm %	32	34	34
Loss on ignition %	8.8	7.2	8.3
pH	5.4	5.6	5.9
C.E.C. (me/100g)	18.3	16.7	8.7

Profile SX69/5787 [Unnamed stagnogleyic ranker]
Horizon (cm)

Horizon (cm)	Description
0-18 Ap	Brown to dark brown (10 YR 4/2 - 4/3) clay loam with very slight mottling on roots near top of horizon; stones numerous, small fragments of shaly rock; crumb to fine subangular blocky; porous; friable; moderate organic matter; numerous fine grass roots; only just moist; earthworms ; clear boundary.
18+	Brownish grey (10 YR 6/2 - 6/3) and pale brown, with brownish yellow and strong brown

Cu	(10 YR 6/6 and 7.5 YR 5/8) around weathering shale with clay partings, and thin fine-grained sandstone bands in places and occasional quartz fragments; roots appear to penetrate the laminae of decomposing shale fragments.

Analyses

Horizon Depth (cm)	Ap 5-13	Cu 25-36
Sand 50 µm-2 mm % Silt 2-50 µm % Clay <2 µm %	29 43 28	25 39 36
Loss on ignition % pH C.E.C. (me/100 g)	8.3 6.4 14.6	5.5 6.5 7.2

2.4 Hallsworth map unit (Hk on soil map)
The Hallsworth series is a clayey pelo-stagnogley soil which is gleyed throughout and is found mostly on subdued footslopes or gently sloping ridge flanks. The Ag horizon is a grey or grey-brown, strongly mottled clay loam, silty clay loam or clay. This overlies a strongly mottled clayey B horizon which has coarse or very coarse prismatic structure. Below about 70cm clay content may be reduced while structure also declines. The profiles are weathered in Head of variable thickness (up to 3 or 4 m), which becomes more open and stony at depth, eventually resting on shale. Some minor variations occur, two semi-natural vegetation phases being mapped by Findlay and C1ayden. These were the moorland phase (Soil Km) with thin organic surface layers, often underlain by thin grey or white horizons, under *Molinia- Juncus*, and the woodland phase (soil Kw) with thin mull humus and often less gleyed subsurface horizons. Additionally some profiles strongly affected by groundwater are intensely gleyed, but little mottled with blue grey horizons, occurring near flushed, concave slope changes. Textural variation is limited, some profiles have silty clay loam upper horizons, occasionally 40-50cm thick (Greyland series). On Falcadon Moor some weak, step-like benches occur across the south facing slope. Apart from being more stony, and perhaps having shallower cover of Head over the Carboniferous there is little difference in the soil. Soils J, Km and Kw of Findlay and Clayden are combined in this unit.

The example profiles are SX69/5684 from Burrows Park, North Wyke, SX69/5586 from Poor Field, SX69/5588 and SX69/5587 (both from Joseph's Moor).

As with Halstow soils, the predominantly micaceous clay minerals give small cation exchange capacity relative to clay content, and the soil has negligible shrink-swell potential. The subsoil is dense and highly impermeable, as is shown by the air capacity figures in example profile SX69/5684. Hydraulic conductivity of these soils (see Harrod 1981) is very slow and the soil remains waterlogged at all but dry times in the summer. Retained water capacity is considerably above the surface soil’s plastic limit. Available water capacity is moderate but is held at relatively high suctions.

It should be noted that although the system of Clayden and Hollis (1984) uses the name Hallsworth for this, the main soil series at North Wyke, the name Tedburn series is maintained in their classification for pelo-stagnogley soils formed *over lithoskeletal* drift, that is where shale or very stony material occurs in the profile *within 80cm depth.*

Profile SX69/5684 Hallsworth series

Horizon	Description

(cm)	
0-27 Apg	Greyish brown (10 YR 5/2) clay; common prominent very fine dark reddish brown (5YR3/4) mottles; few medium subrounded and tabular sandstones; strongly developed fine subangular blocky with greyish brown (10YR 5/3) faces with rusty sheets; low packing density; moderately porous, very fine fissures, fine macropores; moderately firm soil strength; moderately weak ped strength; moderately sticky; very plastic; many very fine fibrous roots; abrupt wavy boundary; many coarse inclusions of Bg.
27-66 Bg	Light grey (5Y 7/1) clay; many prominent medium reddish yellow (7.5 YR 6/8) mottles; few large subrounded tabular stones; moderately developed very coarse prismatic with light grey (5Y 7/1) faces; high packing density; very slightly porous, very fine fissures; very fine macropores; very firm soil strength; very sticky; very plastic; common very fine fibrous roots; few organic coats; gradual wavy boundary.
66-84 BCg1	Grey (N 5/0) clay loam; very many prominent medium reddish yellow (7.5YR 6/8) mottles; common large subrounded tabular stones and very soft shale; massive; high packing density; very slightly porous, very fine fissures; very fine macropores; very fine soil strength; very sticky; very plastic; common very fine fibrous roots; common ferri-manganiferous coats; gradual irregular boundary.
84-107 BCg2	Strong brown (7.5YR 5/6) clay loam; very many fine light grey to grey (N 6/0) mottles; many small subangular tabular stones; massive; high packing density; very slightly porous, very fine fissures; very fine macropores; very sticky; very plastic; a few very fine fibrous roots; common ferri-manganiferous coats; abrupt smooth boundary.
107-131 BCg3	Yellowish brown (10YR5/4) clay loam; common prominent medium light grey to grey (N 6/0) mottles, some subhorizontally banded; many small subrounded tabular stones and soft shale; weakly developed medium platy; high packing density; very slight1y porous, very firm soil strength; moderately firm ped strength; common ferri-manganiferous coats; abrupt smooth boundary.
131-158 BCg4	Olive (5Y 4/3) clay loam; common prominent medium light grey to grey (N 6/0) mottles; many medium subrounded stones; massive; high packing density; very slightly porous, common ferri-manganiferous coats.

Analyses

Horizon Depth (cm)	Apg 0-27	Bg 27-66	BCg1 66-84	BCg2 84-107	BCg3 107-131	BCg4 131-158
Sand 600 µm-2 mm %	1	2	7	9	6	6
Sand 200-600 µm %	3	4	6	8	7	7
Sand 60-200 µm %	8	8	8	9	9	7
Silt 2-60 µm %	50	43	47	47	52	49
Clay <2 µm %	38	43	32	27	26	31
Fine clay <0.2 µm%	9	10	7	5	5	5
Fine clay as % of total clay	24	23	22	18	19	16
Organic carbon %	3.7	0.5				
pH in water (1:2.5)	5.3	6.0	6.1	6.2	6.3	6.5
pH in 0.01M $CaCl_2$	4.9	5.2	5.3	5.4	5.5	5.7
CEC (me/100 g)		10.2	10.2			
Bulk density gcm^{-3}	0.99	1.31	1.55			

Gamma probe density gcm^{-3}	1.17	1.21	1.60		1.91	
Total pore space % by vol	63.3	50.4	41.5			
Available water % by vol	22.1	16.6	14.7			
Air capacity % by vol	12.0	4.8	8.2			
Retained water % by vol	51.3	45.7	33.3			

Micromorphology (thin sections at 34-42, 46-52, 103-110 and 121-127 cm)

Clay coats and intrapedal clay concentrations: few fine void ferriargillans at 34-42, 46-52 and 103-110 cm; absent at 121-127 cm.
2. *Other coats*: common fine and medium grey zones adjacent to voids (albans) at 34-42 and 46~52 cm; rare fine quasi-ferrans at 46-52 cm; few fine neo-ferrimangans at 103-110 cm and 121-127 cm; few fine and medium silt plus clay coats at 46-52,103-110 and 121-127 cm.
3. *Nodules and segregations*: very many to abundant prominent clear and diffuse ferruginous segregations at 34-42 and 46-52 cm; common to many prominent and distinct clear and diffuse ferri-manganiferous segregations at 103-110 cm; few small distinct ferruginous nodules at 34~42 cm; nodules and segregations absent at 121-127 cm.
4. *Mineralogy and weathering*: many fragments of siltstone, micaceous fine sandstone, shale and quartz; sandstone in particular is strongly weathered.
5. *Plasmic fabric*: dominantly ma-insepic in all sections.

Profile SX69/5586 Hallsworth series

Horizon (cm)	Description
0-7 Ag1	Dark grey-brown (10 YR 4/2 - 5/2) clay loam with strong rusty accumulation on roots and root channels; crumb structure; porous, friable; organic matter rather high; roots very numerous; just moist, earthworms; merging boundary.
7-18 Ag2	Dark grey-brown (10 YR 4/2) clay loam with strong rusty accumulations on root channels; very occasional fragments of grit; medium subangular blocky; only slightly porous - peds compact, firm to friable; organic rather high (?); numerous roots; just moist; clear boundary.
18-35 Bg1	Brownish grey (10 YR 6/3) on faces, clay with light grey 10 YR 7/1 - 8/1 and yellow brown to reddish yellow mottles; stony, grit up to 10 cm; prismatic, stubby prisms; many fine pin-holes in peds, tough with sandy patches; dark organic matter down fairly numerous worm tracks; roots not numerous; just moist; merging boundary
35+ Bg2	As above but lighter grey colours (2.5 Y 6/0), on structure faces become commoner with depth.

Analyses

Horizon Depth (cm)	Ag1 2-5	Ag2 10-15	Bg1 22-28	Bg2 40-46
Sand 50 µm-2 mm %	22	27	15	18
Silt 2-50 µm %	56	51	43	45
Clay <2 µm %	22	22	42	38
Loss on ignition %	10.9	9.3	5.1	4.8
pH	6.4	6.2	6.2	6.1

C.E.C. (me/100 g)	15.7	13.3	7.3	6.9

Profile SX69/5588 Tedburn series

Horizon (cm)	Description
0-20 Ahg	Dark grey-brown (10 YR 4/2 - 4/3) silty clay loam with strong red-rusty (5 YR 4/4) mottles along root channels; a few stones, mainly grit; fine subangular blocky structure; friable, porous; few grass roots, numerous birch roots, 0.6-l cm thick; merging boundary.
20-38 B(g)	Brownish yellow (10 YR 6/6 - 7/6) clay with blotching of reddish yellow (7.5 YR6/8) within peds which have numerous pin-holes; large subangular blocky structure; friable; numerous birch roots; merging boundary.
38+ Bg	Clay as above, but faces of peds become greyer in places (2.5 YR 7/2), but with same interior colour to peds; tenacious, fragments of soft shale become more numerous with depth.

Analyses

Horizon Depth (cm)	Ahg 7-15	B(g) 25-35	Bg 45-55
Sand 50 µm-2 mm %	17	11	6
Silt 2-50 µm %	53	33	37
Clay <2 µm %	30	56	57
Loss on ignition %	12.3	6.7	6.8
pH	5.0	5.0	5.0
C.E.C. (me/100 g)	19.8	11.2	10.0

Profile SX69/5587 Hallsworth series

Horizon (cm)	Description
0-15 Ah	Dark grey (10 YR 4/1 - 3/1) humose silt loam; spongy, very fibrous with abundant coarse *Molinia* roots; high organic matter; moist; brown staining on roots, organic matter carried down prominent structure faces into horizon 3; sharp boundary.
15-20 Eg1	Grey (10 YR 6/1) silty clay with strong brown (7.5 YR. 5/6 - 5/8) pipes around roots and red-rusty accumulations on old roots; large subangular blocky tending to prismatic; fissured, tenacious; moderate organic matter; marked reduction in root density, many dead roots; moist; this thin horizon may be the humus-stained top of the horizon below; clear boundary.
20-32 Eg2	White (10 YR 8/1) silty clay to clay with reddish yellow (7.5 YR 6/8) pipes to root channels; prismatic structure, not strongly fissured, tenacious; active roots not numerous, many dead roots; moist to wet; merging boundary.
32+ Bg	White (10 YR 8/1) clay with reddish yellow (7.5 YR 6/8) around roots and abundant blotching of 10 YR 6/8, brownish yellow; occasional stones; prismatic structure, fissured, tenacious; few roots.

Analyses

Horizon Depth (cm)	Ah 5-10	Eg1 15-20	Eg2 25-30	Bg 41-51
Sand 50 µm-2mm % Silt 2-50 µm % Clay <2 µm %		17 47 36	18 44 38	7 41 52
Loss on ignition % pH C.E.C. (me/100 g)	10.8 4.7 32.8	7.3 4.8 12.8	4.1 5.2 6.4	5.4 5.0 11.5

2.5 **Teign map unit** (Tq on soil map)

This unit is restricted to the natural levees of the Taw flood-plain and comprises Soil A of Findlay and Clayden (1957). As well as the Teign series, a loamy typical ranker-like alluvial soil, there are deeper loamy profiles of both typical brown alluvial soils and gleyic brown alluvial soils. Surface horizons are brown sandy silt loam with granular structure throughout the unit. In the Teign series this rests on gravels and is exemplified by profile SX69/5384 taken from Cator's Field, North Wyke. In the brown alluvial soils, it is weakly differentiated from the brown loamy subsurface B horizon, which in the typical subgroup continues to considerable depth, particularly near the horseshoe loops of the River Taw meanders. In the gleyic brown alluvial soil however, mottling is present below 40 cm indicating the influence of groundwater, the soils occurring particularly near to the boundary with map unit 5.

Profile SX69/5384 Teign series

Horizon (cm)	Description
0-20 A	Dark brown (7.5 YR 4/2) micaceous sandy silt loam with slight rusty mottle in top 5 cm; clean angular quartz grains obvious, occasional small rounded stones; crumb to medium subangular blocky structure; porous, mellow; very numerous fine grass roots; just moist; sharp but irregular boundary.
20-46 Cu	Gravel with clay loam matrix very like above, well rounded to subrounded, l-l0 cm diameter mainly black, fine grained siliceous rocks showing banding, with smaller amounts of grey fine micaceous sandstone, granite and metamorphic or volcanic rocks.

Analyses

Horizon Depth (cm)	A 5-7	Cu 25-40
Sand 50 µm % Silt 2-50 µm % Clay <2 µm %	31 52 17	38 37 25
Loss on ignition % pH C.E.C. (me/100 g)	6.8 6.2 12.1	5.6 6.1 9.3

2.6 **Blithe map unit** (Bhe on soil map)

This floodplain unit is made up of loamy over clayey typical alluvial gley soils situated on slightly lower ground than the Teign map unit and further away from the river. The Blithe series has a brownish clay loam A horizon over a loamy, mottled B horizon resting below 30 cm on very stony, grey clay. A feature of the clay is the presence of abundant clinker-like manganiferous concretions, locally termed "black ram". Profile SX69/5387 was described in Long Close by Findlay and Clayden as an example of their soil B, which is the basis of this unit.

Blithe soils are affected close to the surface for long periods by high groundwater, as is indicated by mottling, grey colours and manganiferous material in the subsurface horizons.

Profile SX69/5387 Blithe series

Horizon (cm)	Description
0-18 Ap	Dark grey-brown (10 YR 4/2) clay loam with strong root mottle in top 5cm; some angular coarse quartz grains, occasional stones; medium and fine subangular blocky; porous, friable; numerous roots; just moist; several earthworm channels noted; clear boundary
18-30 Bg	Brown (10 YR 5/2 - 5/3) clay loam with diffuse yellow brown (10 YR 5/6 - 6/6) blotching,; slightly stony, increasing with depth; weak large subangular blocky breaking easily to fine subangular blocky; porous, very friable; numerous roots; just moist.
30-45 2Bg	Light brownish grey (2.5 Y 6/2) clay; very stony, rounded to 2Bg subrounded gravel; medium subangular blocky tending to weak prismatic, fissured; peds with fine pores, tenacious; organic matter in worm tracks only; some fine grass roots; moist; abundant manganese dioxide as hard cindery concretions and coatings to stones.

Analyses

Horizon Depth (cm)	Ap 5-13	Bg 20-28	2Bg 36-45
Sand 50 µm-2 mm %	24	25	34
Silt 2-50 µm %	50	47	27
Clay <2 µm %	26	28	39
Loss on ignition %	7.8	6.8	6.0
pH	6.7	6.3	5.2
C.E.C. (me/100 g)	13.2	10.6	9.2

2.7 Fladbury map unit (Fa on soil map)
The soils of this unit are clayey, usually stony, pelo-alluvial gley soils of the Fladbury series, formed on the margin of the Taw floodplain. In the northern part of the map unit the ground is very slightly elevated and may form a low meander terrace. Fladbury soils have thin, grey or grey brown loamy topsoils, usually showing abundant rusty mottling along roots. At about 15 cm depth this gives place to very stony, mottled grey clay, which at greater depth can be intensely gleyed with bluish colours. The stones are of granite and metamorphic rocks indicating the alluvial nature of the parent material. Manganiferous stains and nodules are usual in the subsoils. This map unit combines soils C, D and Dm of Findlay and C1ayden, Dm being a *Mo1inia-Juncus* moorland phase with a fibrous root mat over a thin grey subsurface. As well as being affected by the high water table in the alluvium for most of the year these soils have dense impermeable B horizons. Example profiles are SX69/5993 from Sandpit Field and SX69/5488 from Joseph's Moor.

Profile SX69/5993 Fladbury series

Horizon (cm)	Description
0-20 Apg	Dark grey-brown (10 YR 4/2 - 5/2) clay loam with reddish yellow and yellow-red (7.5 YR 6/8 and 5 YR 5/8) mottles along root channels; occasional stones; medium to large subangular blocky with vertical faces extending from below to within 5 cm of surface, fissured, tenacious; moderate to high organic matter; very numerous roots; just moist.
20-40 Bg	Olive-grey to light olive-grey (5 Y 5/2 - 6/2) on faces and extending inside peds with blotching of 10 YR 6/8 and reddish yellow (7.5 YR 6/8) clay to silty clay; bouldery gravel, fine-grained dark grey siliceous sediments, smaller amounts of granite and metamorphic rocks, many tabular with rounded edges up to 30 cm in length; very large angular blocky to prismatic, fissured, tenacious; roots concentrated around stones; some manganese dioxide concentrated on structure faces, which become greyer (2.5 Y 6/0) with depth, same material continues as matrix to gravel.

Analyses

Horizon Depth (cm)	Apg 7-12	Bg 28-32
Sand 50 µm %	19	-
Silt 2-50 µm %	49	-
Clay <2 µm %	32	-
Loss on ignition %	9.2	7.8
pH	5.6	6.2
C.E.C. (me/100 g)	16.9	15.8

Profile SX69/5488 Fladbury variant, intergrade to Blithe

Horizon (cm)	Description
0-10 Ah	Dark grey (10 YR 4/1) humose sandy silt loam; many clean angular quartz grains; spongy, very fibrous with abundant *Molinia* roots; high organic matter; moist; clear boundary.
10-22 Eg	Grey (10 YR 5/1) clay loam with dark red rusty (2.5 YR 4/8) lining to root channels; occasional small rounded stones; fine subangular blocky; porous, friable; moderate organic matter; roots less abundant but still very numerous, brown stained; moist; clear boundary
22-45 Bg	Grey (2.5 YR 6/0-7/0) silty clay loam to clay with abundant blotching of brownish yellow (10 YR 6/8), very stony, rounded cobbles up to 12 cm, mainly black fine-grained sandstones, some granite and soft sha1e; large angular blocky structure; fissured, peds with numerous pin-ho1es, tenacious; numerous roots; wet; merging boundary
45-61+ BCG	Blue grey (2.5 YR 6/0) gritty clay loam to clay with subordinate yellow-brown blotching, numerous black or dark brown smears some of which contain much mica and appear

	to be rotting granite, others probably manganese dioxide which is hard and cindery; very stony as horizon above; structure masked by stoniness; wet.

Analyses

Horizon Depth (cm)	Ah 2-7	Eg 12-18	Bg 30-40	BCG 51-61
Sand 50 µm %	42	28	34	40
Silt 2-50 µm %	43	40	31	25
Clay <2 µm %	15	32	35	35
Loss on ignition %	14.6	7.5	10.0	9.3
pH	5.0	5.2	4.8	5.4
C.E.C. (me/100 g)	18.9	10.8	7.3	9.7

2.8 Water retention characteristics

Soil water retention values (volumetric water content at a range of suctions) are a measure of the size and number of pores. These radically influence the soil's physical, environmental and agricultural behaviour.

The content at 0.05 bar suction is approximately equivalent to the volume of pores smaller than 60 µm in diameter, representing moisture content at *field capacity* (Hall *et al.* 1977), that is, water retained when gravitational drainage ceases. At the other extremity of these measurements, water held at >15 bar suction (permanent wilting point) is considered to be *unavailable* to temperate plants. Measurements at intermediate suctions represent progressively finer pores and increasingly difficult plant availability.

Pores coarser than 60 µm (the soil's *air capacity*) provide brief (about 2 days) excess water storage. In soils where air capacity is small, surface ponding or overland flow will be easily triggered. Horizons with air capacity below 5% are generally considered to be impermeable. The total volume of water held at >0.05 bar suction (*i.e*. the sum of available and unavailable water) represents the *retained water capacity*. Soils with a retained water capacity, that is, water retained when gravitational drainage ceases, that exceeds the *plastic limit*, have high risk of surface poaching or compaction, which reduces the soils suitability for grassland use (3.1). Such soils require a period of evaporational drying (by transpiring plants) before changing from a plastic, vulnerable state, to a firm and friable condition.

Measurements of water retention properties in the analyses of three of the representative profiles for the main soils at North Wyke, were made for the visit of the British Society of Soil Science (BSSS) in 1978 (Hogan 1978). The descriptions of these profiles are given in sections above: SX69/5467, Denbigh series (2.2), SX69/5883, Halstow series (2.3) and SX69/5684, Hallsworth series (2.4). Water retention data are shown diagrammatically in Figure 5a, which is taken from the BSSS handbook, taking account of changes in soil series names which have taken place since 1978. Reference should be made to diagrams A4 (Halstow), A5 (Tedburn, this profile now qualifying as Hallsworth) and A6 (Dunsford, this series now included within Denbigh). Diagrams A1- A3 refer to other locations on the Culm visited during this BSSS excursion. Large retained and unavailable water content, small air capacity (below the surface horizons) and large fine earth volume (high soil density), are features of both the Hallsworth and Halstow soils. In contrast the Denbigh profile has very large air capacity throughout, (accounting for its free drainage), but smaller total and available water.

As part of the soil investigations for the Environmental Change Network, described more fully in Appendix II, measurements were made of water content in a number of soil profiles of low permeability, similar to the Hallsworth series. Results are shown in Figure 5b. Pelo-stagnogleys of the Tedburn series, and closely related stagnogleys of the Ticknell and Dale series have similar, characteristic water retention properties. In almost every case, retained water capacity is large (>40 percent) making the soils susceptible to poaching and compaction, with more than half of the water unavailable and held at high suction. However available water content is large (very large in topsoils) providing adequate water for grass growth through the growing season in most years. Air capacity is small (<10 percent) in the topsoils, becoming negligible in subsoils, indicating the low permeability of these profiles.

It should be born in mind that in clayey soils, the Hallsworth, Halstow and Fladbury map units at North Wyke, shrinkage following summer drying, temporarily increases coarse porosity. Vertical fissures between prismatic structural aggregates (peds), as described in sections 2.3, 2.4 and 2.7, widen as the peds shrink. Although the shrink-swell capacity of these soils is small (compared with many clayey soils in this country), it is sufficient to allow vertical by-pass flow from mid-summer, until thorough rewetting and swelling take place in the autumn or early winter. See also notes on soil cracking in Appendix IV.

Figure 5a Water retention characteristics of the main soils around North Wyke

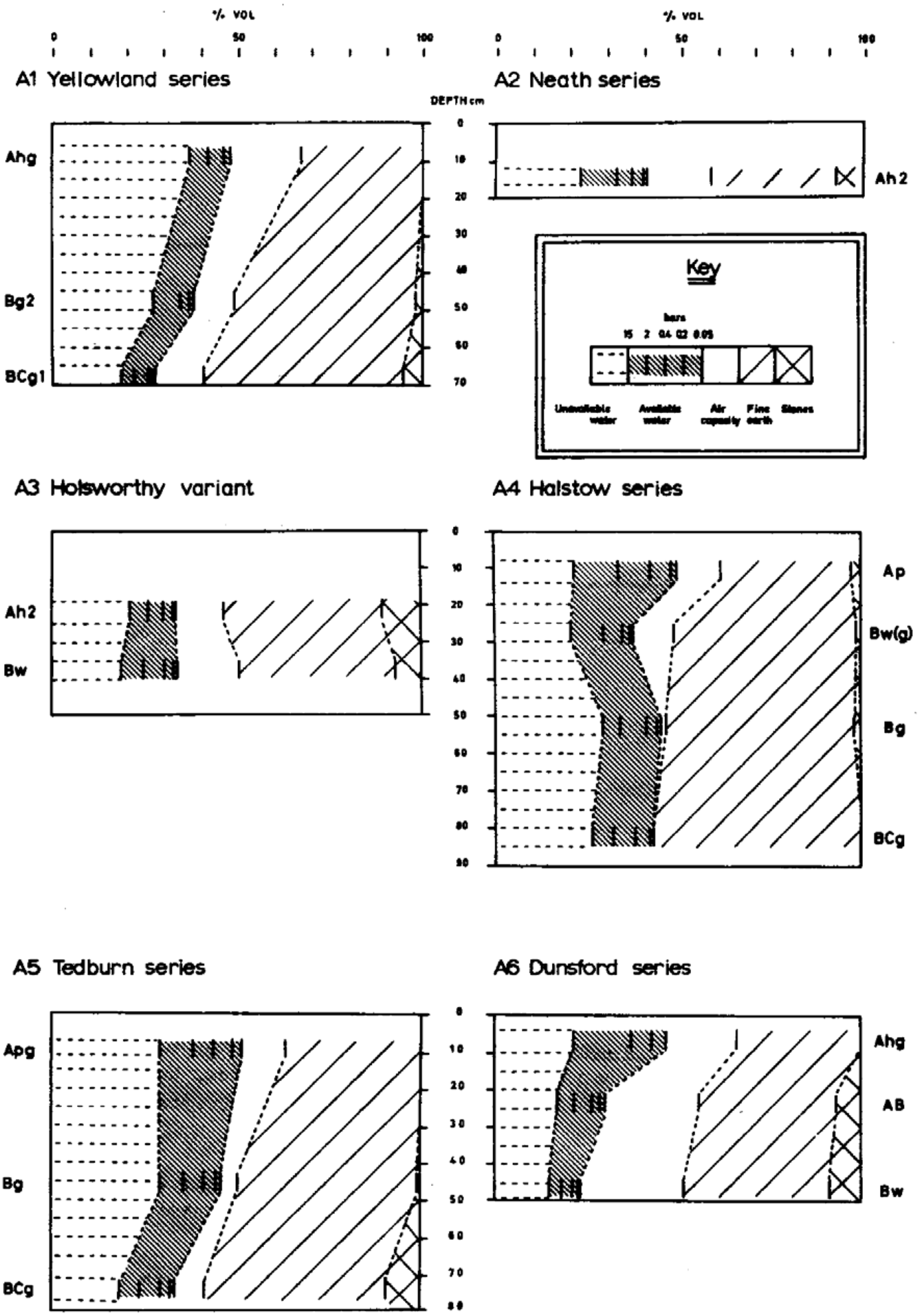
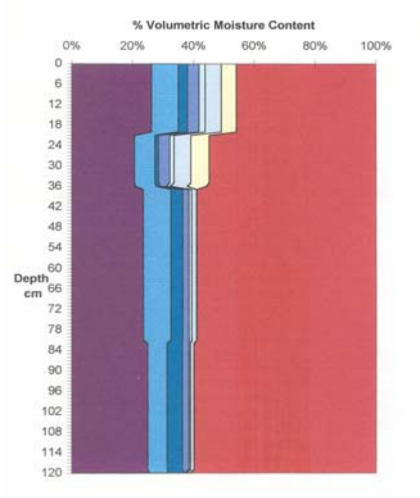
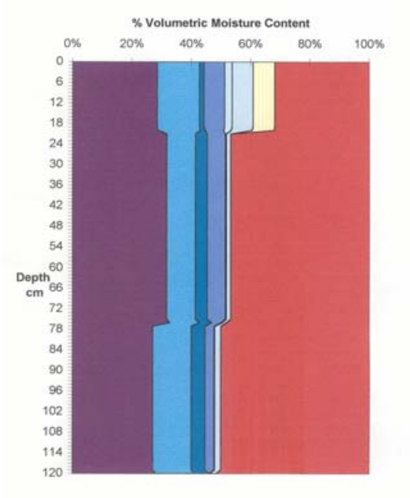


Figure 5b Water retention characteristics of soils at ECN sites at Rowden

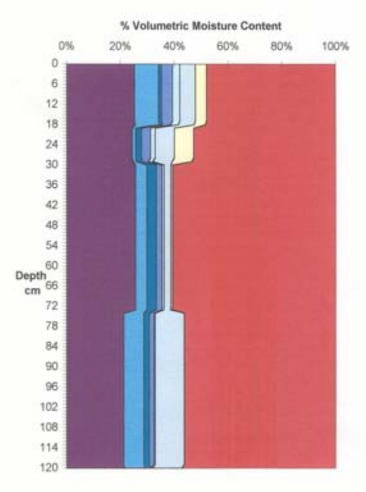
a) Tedburn series



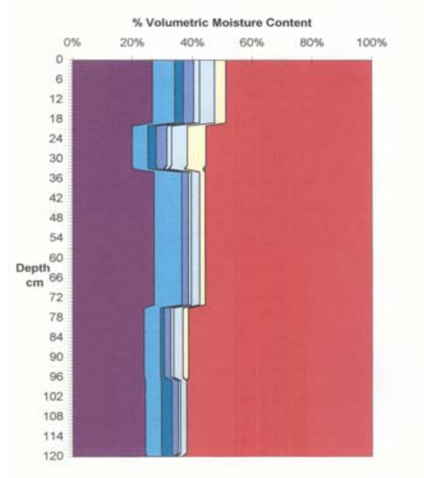
b) Tedburn series



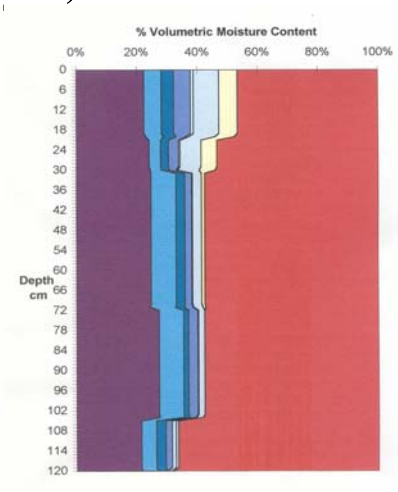
c) Ticknell series



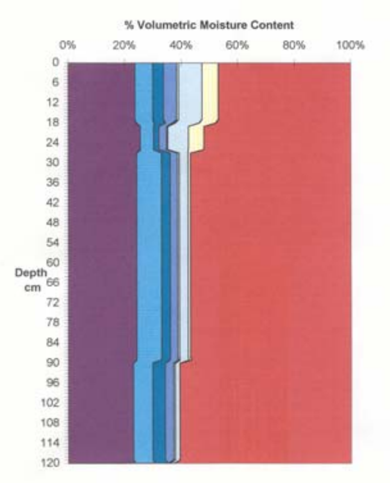
d) Dale series



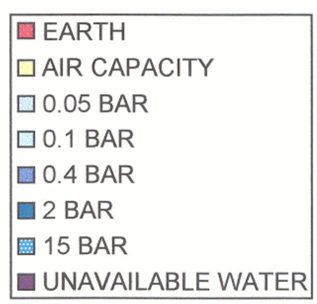
e) Dale series



f) Dale series



Key



3. SOILS AND LAND USE

The most extensive soils mapped are Hallsworth and Halstow, both present management difficulties stemming from their clayey texture and slow permeability, the differences being of degree rather than kind. Similar characteristics are found over part of the Taw floodplain on the Fladbury and Blithe map units. Only the Denbigh and Teign soils are free from serious wetness problems. Table 6 summarises important aspects of land use potential in the soils. Additional information on soils similar to those of North Wyke and Rowden in adjacent parts of Devon is summarised in Harrod (1981). Data on these soils from the wider national database are presented in section 4.

3.1 Soil suitability for grassland

The physical properties of soils which influence land use for pasture have been fully summarised by Harrod in Jarvis and Mackney (1979). While differing levels of management will produce different results, the soils and their environment impose serious limitations on the scope of grassland use, this being conditioned by the potential yield of grass and the ease of utilisation. Given suitable fertilizer application, yield is governed by climate, particularly length of the season with suitable temperature, by the amount and distribution of rainfall, and by properties of the soil. Rainfall is effective in terms of grass yield only if moisture is stored in the soil until needed by the growing crop. While some soils are able to store adequate available water (AWC – available water capacity) to meet the requirements of crop growth, others are readily droughty due to shallow profile depth and consequent small AWC, while elsewhere moisture reserves may be supplemented, by ground-water.

Utilisation of a crop is strongly influenced by the ease of trafficability and susceptibility to poaching of the ground, which in turn can affect subsequent yield. In much of western Britain, climate and soils are conducive to large crops of grass, but problems due to wetness, with poaching by grazing stock or difficulty in mechanical harvesting, often leave part of the potential yield unrealised.

The scheme of Harrod (1979) offers a standard means of assessing both potential production of soils under grass and their trafficability and poaching risk using soil profile data as presented in section 2. Interpretation is in relative terms, which are appropriate nationally and, if needed, can be used to place land in broad suitability classes.

a) Good summer pasture*: *soils with high potential yield but difficult trafficability and high poaching risk

This includes Hallsworth, Ha1stow, Fladbury and Blithe map units. These soils can produce heavy grass crops, with the local climate encouraging growth until late in the year. Susceptibility to summer drought is slight in well managed pasture, probably due to moderately high AWC, enhanced by slow moisture release and impeded drainage. The principal problem in the managing of these soils for grassland use is the high poaching risk, so that grazing and trafficking needs careful timing. It should be noted that the plastic limit of these soils (the moisture content at which the soil changes from being friable with high bearing strength to plastic and easily deformed) is well below the retained water capacity (the moisture content at field capacity, after gravitational drainage has ceased). This remains true whether the land has been artificially drained or not. Consequently the soils need a period of drying (by evapotranspiration) before the ground can support stock or machines without deforming and compacting. Usually in spring considerable grass will be available before the soil conditions are suitable to encourage its use, while the danger of damage will return periodically in wet spells in summer. By early autumn in most years the ground becomes too wet to stock or travel over unless damage to the sward and soil is to be accepted. Of the soils listed, the Halstow and Blithe map units have slightly greater flexibility. At this point it is worth commenting that winter stocking of such land can have environmental consequences including damage to soil structure and loss of infiltration, slurrying of the soil surface and encouragement of turbid runoff.

b) Pasture with summer drought risk: soils with high trafficability and low poaching risk but reduced potential yield

The Denbigh and Teign map units are included. Stoniness or shallowness over shale or gravel induce some degree of droughtiness over parts of these map units. On both, patchiness may be explained by the kind of variation mentioned in the map unit descriptions. Poaching risk is slight, these freely draining soils being open to damage only at the wettest times. Light winter stocking and trafficking may be feasible.

c) Slopes greater than 11^o

Small areas of the Denbigh map unit east of North Wyke and in Burrows Park have steep slopes. Here poaching risk is somewhat increased and efficiency and safety of machinery reduced.

3.2 Soil suitability for slurry acceptance

Lea (1979) described criteria for assessing suitability of soils (and their sites) for disposal of farm slurry without causing subsequent management problems or pollution. Most of the soils here are poorly suited, the Denbigh and Teign map units being exceptions. Hallsworth, Halstow, Fladbury and Blithe soils have restricted permeability and difficult trafficability. In the case of Halstow problems are less acute than on the Hallsworth soils. On the alluvial soils, flood risk, particularly in the winter half year, poses a pollution hazard, which is the only limitation on Teign soils.

3.3 Ease of cultivation

Workability of soils can be rated by similar soil properties (Jones 1979) to those influencing poaching risk and trafficability. On the Hallsworth, Halstow (to a slightly lesser degree), Fladbury and Blithe map units, timeliness is essential. Cultivation should not be attempted at or near field capacity but should be confined to summer periods with a moisture deficit, otherwise smearing and marked plough pans will be induced. This limitation will be reduced but not removed by drainage. In addition to the need for timeliness traction aids, such as cage wheels, or high power or crawler tractors will be advantageous. On the Denbigh and Teign map units, cultivation after a few dry days at anytime of year is feasible and good tilths produced with traditional tackle. Although autumn cultivation may be useful, frost tilths are rarely formed in this district, where heavy winter rain slakes bare soil to form structureless caps. Flexibility of the soils is greater on the Teign than the Denbigh map unit, although flood hazard cannot be discounted.

3.4 Soil suitability for direct drilling

Soil conditions influencing cultivation also affect ease of direct drilling. The higher soil density and smaller coarse porosity compared with subsoils, tend to make topsoils more prone to waterlogging and root restriction. Advantages are that the work is completed quickly and is much less exposed to the fickleness of the weather. The free-draining soils of the Denbigh and Teign map units present good prospects of success with this technique, although flood risk on the Teign soils may be a minor hazard. On the other soils, Hallsworth, Halstow (less so than the Hallsworth), Fladbury and there is serious likelihood of poor crop establishment due to smearing of drill slits, ponding of water and slug damage. While summer work is essential, much will still depend on the season. In most cases restrictions on management are less severe for Halstow and Blithe map units than for Hallsworth and Fladbury

Table 6 Land use potential of the soil map units

Map Units	Denbigh	Halstow	Hallsworth	Teign	Blithe	Fladbury
Potential grass yield	Moderate	High	High	Moderate	High	High
Trafficability	High	Low	Low	High	Low	Low
Poaching risk	Low	High	High	Low	High	High
Slurry acceptance	High	Low	Low	(High)	Low	Low
Workability	High	Low	Low	High	Low	Low
Ease of direct drilling	High	Low	Low	High	Low	Low
Drainage need	-	High	High	-	High*	High*
Ground-water	-	-	Limited	-	High	High
Surface-water	-	High	High	-	High	High
Secondary treatment	-	High	High	-	High	High

*Effectiveness of drainage dependent on river levels

3.5 Soils and land drainage

Only the Denbigh and Teign map units are free from serious soil drainage problems. Most of Rowden and North Wyke is underlain by clayey, dense and impermeable subsoil B horizons, with few drainable pores and very slow hydraulic conductivity. Inevitably this results in a surface-water problem which is exacerbated by the district's high rainfall. This can be compounded by ground-water: on the Hallsworth unit, this is particularly along the concave upslope junction with other soils where springs and flushes rise from the relatively permeable, stony Head occurring between the soil and unweathered Carboniferous rocks; on Fladbury and Blithe soils, the water-table in the alluvium is maintained by the river level and periodic flooding. An evaluation of groundwater affecting surface water gley soils more widely on the Culm Measures outcrop is described in Harrod [1981, chapter 3]. Research carried out on undrained stagnogley soils at North Wyke indicated the shallow topsoil together with a high water table from autumn to early spring could be responsible for low earthworm diversity (Knight *et al.* 1992)

Given that springs and flushes are dealt with, drainage problems on both the Hallsworth and Halstow soils are similar, though are more acute on the former. Some improvement of the very limited permeability of the subsoils is vital. While response to secondary treatment by Halstow and Hallsworth soils is generally less than ideal, and failures have occurred, qualified success is more usual. Certainly on Hallsworth soils at Langabeare (Trafford 1971) mole channels periodically drawn into permeable backfill over drains at 1m depth were effective. Comparison of drainage with and without moling on Tedburn [now Hallsworth] soils (Harrod 1981) confirms the benefit in substantially reducing waterlogging of surface horizons.

On Fladbury and Blithe soils, improvement of permeability of subsoils can only be worthwhile and effective if the water-table can be depressed. This can only be feasible where the normal river level remains well below the soil surface.

While effective drainage will substantially improve the soils from their undrained state and increase the time over which they can be stocked and trafficked, there are limits to this benefit on clayey land. However intensive, drainage can only remove water by gravity when the soil is above field capacity. Clayey soils, notably Hallsworth and Halstow here, have retained water capacity (water content at field capacity) in excess of the plastic limit. Plastic limit represents the moisture content at which the soil changes from a robust, friable state to a delicate, deformable and plastic condition. Consequently these soils still require a substantial period of drying of the topsoil by evapotranspiration before they acquire sufficient bearing strength to be able to sustain stock or traffic without incurring damage. Results of studies measuring changes in soil strength with drying in contrasting soil types are presented in Appendix III.

4. SOIL CAPACITIES AND LIMITATIONS

4.1 Explanation

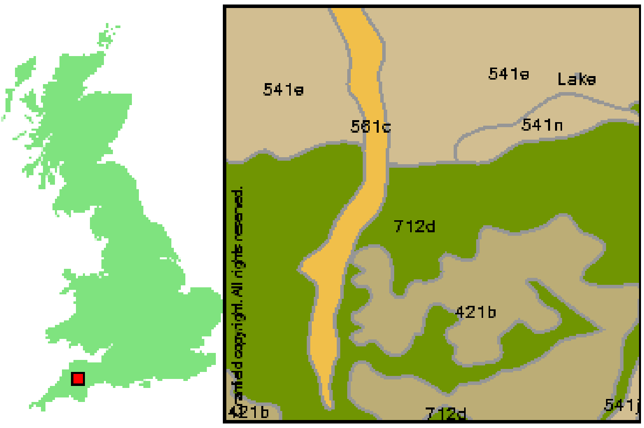
Since the production of the 1981 soil survey of North Wyke and Rowden, the National Soil Resources Institute (and its predecessors) have developed a database of soil information for England and Wales (the land Information System - LandIS), much digitised and linked to the 1:250,000 National Soil Map. It is now possible to obtain a Soils Site Report for any specified area (http://www.landis.org.uk/gateway/reports/), which identifies the soils occurring in that location, portraying the appropriate part of the National Soil Map, describes the properties of each soil map unit depicted, and uses thematic maps and charts to describe the relevant capacities and limitations of each soil, and how these might impact on a range of factors such as surface water quality. The information provided in sections 4 and 5 is taken from a Soils Site Report generated for a 5x5 km area around North Wyke, and refers to the map units appearing here on the National Soil Map (Figure 6). In consequence, it is important to note that class descriptions are intended for nation-wide application, and not tailored to specific local circumstances.

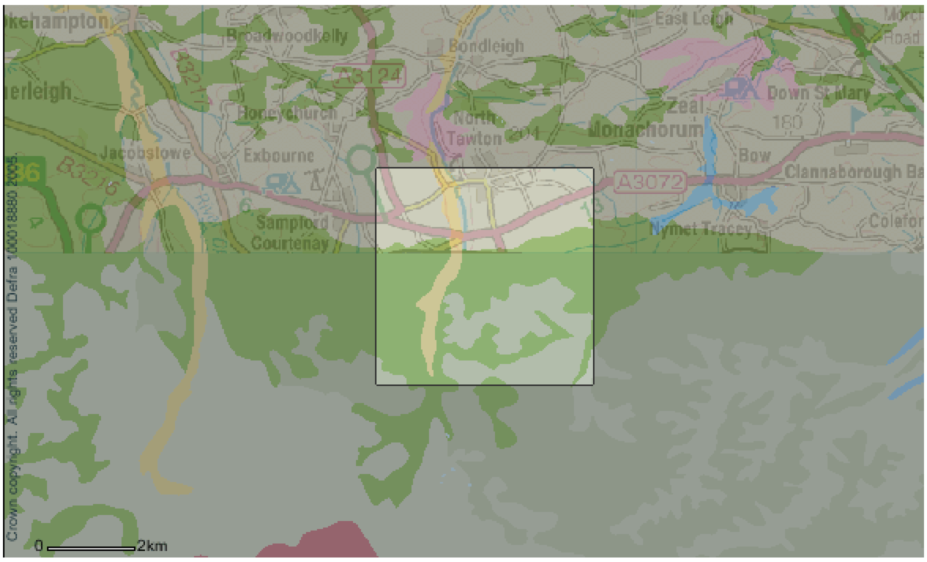
4.2 Hydrology of Soil Types (HOST)

The HOST classification (Boorman *et al.* 1995) describes soils in terms of the predominant pathway of water movement over, laterally through or vertically down the soil profile, based on properties of the soil, substrate and depth to groundwater. All soil series have been allotted to one of 29 HOST classes. It is widely used to predict river flows, flood risk and to model the dynamics of diffuse pollution (Hollis *et al.* 1995). The HOST class of soils around North Wyke are shown in Table 7, together with a brief description of their hydrological characteristics. It should be noted that the Crediton and Alun soil series do not appear on the detailed soil map of North Wyke and Rowden (Figure 4), though are found on the National Soil Map, the Alun in place of the Teign series, and the Crediton series occupying the redland at de Bathe. This is further described in section 5.1 Similarly these soils are included in the separate interpretations covered in this section (4.3 - 4.9).

Brookman *et al.* (1994), reporting the results of research at North Wyke into pollution risks resulting from disposal of dilute farm wastes using low rate irrigation (see also section 5 and Appendix IV), indicate the national extent and occurrence soils of the same or similar HOST category, as a means of contextualising a local study.

Figure 6 National Soil Map of the area around North Wyke





Key to soil associations
421b Halstow
541e Crediton
541j Denbigh 1
541n Trusham
561c Alun
712d Hallsworth 1

Table 7 HOST classes

National Soil Map Unit	HOST class	Description of HOST class
Crediton (541e)	3	Free draining permeable soils on soft sandstone substrates with relatively high permeability and high storage capacity
Alun (*includes Teign*) (561c)	8	Free draining permeable soils in unconsolidated loams or clays with groundwater at less than 2 m from the surface
*Blithe, *Fladbury	9	Slowly permeable, seasonally waterlogged soils in unconsolidated clays with groundwater at less than 40 cm from the surface
*Denbigh	17	Free draining permeable soils on hard (slate and shale) substrates with relatively low permeability and low storage capacity
Halstow (421b)	21	Slowly permeable soils with slight seasonal

		waterlogging and low storage capacity over slowly permeable substrates with negligible storage capacity
Hallsworth (712d)	24	Slowly permeable, seasonally waterlogged soils over slowly permeable substrates with negligible storage capacity

* At North Wyke, these soils occupy areas too small to depict on the National Soil Map

4.3 Ground movement potential

Clay-related ground movement is the most widespread cause of foundation failure in the UK and is linked to the seasonal shrinkage and swelling of the clay. This classification relates to the clay content of a soil and to the type of clay mineralogy, which regulates the potential capacity to shrink and swell. Categories for soils of the North Wyke area are given in Table 8.

Table 8 Potential for ground movement

National Soil Map Unit	Ground Movement Class	Description
Crediton (541e)	1	Very low
Alun (includes Teign) (561c) Halstow (421b)	2	Low
Hallsworth (712d)	3	Moderate

4.4 Flood vulnerability

The likelihood of inundation by flood water depends on a variety of factors. These include low-lying position, duration and intensity of rainfall, and exceptionally high tides or strong winds. Sediment transported by and deposited from floodwaters can compound damage to properties resulting from flooding. Identification of those areas subject to historic flooding (coinciding with soils developed in alluvium) is a key factor in assessing present-day flood risk. The alluvial soils along the Taw mapped as Teign (Alun (561c) on the national soil map), have major flood risk, while all other soil units are at low risk.

4.5 Risk of corrosion to ferrous iron

Buried iron pipes and other utilities and structures corrode at rates influenced by soil conditions (Jarvis and Hedges 1984). Important controlling factors are acidity, degree of oxidation or reduction and sulphide content, and wetness. Degree of risk in soils around North Wyke are given in Table 9.

Table 9 Risk of corrosion to ferrous iron

National Map Unit	Corrosion Risk Class	Description
Crediton (541e) Alun (includes Teign) (561c)	1	Non-aggressive
Halstow (421b)	2	Slightly aggressive
Hallsworth (712d)	3	Moderately aggressive

4.6 Pesticide leaching risk

The natural permeability and water regime of soils are influential in determining the fate and behaviour of pesticides applied to the crop and soil surface (Hollis *et al*. 1995). This system of vulnerability assessment was devised as part of the national initiative for Policy and Practice for the Protection of Groundwater. This divides soils into three primary vulnerability classes:

- H. Soils of high leaching capacity with little ability to attenuate non-adsorbed pesticide leaching, which leaves underlying groundwater vulnerable to pesticide contamination
- I. Soils of intermediate leaching capacity with a moderate ability to attenuate pesticide leaching
- L. Soils of low leaching capacity through which pesticides are unlikely to leach

These primary classes are further subdivided into nearly forty subclasses, four of which are identified around North Wyke (Table 10). However, it should be pointed out that this system does not take into account differences in land cultivation which can have a significant impact on pesticide behaviour.

Table 10 Pesticide leaching classes

National Map Unit	Pesticide Leaching Class	Description
Halstow (421b)	H1n	Shallow soils over hard, non-porous rocks
Crediton (541e)	I1dt	Deep loamy soil over soft sandstone with deep groundwater
Alun (includes Teign) (561c)	I1sy	Deep loamy soil; groundwater at shallow depth
Hallsworth (712d)	Lq	Impermeable soils over soft substrates of low or negligible storage capacity that sometimes conceal groundwater-bearing rocks at depth

4.7 Pesticide runoff risk

The physical properties and water regime of soils influence the speed and extent of lateral water movement over and through the soil at different depths (Hollis *et al.* 1995). On this basis, soils can be classed according to their potential to generate pesticide runoff. Mineral soils are further subdivided according to their potential for pesticide adsorption (Table 11).

Table 11 Pesticide runoff risk

National Map Unit	Pesticide runoff class	Description
Halstow (421b) Hallsworth (712d)	S2m	Soils with high runoff potential but moderate adsorption potential
Alun (includes Teign) (561c)	S3l	Soils with moderate runoff potential and low adsorption potential
Crediton (541e)	S4l	Soils with low runoff potential but low adsorption potential

4.8 Hydrogeological rock type

A hydrogeological classification of soil parent material (Boorman *et al.* 1995) provides a framework for distinguishing among soil substrates according to their general permeability and whether they are likely to overlie an aquifer. Nationally, every soil series has been assigned to one of 32 substrate classes, each of which is characterised according to its permeability (*permeable, slowly permeable* or *impermeable*). Categories of soils around North Wyke are shown in Table 12.

Table 12 Hydrogeological rock types of soil parent materials

National Map Unit	Rock Type	Description
Crediton (541e)	1	Soft-bedded sandstone or weakly consolidated sands
Halstow (421b)	8	Soft shales with subordinate mudstones and siltstones
Alun (includes Teign) (561c)	15	River alluvium
Hallsworth (712d)	22	Till and compact Head

4.9 Groundwater Protection Policy (GWPP) leaching

GWPP classes describe the leaching potential of pollutants through the soil (Hollis *et al*. 1995; Palmer *et al*. 1995). The likelihood of pollutants reaching groundwater is described. Different classes of pollutants include liquid discharges, adsorbed and non-adsorbed pollutants.

Table 13 GWPP leaching classes

National Map Unit	GWPP Leaching Class	Description
Halstow (421b)	H1	Soils of high leaching potential, which readily transmit liquid discharges because they are either shallow, or susceptible to rapid bypass flow directly to rock, gravel or groundwater.
Crediton (541e) Alun (includes Teign) 561c	I1	Soils of intermediate leaching potential, which have a moderate ability to attenuate a wide range of diffuse source pollutants, but in which it is possible that some non-adsorbed diffuse source pollutants and liquid discharges could penetrate the soil layer.
Hallsworth (712d)	L	Soils in which pollutants are unlikely to penetrate the soil layer either because water movement is largely horizontal, or because theyhave a large ability to attenuate diffuse source pollutants.

5. NATIONAL CONTEXT OF SOILS OCCURRING AT NORTH WYKE AND ROWDEN

5.1 Introduction

Much of the information presented in this section, as in section 4, is taken from the Site Soils Report for a 5x5 km area around North Wyke. Because of limitations of scale, the mapped areas (soil associations) indicated at North Wyke and Rowden (Harrod 1981) had required some simplification and generalisation for portrayal on the 1:250,000 National Soil Map. Also, as explained in section 2.1, some changes have occurred in soil series names, while this report also includes soils of other land lying beyond the boundaries of North Wyke and Rowden. In this locality, the National Soil Map indicates Halstow remains unchanged, while Dunsford, Teign and Tedburn appear as Denbigh, Alun and Hallsworth associations respectively. Crediton series is mapped at De Bathe. The Taw series is now included in Fladbury, though its extent at North Wyke was insufficient to depict on the National Soil Map. Information on the national extent of Fladbury soils is taken from the NSRI database for this soil association which has been mapped extensively elsewhere.

It is important to note that the functional capabilities of any individual soil are likely to vary among geographical locations due to factors such as climate. In consequence, care should be taken in making assumptions about how a particular soil occurring at North Wyke may behave where it occurs elsewhere in the country. Similarly caution should be exercised in the extrapolation of research results of field experiments at North Wyke to other localities having similar soils.

For each soil association, the Soil Site report includes schematic diagrams of the vertical soil profile of the major constituent soil series, and also provides graphical summaries of soil properties of selected attribute data as follows:

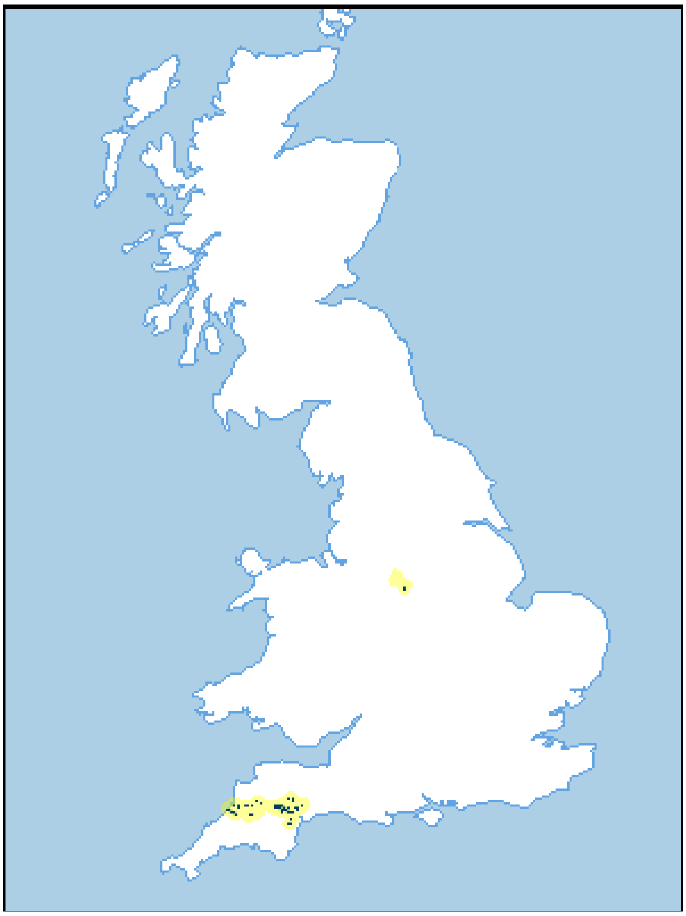
- Soil depth to rock, gleying, and semi-permeable layers (upward and downward percolation)
- Soil hydrological information (integrated air capacity (IAC), standard percentage runoff (SPR) and base flow index (BFI)
- Available water content (for grass, cereal, sugar beet and potatoes)

For soil series named in the following sections but not described elsewhere in this report, Clayden and Hollis (1984) provide definitions and reference sources for more detailed descriptions, while their distribution is recorded on the appropriate regional sheets of the National Soil Map (Soil Survey of England and Wales, 1983). It should be noted that the distribution of soil associations depicted on the following maps (Figures 7–11) applies only to England and Wales, and it is possible that similar soils may occur in Scotland, enquiries concerning which should be directed to the Macaulay Institute (http://www.macaulay.ac.uk).

5.2 Halstow association (421b)

These slowly permeable clayey soils often over shale occupy 280 km^2 (0.19%) of land in England and Wales mainly confined to clay shales of the Culm in Devon and Cornwall (Figure 7). The overall national proportions of component series are Halstow (40%), Hallsworth (20%), Tedburn (20%), Denbigh (10%) and other minor soils (10%), though these proportions vary from one location to another. Brookman *et al.* (1994) list soils of the same HOST category found elsewhere in England and Wales.

Figure 7 Distribution of the Halstow association

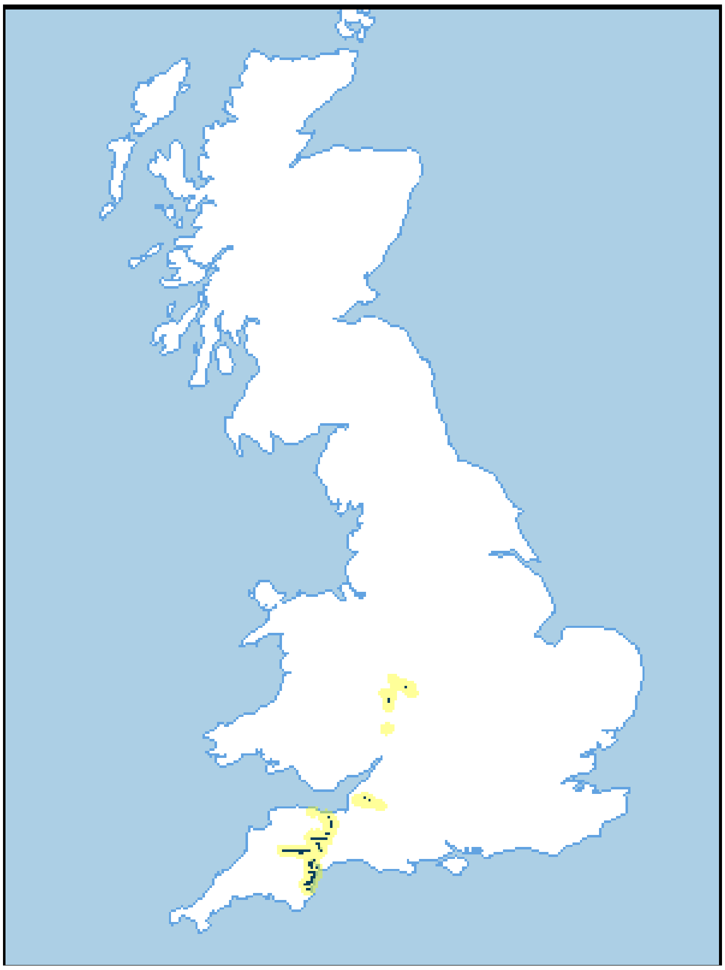


The distribution of the Halstow association is shown in black.
Yellow areas indicate where very small areas are found.

5.3 Crediton association (541e)

These well drained gritty loamy soils occupy 410 km^2 (0.27%) of land in England and Wales mainly confined mainly to Permian breccias in Devon and Somerset, with a small amount found in the West Midlands (Figure 8). The overall national proportions of component series are Crediton (40%), Shaldon (20%), Wrington (20%), Bromsgrove (10%) and other minor soils (10%), though these proportions vary from one location to another.

Figure 8 Distribution of the Crediton association

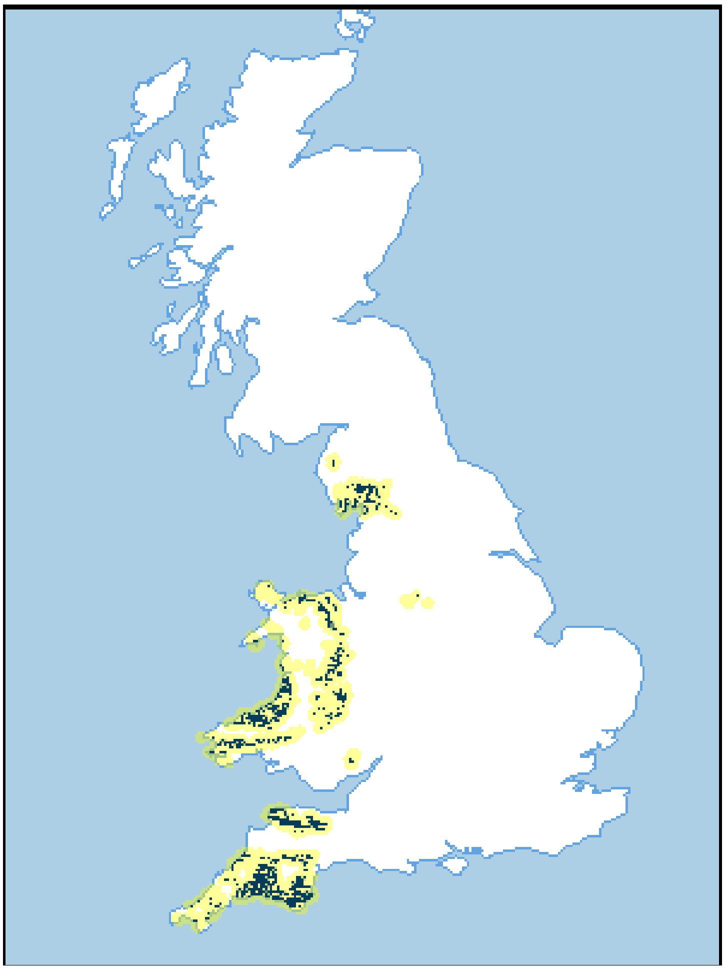


The distribution of the Crediton association is shown in black.
Yellow areas indicate where very small areas are found.

5.4 Denbigh 1 association (541j)

These well drained medium loamy and silty soils over slate occupy 4630 km^2 (3.06 %) of land in England and Wales, extensively in south-west England and Wales and also north-west England (Figure 9). Associated soils include similar soils affected by slight seasonal waterlogging due to slowly permeable subsoils, and shallow soils over rockThe overall national proportions of component series are Denbigh (40%), Barton (10%), Powys (10%), Sannan (10%), Manod (5%) and other minor soils (25%), though these proportions vary from one location to another. Brookman *et al.* (1994) list soils of the same HOST category found elsewhere in England and Wales.

Figure 9 Distribution of the Denbigh 1 association



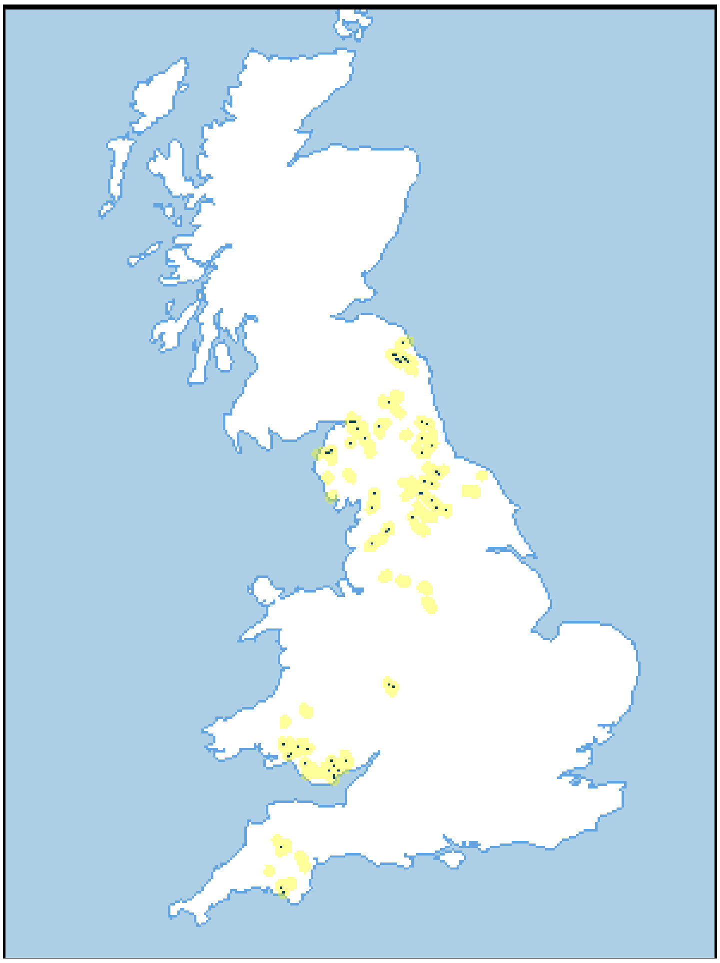
The distribution of the Denbigh 1 association is shown in black.
Yellow areas indicate where very small areas are found.

It should be noted that Denbigh soils at North Wyke, mapped as the Denbigh-Cherubeer unit (Dg-Chb) (Figure 4), are closer to the concept of the Denbigh 2 association of the National Soil Map. Here well drained Denbigh soils are associated with profiles having some degree of seasonal waterlogging expressed by gleying in the subsoil. The separations of the Denbigh-Cherubeer map unit at North Wyke are too small to appear on the small scale National Map; the Denbigh 1 association, appearing on the 5 x 5 km area (Figure 6), occurs on steep land and away from North Wyke, where the main associated soils are shallower but generally not wetter than the Denbigh series.

5.5 Alun association (561c)

These deep stoneless permeable light loamy soils occupy 349 km^2 (0.23 %) of land in England and Wales, occurring principally along many river floodplains in the north of England and in south Wales (Figure 10). Associated soils are variably affected by groundwater, over gravel in places. The land can be at risk of flooding. The overall national proportions of component series are Alun (50%), Enborne (15%), Trent (15%) and other minor soils (20%), though these proportions vary from one location to another.

Figure 10 Distribution of the Alun association

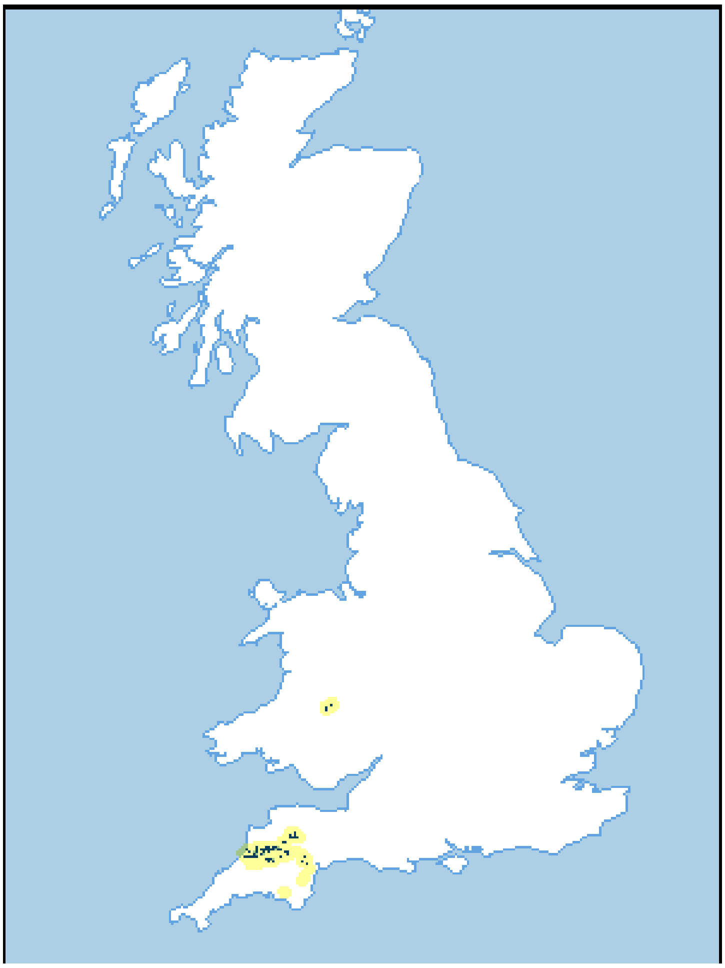


The distribution of the Alun association is shown in black.
Yellow areas indicate where very small areas are found.

5.6 Hallsworth 1 association (712d)

These slowly permeable clayey soils occupy 336 km^2 (0.22 %) of land in England and Wales, almost entirely over clay shales of the Culm in Devon and Cornwall with a small occurrence in mid-Wales (Figure 11). The overall national proportions of component series are Hallsworth (60%), Tedburn (15%) and other minor soils (25%), though these proportions vary from one location to another. Brookman *et al.* (1994) list soils of the same HOST category found elsewhere in England and Wales.

Figure 11 Distribution of the Hallsworth 1 association



The distribution of the Halsworth 1 association is shown in black.
Yellow areas indicate where very small areas are found.

5.7 Fladbury 1 association (8.13b)

These stoneless clayey soils, variably affected by groundwater, occupy ha (0.54%) in England and Wales, and occupy many river valleys predominantly from south-west England to the east Midlands and in Essex. Due to its local occurrence being limited to a narrow, alluvial backland strip in the Taw Valley, it is included within the Alun unit (5.61c) on the small-scale National Soil Map. In consequence no map of its national distribution is included with the Site Soil report for the 5x5 km area around North Wyke. The overall national proportions of component series are Fladbury (70%), Thames (15%) and Wyre (15%). Despite being uniformly clayey, the proportion of component soils occurring varies from place to place depending on the presence or otherwise of calcareous soil material and the degree of natural drainage. .Brookman *et al.* (1994) list soils of the same HOST category found elsewhere in England and Wales.

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Acknowledgements

The following staff at North Wyke Research are thanked for their help in the production of this report: Deb Beaumont, Bruce Griffiths, Mel Leonard and Andy Stone. Help was also provided by Dick Thompson and his colleagues at NSRI (Cranfield University) for supplying data from LandIS via a Soils Site Report for the area around North Wyke, and giving permission for the inclusion of maps.

APPENDICES

APPENDIX I SOILS OF NEIGHBOURING RESEARCH LOCATIONS

Long-term use or renting by IGER of land and sub-catchments locally, but beyond North Wyke and Rowden, has taken place for a number of years. At each location described here, soil surveys have been carried out, with descriptions given of the soils found and, where appropriate, a soil map is provided.

a) De Bathe (NGR SS666 005)
The freely draining red soil sites east of de Bathe Cross form a useful contrast with the predominantly heavy, wet land at North Wyke and Rowden. Shown on the National Soil Map (Soil Survey of England and Wales 1983) as Crediton Association (541e), these comprise very stony, loamy typical brown earths of the Crediton series together with typical argillic brown earths of the Shaldon series. Topsoils are reddish brown and overlie red or reddish brown subsoils, with weathering Permian breccia below about 70 cm. Subsoils are somewhat heavier (clay loam) in the Shaldon compared with the Crediton series. Topsoil organic matter contents are visibly less than on the Halstow (2.3) and Hallsworth (2.4) soils at North Wyke and Rowden, the red land having a history of more frequent cultivation. Close examination of these soils between de Bathe Cross and Stone Cross confirms the predominance of Crediton and Shaldon series, the two occurring as an admixture lacking any clear pattern of distribution one against the other.

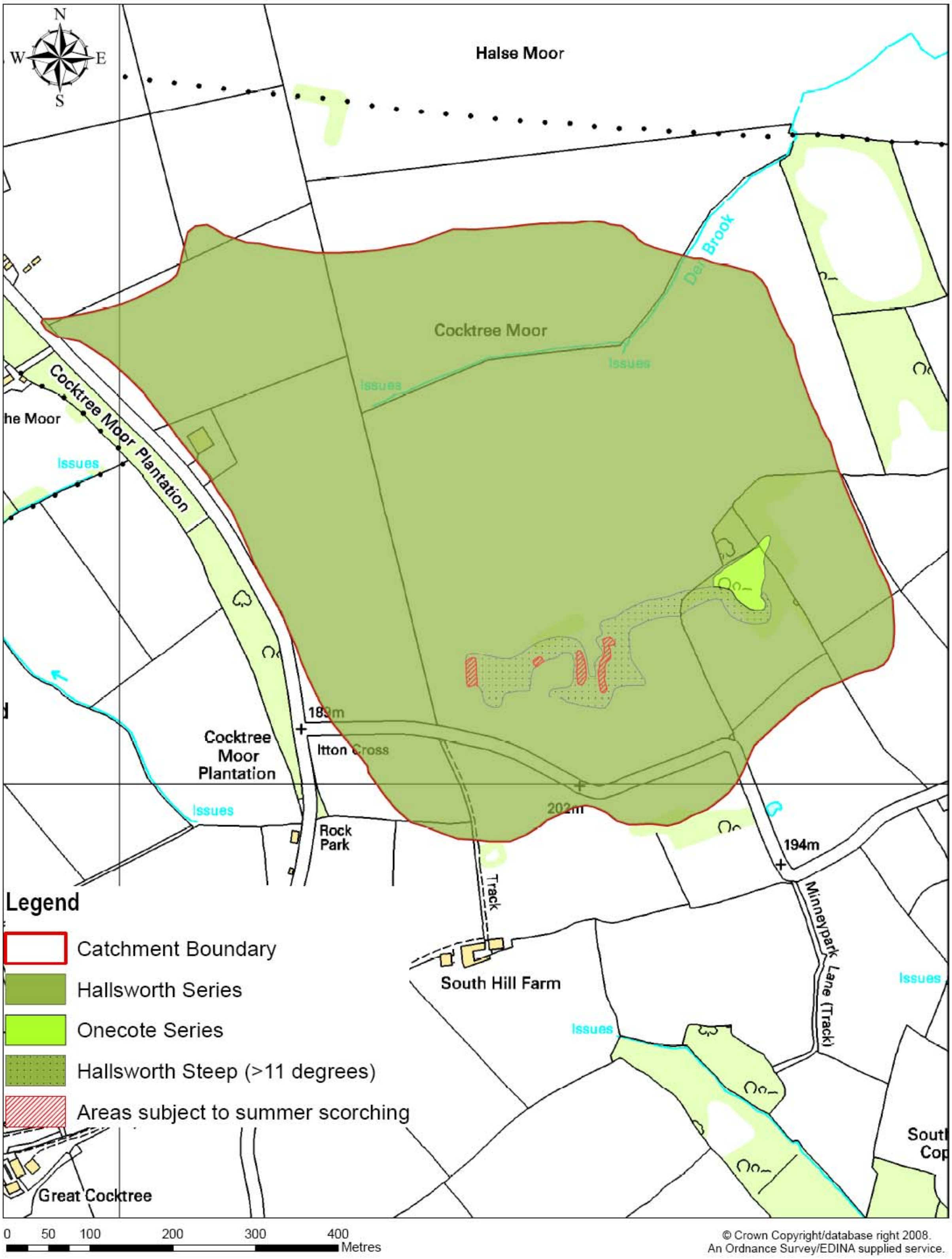
However, many of the subsoils contain small amounts of fine, black ferri-manganiferous stains and concretions, usually absent from the Crediton and Shaldon series further east. Normally ferri-manganiferous deposits are associated with gleyed soil horizons, indicating seasonal wetness and anaerobic conditions, although gleying is nowhere present on this red land. It is well established that in soils derived from red rocks, the iron minerals weather less readily from ferric to the reduced ferrous forms associated with gleying, belying (Clayden, 1971, p 68) the duration of waterlogging, due to either soil hydrology or climatic wetness. In this context it is worth noting that the western extremity of the red rock outcrop near Holsworthy, carries gley soils of the Hollacombe series [Harrod, 1978]. De Bathe Cross lies midway between Holsworthy and the somewhat drier country around Exeter, and the ferri-manganiferous deposits here may herald the approach of a climatically controlled threshold of soil weathering and hydrology. Examination of soil hydrology, particularly duration of subsoil waterlogging, in the red soils around de Bathe, seems desirable, preferably with comparable measurements on Crediton series nearer to Exeter. Simple techniques, such as the shallow dipwells used by Clayden (1971, Appendix II), would suffice.

b) Den Brook (NGR SX 67712 99685)
This has been used, together with Drewston (described below) as a study catchment for research to assess the potential loss of P from agriculture and risks to water quality (Page *et al.* 2005).The Hallsworth series (2.4), a clayey typical pelo-stagnogley soil weathered in Head from shales of the Crackington Formation, dominates the catchment, even blanketing much of the steeper ground (Figure 12). It is the main soil also found at Rowden and Falcadon Moors. Topsoil, at least when structurally in "good heart", provides a small amount of excess water storage when the soil is at field capacity. Thickness of 25 to 30 cm occurs under about 60 percent of the land. Topsoils 15 cm or thinner affect about a third of the ground, (about 9 percent being 10 cm or less), while topsoils thicker than 35 cm occupy a further 9 percent. Topsoil thickness may partly reflect variations in land cover. Woodland topsoils tend to be thinner than those under pasture. However, the effects of mechanised "improvement" and land drainage must not be overlooked, bulldozing of banks and tree stumps, for example, producing both thicker and thinner topsoil, and at least in one location, buried profiles.

There are some variations away from the modal Hallsworth profile. About a fifth of profiles, mostly towards the north of the catchment, have a small number of red mottles in the subsoil. These may be of geological origin, reflecting the nearness of the Permian red rocks of the Crediton "finger," or they may be relict palaeosol features. Sporadic profiles with less gleyed topsoils and subsoils are present, but nowhere are they sufficiently concentrated to map out. About 10% of the land is underlain by soils with smaller clay content in the subsoil, mostly silty clay loams of the Cegin series. Occasional areas with significant accumulations of organic matter in the topsoil occur around sites of springs and flushes. Except for the area mapped at 758 902 in the southeast of the catchment, these are too small to delineate by mapping.

Figure 12 Soil map of the Den Brook catchment

Soils of the Denbrook Catchment



Soil mapping by T.R.Harrod

In other parts of the Culm shale country, such as the 'dunland' of the Middle Teign valley (Clayden 1965) and Exeter district (Clayden 1971), the clayey soils on gentler slopes give way to lighter, freely drained "shilloty" soils on steep slopes, in a hydrological or catenary sequence. It is likely that the slopes here at Den Brook are approaching the threshold of this change. However, close augering there shows that ungleyed brown soils are largely absent. This is so even in the strips that scorch badly in dry weather, where the clayey subsoils are more shaley and shallower over shale bedrock.

A small area of Onecote Series (Hollis 1975), clayey cambic stagnohumic gley soils is formed in an area of springs at SX677992, where topsoils are humose or peaty and developed over grey, intensely gleyed subsoils. The field immediately north of Itton Cross contains occasional flints in the topsoil. These would have been brought in with imported straw from Hampshire and are not of geological or archaeological interest.

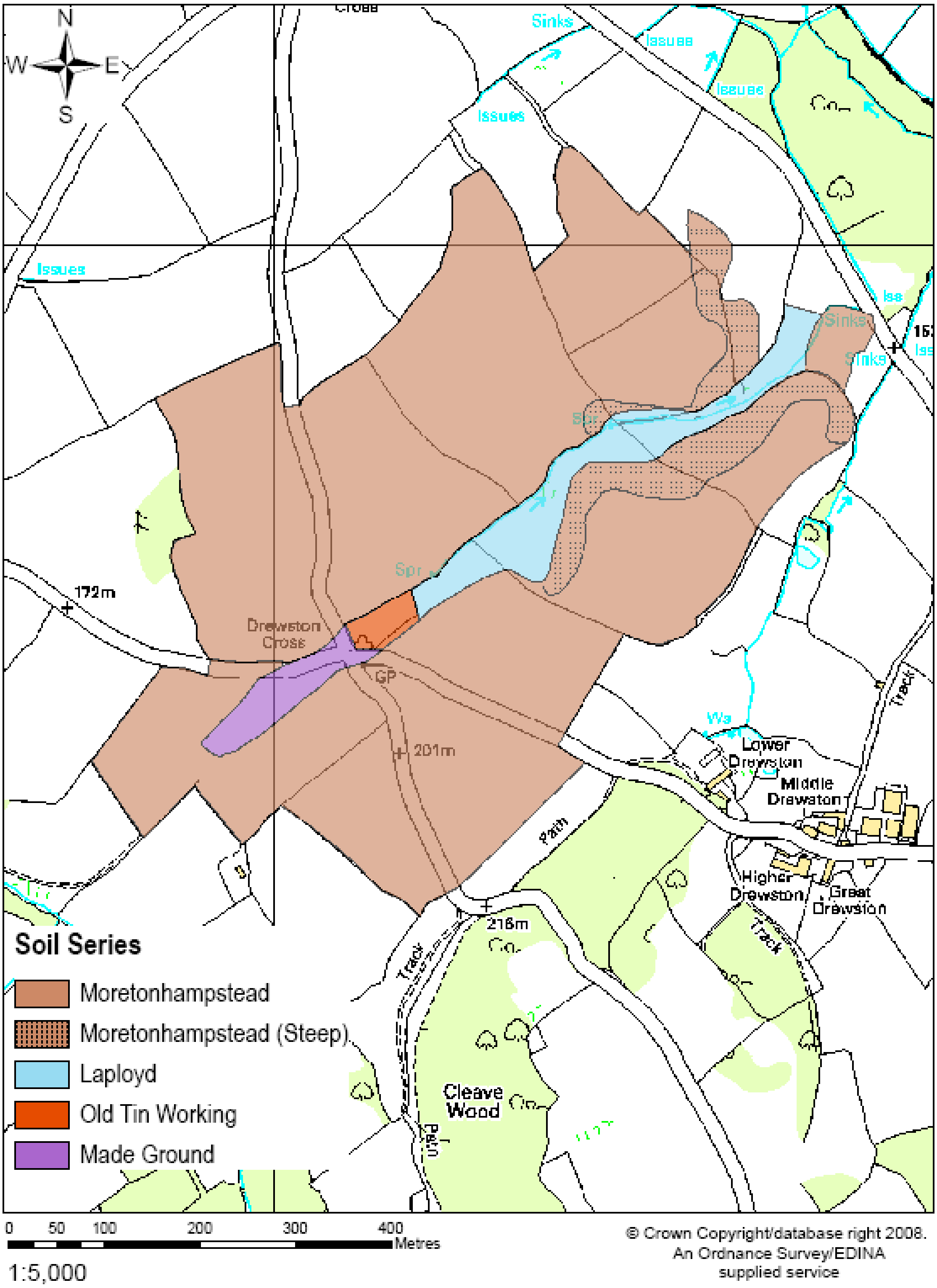
c) Drewston (NGR SX 72495 87857)
This has been used, together with Den Brook (described above) as a study catchment for research to assess the potential loss of P from agriculture and risks to water quality (Page *et al.* 2005). This small catchment overlies Dartmoor granite in the rain-shadow east of the high moorland. The soils are weathered in 0.3- 4 m of gritty or gravelly and variably bouldery residue (often termed *growan*) of the granite. In places the granite has suffered chemical decomposition, either by deep weathering during hot episodes during the Tertiary, or earlier during the cooling of the granite magma.

The porous nature of the soils and the growan, plus fracturing of the granite, means that most of the soils are freely draining Moretonhampstead series, typical brown podzolic soils (Figure 13). These are stony, gritty sandy silt loam or sandy loam, with dark brown topsoils over strong brown or brown subsoils, passing to pale brown growan by about 70 cm. Soil profile depth varies from about 25-100 cm, depending on the thickness and boulderiness of the growan. Soils of the Moretonhampstead series in this area are a little unusual in that topsoil thickness can be frequently as much as 35–50 cm.

Slopes are generally slight to moderate (less than 12^{o}) but steeper on the immediate valley side leading down to the bottom land. The valley bottom carries humic gley soils of the Laployd series, which are strongly affected by groundwater and springs. Topsoils are humose, gritty sandy silt loams over mottled, greyish gritty sandy loams, sandy silt loams or clay loams. Near Drewston Cross, the valley line has been open mined, as it follows a tin lode, with the excavated ground south west of the Cross subsequently filled with builders' rubble and other refuse.

Figure 13 Soil map of the Drewston catchment

Soils of the Drewston catchment, Chagford



Soil mapping by T.R.Harrod.

APPENDIX II ENVIRONMENTAL CHANGE NETWORK

The Environmental Change Network (ECN) was established as a number of selected sites across the UK to collect comparable long-term environmental data at regular intervals in order to predict long-term trends in environmental change in response to changing land use, climate and pollution levels. A key environment factor to be assessed and regularly monitored was that of soil, and one of the sites was set up at North Wyke (at Rowden SX 659980) in 1992. The target sampling site (TSS), that area designated for destructive sampling at future monitoring dates, is 0.66 ha, which is 34 percent smaller in area than the optimum, due to vegetation requirements and constraints imposed by the research activities at North Wyke. Details of the methodology and soils together with preliminary analytical results are described by Beard (1993).

The availability of the soil report and map (Harrod 1981) for this site precluded the need for extensive preliminary investigations of the soils at North Wyke: in 1992, a grid survey at 50 m intervals were undertaken by hand augering to enable selection of the optimal, suitably uniform location for the TSS, Subsequently a 25 m grid survey was made of the TSS itself. The results of these detailed surveys suggested a more complex pattern of soils (Bardsey, Dale, Greyland, Hallsworth, Tedburn series and ‘disturbed land’) than indicated by the previous 1:10,560 scale map (Hallsworth map unit), reproduced at 1:10,000 scale in the ECN report. This is due partly to the scale of investigation, but primarily to differences in interpretation of the lithological component of the soil series definition. This hinges on the Bardsey and Dale series (not mentioned in descriptions of the soils of North Wyke) differing from Cherubeer and Hallsworth series in being described as profiles *passing to shale* rather than *in drift containing sandstone and shale*: *ie* a difference in interpretation of relationship to parent material. In undertaking the soil survey of North Wyke (Harrod 1991) it had also been considered important not to add undue complication by the introduction of too many soil series names for soils essentially very similar in character and behaviour, while at the same time retaining consistency of interpretation of parent material over the Carboniferous outcrop of central Devon as a whole.

Soil pits were excavated for profile descriptions and as part of the requirements for sampling on a 20 year cycle. Six descriptions are given of the Dale (3), Tedburn (2) and Ticknall (1) series, together with results of particle-size and chemical analyses. Water retention properties are described using diagrams which are also included in this report (2.8).

APPENDIX III EXAMINATION OF SOIL STRENGTH UNDER PASTURE IN MID-DEVON

Introduction

The object of the work was to gauge the scope of an approach relating soil strength to routine soil survey observations and interpretations used for assessing soil workability in conjunction with weather and climatic data, supported by a data base suitable for statistical analysis.

The broad interactions of soil with meteorological and climatic conditions can be taken as similar in influencing the workability of soil on the one hand, and the ease of trafficability and risk of poaching on the other. Consequently, in the early 1980s, it seemed possible to develop the Soil Survey methodology on landwork assessments for different soils and districts into an assessment of safe grazing days. To test this idea, a small pilot study was carried out on farms in mid-Devon between September 1983 and December 1985.

Method

The sites chosen were on long-established grass fields on two dairy farms having soils known to occur extensively in mid-Devon, including around North Wyke: Hallsworth series (pelo-stagnogley soils), Halstow series (non-calcareous pelosols), Crediton series (typical brown earths), and Alun series (typical brown alluvial soils). For each series, four sites were monitored, across two fields in the case of the Hallsworth, Halstow and Alun series, and within a single field for the Crediton series. In each case, sites were at least 50 m apart. All 16 sites were within 1.5 km of grid reference SX782982. At each of the Hallsworth, Halstow and Alun sites, a dipwell was installed to 80-90 cm depth. Only one dipwell was used on the Crediton series, since this very permeable soil has a reputation for very rapid drainage and ready winter trafficability.

Monitoring comprised measuring soil strength at each site using a hand-held Farnell soil assessment penetrometer during autumn, winter and spring periods, when the soils were weak, being near or above field capacity. The disadvantage of the instrument being hand-operated was minimised by restricting this study to a single operator. For such a pilot study, the Farnell instrument has the advantage over automated penetrometers in both the speed with which it can be used, and its capability for use at shallow depths. In addition, stones in the soil can be detected and results rejected if conditions are considered unsuitable, ie if it is likely that measurements might be reflecting stoniness rather than soil strength.

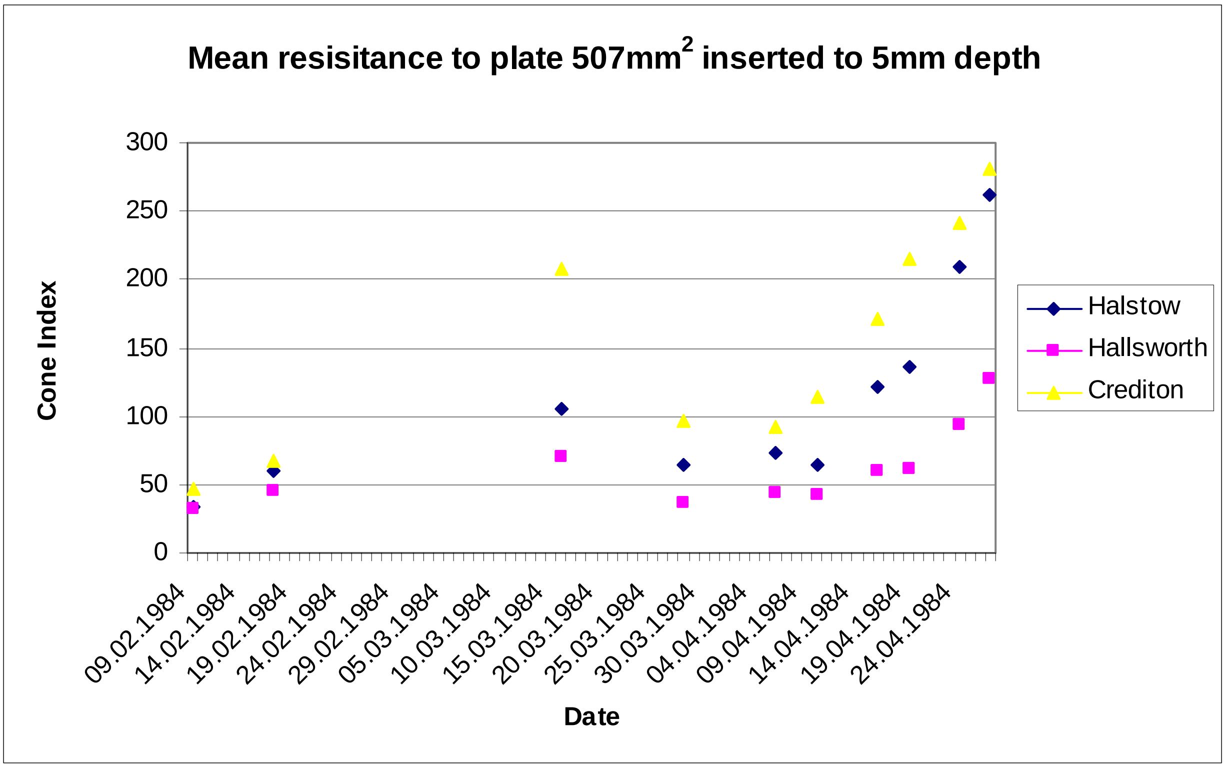
Measurements were made at about 10 day intervals, though more frequently if weather and ground conditions changed. At each visit, 10 observations were made ‘at random’ within 10 m of the site centre, usually marked with a dipwell, using each of the following methods:

- The standard Farnell 129 mm^2 (CBR) cone inserted to 10 cm depth
- A 507 mm^2 flat circular plate inserted to 5 mm
- The 507 mm^2 plate inserted to 10 cm

Results

The spring of 1984 was particularly fortunate in regard to this pilot study, since following a wet spell at the end of March, only 7.9 mm of rain fell until 22 May. This allowed a direct comparison to be made of changes in measured soil strength with the development of a moisture deficit, without

Figure 14 Results of soil strength study



the complication of fluctuations in soil strength attributable to sporadic re-wetting of the soil as would be seen in rises in dipwell water levels.

The field capacity period in 1984 ended on 6th April. On 8th April, soil strength of the well drained Crediton and Alun series rose to index 100 (Figure 14), which equates to a loading of about 0.425 MPa (4.3 kg cm^{-2}). Both series would be given soil assessment a on the scale of weightings aa to f, using Soil Survey field capacity data sets for estimating machinery work days (Findlay et al. 1984). The mean Halstow values crossed the index 100 line on 14th April, 8 days after the end of capacity when the meteorological soil moisture deficit was 12.5 mm. Halstow soil assessment in this district is d. The mean Hallsworth (soil assessment e) values were delayed a further 8 days until 22nd April before exceeding index 100, when soil moisture deficit was 32 mm.

The mean date for the end of the field capacity period here is 28th April (Jones and Thomasson 1985). Data given by Harrod (1981, p 12) for Eggesford, about 10 miles further down the Taw Valley suggests that in April and May, soil moisture deficit develops at about 2.7 mm per week. At this rate, it would take Halstow soils on average 4 to 5 weeks to develop the 12.5 mm deficit required to attain the index 100 strength which occurs in Crediton and Alun soils shortly after field capacity is reached. Under similar average conditions, 6-8 weeks might be required for Hallsworth soils. Soil weightings for estimating machinery work days place Halstow 20 days, and Hallsworth 25 days behind Crediton soils in the spring for undertaking land-working under similar conditions.

Conclusion

The evidence available from the spring of 1984, suggests that while the relative ordering of soils is appropriate, in simple terms of changes in soil strength under grass, the original formula for calculating safe grazing days may underestimate the time required for these soils to strengthen. It may also point to the need for a review of the soil assessment weightings.

These results represent only 8 of the 29 sets of site visits for one of the three observation categories for soil strength. The work demonstrates the value in the use of a simple penetrometer in rapidly providing a substantial amount of reliable data on soil strength at relatively low cost.

APPENDIX IV RESEARCH PROJECT AT NORTH WYKE TO INVESTIGATE THE DISPOSAL OF DIRTY WATER BY LOW RATE IRRIGATION

Summary of findings

These notes summarise a report by Brookman, Pain and Harrod (1994) into work carried out at North Wyke. The disposal of dirty water (dilute farm wastes including parlour washings and yard run-off) by low rate irrigation can lead to pollution by surface flow across the land or contamination of drainage waters. Investigations measured the impact of such irrigation on the volume and composition of run-off, drain flow and soil water. Results indicated where improvements might be made in best management practices.

Pollution was dependent on soil type and conditions, application rates and presence or absence of artificial drainage. Irrigation should be avoided on wet sloping land. High risk of pollution also occurred on well drained permeable soils under dry conditions, and on drained land under all but the driest of summer conditions.

Key issues were found to be application rates, design and operation of systems of delivery, and the need for farm-specific design strategies, establishing safe distances between irrigation locations and water courses

Extrapolation of soil research results from North Wyke

When extrapolating the results of soil research at North Wyke to other localities, there are a number of important considerations to bear in mind. While the National Soil Map indicates where the same soils associations are found elsewhere in England and Wales (Figures 7-11), these do not take into account other factors which are likely to affect land use, crop performance, and wider environmental impact. The main factors to consider are slope, climate and weather, and management practices. Conversely there are also soils which differ in their profile class from those at North Wyke because, perhaps, they have formed in different parent material, but may otherwise be similar with, for example, have the same HOST category. These have been listed by Brookman *et al.* (1994).

Slope

In general terms, the steeper the slope the greater the likelihood of run-off being generated. However, the character of run-off varies with slope form. Concave landforms are particularly prone developing a concentration of channels for run-off, independent of gradient. At the farm and field scale, it is particularly important to take into account both natural slope characteristics and man-made features such as wheelings, tracks and gateways in assessing hydrological pathways for drainage waters and consequent risk of pollutant transport.

Climate and weather

Variations in (particularly) rainfall, temperature and latitude across the country affect the duration and degree of both soil wetness and dryness. While the duration and intensity of the general seasonal cycle of wetting and drying will vary from year to year, circumstances in individual years (wet summer periods or dry winters) can lead to interruptions in both field capacity and soil moisture deficit periods, in addition to affecting the amount of excess winter rain and consequent run-off generated. The meteorological field capacity and soil moisture deficit periods, calculated from rainfall and evapotranspiration, assumes the soils are freely drained. In practice the actual soil moisture regime will differ in the case of hydromorphic soils (the majority of soils at North Wyke and Rowden) depending on the water retention properties of the soils, and the effectiveness of artificial drainage. Then field capacity period, adjusted to take account of soil properties, is much longer in duration than its meteorological equivalent.

Soil cracking

Cracks develop in slowly permeable and clay soils as they dry out in summer, though this may not be obvious at the surface under well-managed grassland. The propensity to crack depends on interactions among soil characteristics and environmental conditions (Reeve *et al.* 1980). Critical soil properties are clay content, clay mineralogy, water retention characteristics and structural development. Climate is the most important environmental factor determining whether sufficient water is lost to cause soil shrinkage as moisture deficits develop. Broadly speaking, Brookman *et al.* (1994) suggest a soil moisture deficit value of 75 mm as an arbitrary threshold for the onset of cracking, and provide maps depicting changing soil moisture deficits across England and Wales based on LandIS data. This illustrates national geographical variations, broadly duration and intensity increasing from west to east.

A Defra-funded project (*WQ0118 Understanding the behaviour of livestock manure multiple pollutants through contrasting cracking clay soils*) with ADAS is underway (2007-2012) to improve understanding of the interactions that occur on contrasting cracking clay soils among livestock manure pollutants (nitrate-N, ammonium-N, phosphorus, sediment and microbial pathogens), loss processes and pathways to water, and to test options for practical mitigation.

Land management

The infiltration rate and storage capacity of water together with contained nutrients and/or pollutants both within the soil and on the surface depend on land use and management, and cannot be determined for individual locations from LandIS. Adverse effects of management, such as ill-timed stocking or trafficking, causing damage to soil structure, are more likely to occur on wetter soils. However drier soils can also be adversely affected. Under grassland, activities such winter grazing with sheep can cause slurrying of the soil surface during wet conditions leading to a serious reduction in filtration rate and consequent increase in run-off risk. Similarly arable land can suffer structural degradation by capping, erosion and compaction. In general, freely drained medium-textured soils tend to become restructured more readily than wet heavy soils, a process that can be aided significantly by earthworm activity. Some studies of the role of earthworms in pasture soils at North Wyke are reported by Knight *et al.* (1992). Crop type influences some hydrological soil properties; subsoil cracks may not evident at the surface under well managed grassland while in the case of arable land, topsoil degradation can enable subsoil cracks to reach the surface.