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SEDIMENT YIELDS AND SEDIMENT DELIVERY IN THE CATCHMENTS OF SLAPTON LOWER LEY, SOUTH DEVON, UK.

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ABSTRACT

Existing sediment yield data for the catchments draining to Slapton Lower Ley are compared with published estimates for the catchment of the nearby Old Mill reservoir and are shown to be only about one third of what might be expected based on the data from that catchment. In order to explain this difference, field surveys, coupled with ^{137}Cs, mineral magnetic, geochemical and physical analysis of catchment soils and floodplain and lake sediments, have been used to first, examine the delivery of sediment from the hillslopes to the Lower Ley and construct a sediment budget for the main (Start) catchment draining into the lake; secondly, identify the dominant sources of the sediment deposited on the Start floodplain and in the Lower Ley and ascertain if there have been any changes in the main sources since the Second World War; and thirdly, evaluate the evidence provided by the lake-sediment record at Slapton for interpreting catchment processes. For the Start catchment, it is shown that a large amount of the material eroded from the hillslopes does not reach the basin outlet but is stored at intermediate locations such as upslope of hedge boundaries and on the floodplain. The amount of material stored in these locations since 1954 has been estimated and a tentative sediment budget for the Start catchment has been constructed. This budget suggests that some 15% of soil eroded from hillslopes is deposited behind hedgerows, whilst a further 58% is transferred to storage on the Start floodplain. Only 27% of the eroded soil reaches the Lower Ley. The most recent floodplain sediment is dominated by topsoil, primarily from pasture land, with increased contributions from subsoil sources at greater depths. With the exception of a short period of catchment disturbance in the 1940s, sediment accumulating in the lake is of topsoil origin, probably from areas of grazed pasture rather than cultivated fields. The physical characteristics of the Ley (i.e. water residence time and sediment trap efficiency), and the low sediment delivery to the lake, introduce significant limitations regarding the potential of the lake-sediment record at this site for inferring catchment processes.

INTRODUCTION

Over the last three decades, a substantial amount of research has been undertaken on the hydrology, water quality and sediment yields of the catchments draining to Slapton Ley in South Devon (Troake & Walling, 1973, 1974; Troake *et al.*, 1976; van Vlymen, 1979; Burt *et al.*, 1983, 1988; Johnes & O'Sullivan, 1989; Heathwaite *et al.*, 1990; Owens, 1990; Heathwaite, 1993; Heathwaite & Burt, 1993; O'Sullivan, 1993) and on the palaeolimnology of Slapton Ley (Crabtree & Round, 1967; O'Sullivan, 1989, 1992; O'Sullivan *et al.*, 1989, 1991; Heathwaite & O'Sullivan, 1991; Foster *et al.*, 1993;

Heathwaite, 1993). To date, however, no attempt has been made to evaluate the estimates of sediment yield produced by these various studies, to set them in a wider regional context or to examine the overall sediment budget of the catchments draining to the Ley. The most recent estimates of annual suspended sediment yield from the Gara, Slapton Wood, Start and Stokeley Barton streams were reviewed by O'Sullivan *et al.* (1989) and are shown in Table 1 (for site locations see Fig. 1). The estimates for the individual catchments range from <10 to >70 t km^{-2} year^{-1} and reveal a number of potential inconsistencies. For example, the specific sediment yield estimated for the Slapton Wood catchment for 1987–88 is significantly higher than the yields for the Gara, Start and Stokeley Barton streams for the same period and is also substantially higher than the two other estimates for the same catchment based on different periods. The total sediment flux to the Lower Ley at Slapton has also been estimated by O'Sullivan *et al.* (1991) by using unsupported lead-210 (^{210}Pb) and caesium-137 (^{137}Cs) measurements to establish a chronology for two lake sediment cores collected in 1987 (Heathwaite & O'Sullivan, 1991) and thereby estimate rates of sediment accumulation. This work suggested that since *ca* 1977 about 8 t ha^{-1} of dry sediment have been deposited annually on the lake bed, which is equivalent to a total mass accumulating in the Lower Ley of 610 t year^{-1}. By dividing the mass by the total catchment area of both the Upper and Lower Leys (46 km^2), O'Sullivan *et al.* (1991) derived a catchment sediment yield of 13.4 t km^{-2} year^{-1}. Although this appears to be consistent with the annual sediment yield estimates for the Start stream, it assumes that sediment delivered to the Higher Ley from the Gara and Slapton Wood catchments also reaches the Lower Ley. This is unlikely, since Burt (1994 pers. comm.) has estimated that only *ca* 118 t of sediment is transferred from the Upper Ley to the Lower Ley each year. Recomputing the sediment yield, based on the total catchment area of the Lower Ley (which is larger than the areas contributing to the river measuring stations of Table 1) and correcting for the transfer between the Upper and Lower Ley, provides a sediment yield estimate of *ca* 32 t km^{-2} year^{-1}. However, this value needs further adjustment to take account of the organic matter content of the lake sediment and the trap efficiency of the lake. The bottom sediments in the Lower Ley have an organic matter content exceeding 30% of the dry weight. Expressing these data on a minerogenic basis produces a reduced sediment yield estimate of *ca* 22 t km^{-2} year^{-1}. On the basis of van Vlymen's (1979) data, the capacity-inflow ratio (the ratio of lake volume to the annual runoff input) for the Lower Ley is calculated to be 0.05. Using the trap efficiency curve published by Brune (1953), the trap efficiency for the Lower Ley, based on a capacity inflow ratio of 0.05, is estimated to be only 76%. The trap efficiency-corrected estimate of minerogenic sediment yield to the Lower Ley therefore becomes 29 t km^{-2} year^{-1}.

These various studies suggest that, with the exception of the 1987–88 estimate for the Slapton Wood stream, maximum sediment yields from the catchments draining to Slapton Ley are *ca* 30 t km^{-2} year$^{-\lesssim 1}$. However, an analysis of sediment deposits in the nearby Old Mill reservoir (see Fig. 1 for location), reported by Foster & Walling (1994), has shown that sediment yields over the last 15 years, in an area of similar climate, lithology and land use, were *ca* 90 t km^{-2} year^{-1} (Fig. 2). The contemporary sediment yield from the Old Mill catchment is approximately three times greater than the lake-sediment based estimate of sediment yield to Slapton Lower Ley calculated above. Although sediment yields from the Old Mill catchment have increased over the past 50 years, evidence based on radionuclide and mineral magnetic fingerprinting of reservoir sediments and catchment soils suggested that, with the exception of a single high

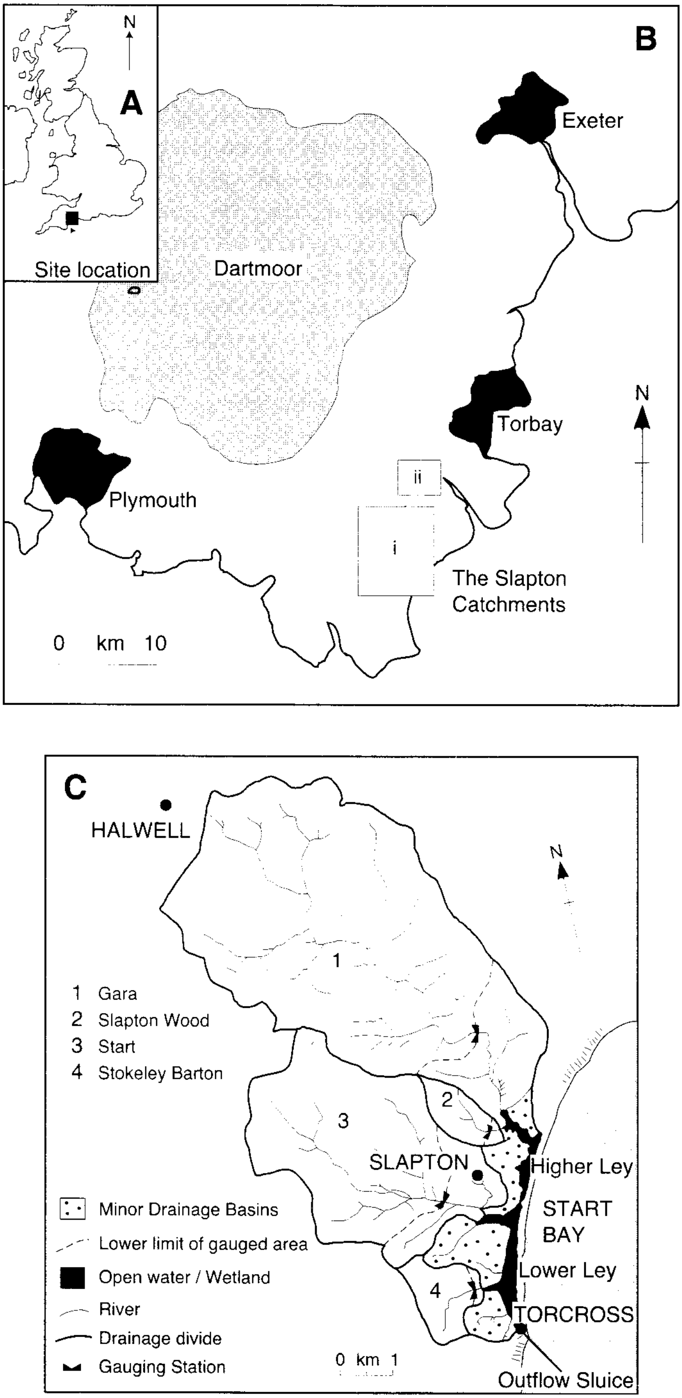

FIG. 1
Location of the study sites (A and B) showing the approximate area of the Slapton Ley (Box i) and Old Mill (Box ii) catchments. Details of the Slapton catchments are given in C.

magnitude event, sediment sources had not changed since the reservoir was constructed in 1942 (Foster & Walling, 1994).

The above evidence suggests that there are significant differences in suspended sediment yield between the catchments of the Lower Ley at Slapton and those from the catchment of the nearby Old Mill reservoir. These differences may simply reflect contrasting rates of soil erosion and sediment transport between these two areas. However, the close proximity of the two areas, and their similarity in terms of current land use, land use history, lithology, relief and climate, might be expected to produce more similar sediment yields. The possibility that the rates of sediment mobilisation operating in the two catchments are similar, but that contrasts in sediment delivery processes and in the overall sediment budget of the catchments draining to the Ley may result in different sediment outputs, must also be considered.

None of the studies undertaken in the Slapton catchments to date has adopted a holistic approach, based on the lake-catchment framework, in order to quantify the relationship between rates of soil erosion, sediment transport and deposition, and thereby to establish a sediment budget, or to identify changes in sediment sources through time (*cf.* Oldfield, 1977; Foster *et al.*, 1988). The work presented in this paper attempts to address this problem and has three specific aims:

- To examine the transfer of sediment through the Start catchment and into Slapton Lower Ley, and to reconstruct a sediment budget for the Start catchment since 1954.
- To identify the main sediment sources and to ascertain if there have been any changes in the dominant sources over the same time period.
- To assess the value of the lake-sediment record for interpreting catchment processes within the study area.

Before considering these issues in detail, a brief description of the study area is provided.

THE STUDY AREA

Slapton Ley and its contributing catchments are located in the South Hams region of South Devon (Fig. 1). The area is underlain by slates, shales, siltstones and mudstones of Devonian age (Dineley, 1961; Brunsden, 1965). The oldest sedimentary rocks are Lower Devonian shales, slates and grits. At the base of this sequence are the Dartmouth slates, which consist of purple-green glossy slates with grit and quartz bands and the Lower Devonian Meadfoot beds, which comprise grey shales, grits and calcareous shale bands.

Soils of the Denbigh series are to be found throughout the area, and Manod series soils occupy the main valleys of the Start and Gara streams (see Fig. 1C for locations). Denbigh soils are stony, well-drained and of moderate depth. They are fine and loamy and produce typical brown earths overlying solid or shattered rock. Manod series soils consist of free draining fine loamy soils developed over Palaeozoic mudstones, siltstones or slates. The Manod series is a typical brown podzolic soil (Trudgill, 1983; Findlay *et al.*, 1984).

Mean annual precipitation for Slapton village (1961–1993) is 1049 mm. Precipitation is highly variable, with monthly coefficients of variation exceeding 40% (Ratsey, 1975). Variability is greatest in spring and autumn. Most precipitation is associated with

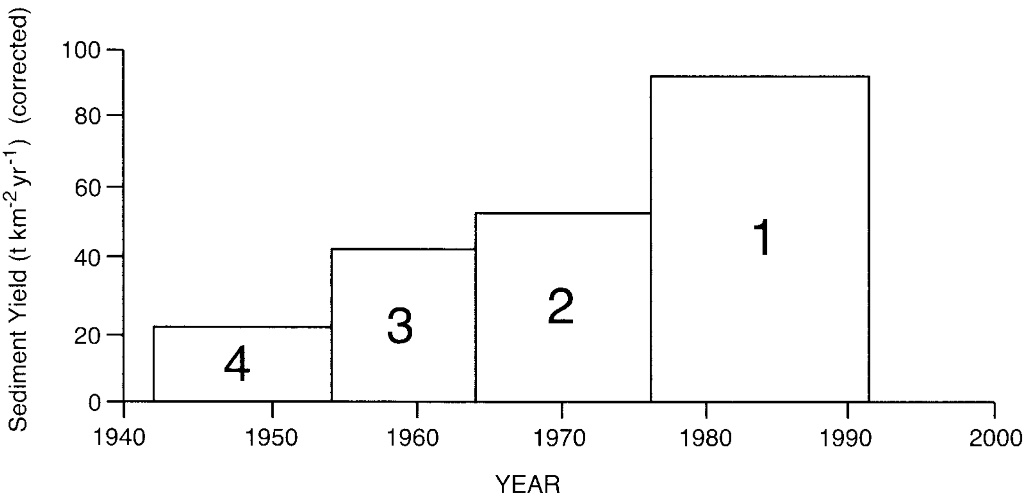

FIG. 2
Sediment yields in the catchment of the Old Mill reservoir (corrected for the autochthonous content) derived from a reservoir-sediment based reconstruction of sediment yield (after Foster & Walling, 1994).

TABLE 1. *Estimates of sediment yield from the Slapton catchments*

		Suspended sediment yield			
	Area		(t km^{-2} year^{-1})		
Catchment	(km^2)*	(t year^{-1})*	*	‡	†
Gara	23.62	218.48	9.25		
Slapton Wood	0.93	67.76	72.86	14.2#	8.4
Start	10.79	104.36	9.67		
Stokely Barton	1.53	47.83	31.26	11.6¤	
Total	36.87	642.30	17.42		

* From O'Sullivan *et al.* (1989) (data for 1987–88)
‡ From Park (pers. comm.)
  # is based on 4 years of data (1978–1981)
  ¤ is based on 2 years of data (1980–1981)
† From Troake & Walling (1973) (data for 1971–72).

south-westerly and north-westerly airstreams from the Atlantic which account for 58% of the total precipitation and 57% of the rain days.

Table 2. *Characteristics of Slapton Ley and its catchment*

Basin area (km^2)	46
Lake (Lower Ley) area (km^2)	0.771
Lake to catchment area ratio	59.7
Mean depth (m)	1.55
Maximum depth (m)	2.5
Volume (10^6 m^3)	1.77
Maximum altitude (m)	183
Minimum altitude (m)	*ca* 5

The freshwater lagoon of Slapton Ley (Fig. 1C) developed as a result of the shoreward movement of sediment from the Skerries bank, which lies some 2–3 km south-east of the Slapton barrier beach, as post-glacial sea levels rose (Robinson, 1961; Hails, 1975). From radiocarbon dating of basal sediments it has been shown that Slapton Ley formed at around 2889 $\pm$ 50 years BP (Morey, 1976). The physical characteristics of Slapton Ley and its catchments are listed in Table 2.

THE APPROACH

A number of investigations involving both field surveys and laboratory analysis of soils and sediments have been undertaken by the authors in order to shed further light on the sediment delivery dynamics and sediment budgets of the study area and to identify changes in sediment sources that may have occurred over the last 40 years. As part of these investigations, soil samples and floodplain and lake sediment cores have been collected from a range of sites in the Slapton catchment (Fig. 3). These have been subjected to physical, geochemical, mineral magnetic and radionuclide measurements. The following sections provide some general background to the techniques involved, more detailed information is contained in Owens (1990, 1994) and Foster & Walling (1994).

Caesium-137 measurements

Significant quantities of the artificial radionuclide ^{137}Cs were released into the environment by the testing of thermo-nuclear weapons during the period extending from the early 1950s through to the mid 1970s (Fig. 4). Release into the stratosphere resulted in global dispersal, and fallout to the ground surface occurred mostly with precipitation. The most significant fallout occurred between 1958 and 1965 and inputs have generally declined since this latter date. Caesium-137 was also liberated by the Chernobyl nuclear accident in 1986 (Fig. 4), although south-west England did not receive measurable ^{137}Cs fallout as a result of this event.

Caesium-137 reaching the land surface as fallout is strongly and rapidly adsorbed by the surface soil, particularly by the clay and organic fractions, and the distribution of ^{137}Cs in an undisturbed soil profile usually declines exponentially with depth. In cultivated soils, ^{137}Cs is generally well mixed within the plough layer (Walling & Bradley,

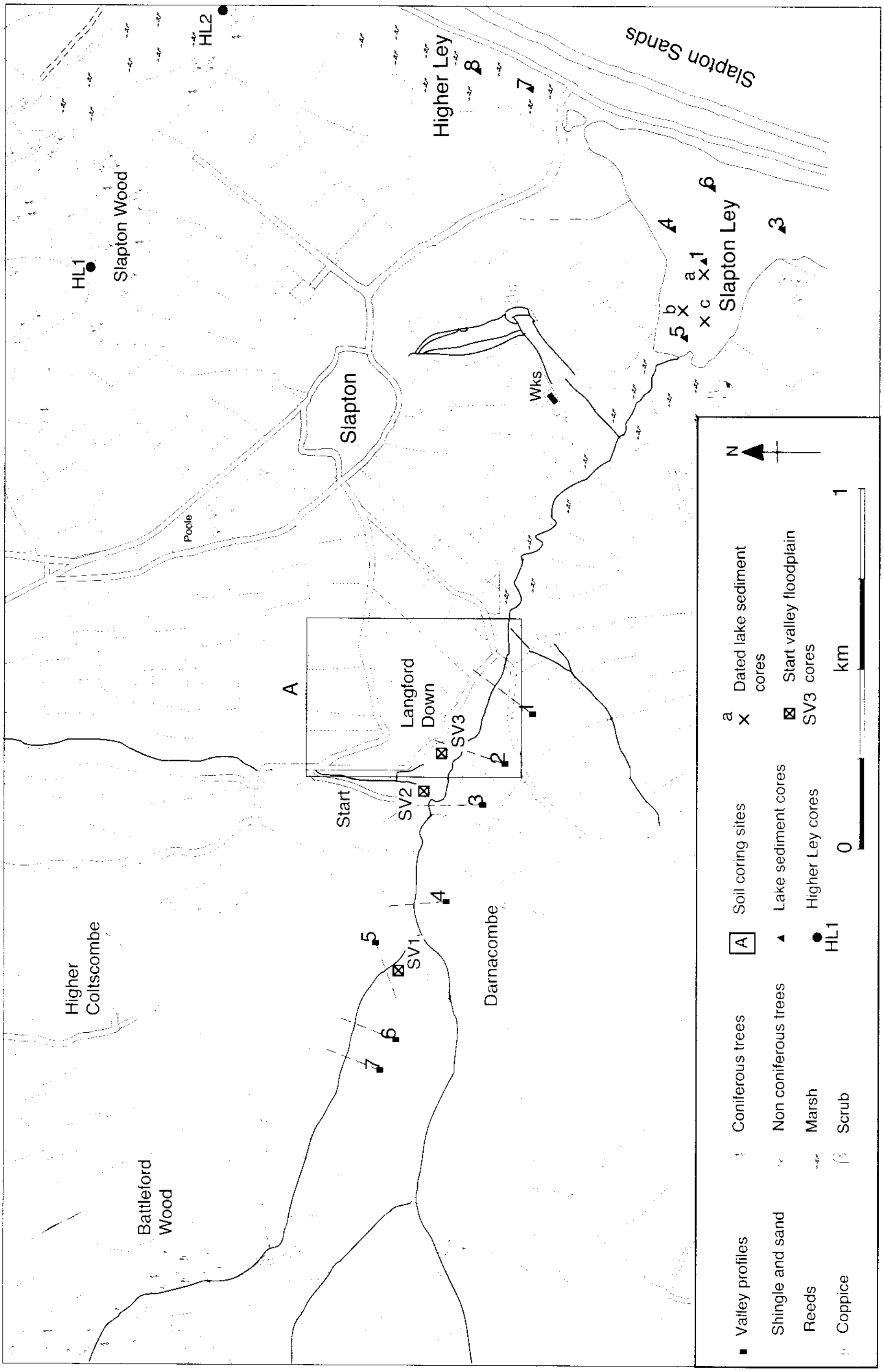

FIG. 3
Details of the lower Start catchment and Slapton Lower Ley, showing locations for sampling soils, floodplain and lake sediments.

1988; Walling & Quine, 1990). Caesium-137 measurements have been used for a number of purposes in studies of soil erosion and sediment transport (*cf.* Ritchie & McHenry, 1990). For example, ^{137}Cs has been used for dating lake and reservoir sediments (Pennington *et al.*, 1973; Ritchie *et al.*, 1973); for assessing rates and patterns of soil erosion (Walling & Quine, 1990); for quantifying rates of sediment accretion on floodplains during periods of overbank flow (Walling & Bradley, 1990; Walling *et al.*, 1992); and for identifying dominant sediment sources by comparing the activities of likely source materials with those of fluvial suspended sediment or recently deposited sediments in lakes and reservoirs (Walling & Woodward, 1992; Foster & Walling, 1994; He & Owens, 1995).

Mineral magnetic, physical and geochemical properties

There is a growing body of evidence to suggest that mineral magnetic analysis of fluvial sediment may provide a semi-quantitative indication of dominant sediment sources within a drainage basin (Walling *et al.*, 1979; Thompson & Oldfield, 1986; Foster & Walling, 1994). A range of properties are measured in order to determine the response of minerals to an applied magnetic field of varying strengths and the interpretation is often made in terms of dominant magnetic mineralogy and magnetic domains or of magnetic grain size (*cf.* Thompson & Oldfield, 1986). It is not the purpose of this paper to provide a detailed mineral magnetic interpretation of the sediments analysed, but to use magnetic properties in order to fingerprint the most likely sediment sources.

Geochemical analysis is often used for similar purposes in lake sediment studies. Since the pioneering work of Mackereth (1966), numerous attempts have been made to interpret the geochemical signatures of lake sediments in order to determine the relative significance of atmospheric fallout, internal productivity and diagenesis, and catchment inputs to the lake sediment body (Engstrom & Wright, 1984; Bengtsson & Enell, 1986; O'Sullivan *et al.*, 1991; Owens & Slaymaker, 1993). Similar approaches have been adopted in order to determine sediment provenance from an analysis of actively transported fluvial sediment (Peart & Walling, 1988; Walling, 1990).

The physical properties of sediment, particularly particle size, bulk density and loss on ignition, provide further information concerning the nature of the deposit, the energy conditions under which it was transported and/or deposited and historical changes in organic productivity at the site of deposition (Håkanson & Jansson, 1983). Furthermore, in order to compare sediment properties with source materials, it is essential that comparisons account for physical sorting processes, since many of the geochemical and mineral magnetic properties are influenced by particle size composition (Peart & Walling, 1982; Walling, 1990). Corrections are also required for organic matter content because, in high quantities, it can dilute the mineral magnetic signal, whereas its presence can preferentially increase the concentrations of heavy metals and phosphorus through sorption processes (Horowitz, 1991).

The following sections present evidence which is used to address the three main aims identified at the beginning of the paper.

SEDIMENT DELIVERY IN THE START CATCHMENT

In this section, we examine the delivery of sediment from the hillslopes to the lake and subsequently construct a tentative catchment sediment budget. Attention has been focused on the main catchment draining into the Lower Ley, namely the Start.

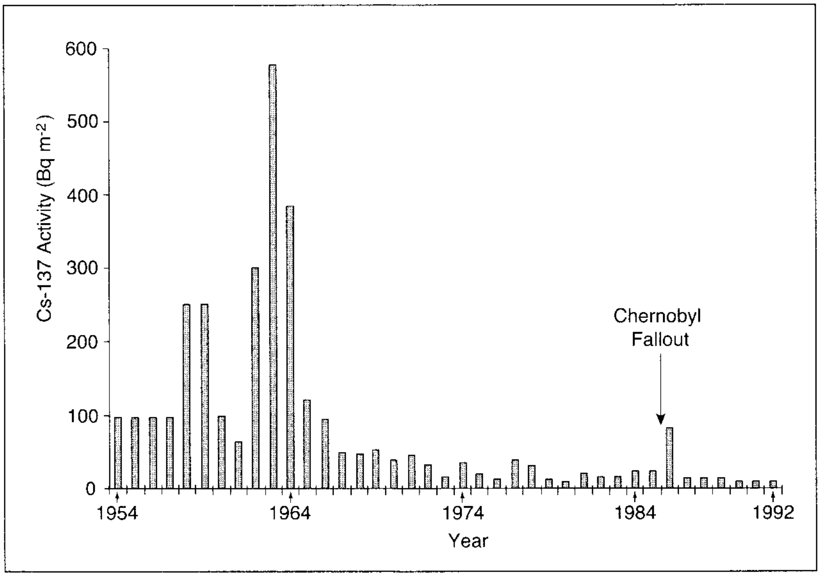

FIG. 4
The atmospheric ^{137}Cs fallout as recorded at Chilton, Oxfordshire.
(Data courtesy of AERE Harwell).

Soil erosion and within-field storage

From a consideration of the differences in sediment yield evident between Old Mill reservoir and the catchments draining to Slapton Ley, it seems reasonable to suggest that a significant amount of eroded material might enter storage before reaching the flow measuring station at the catchment outlet or Slapton Ley itself. A preliminary reconnaissance survey of the sediment budget of the Start catchment undertaken by the authors revealed extensive areas of sediment accumulation immediately upslope of hedge boundaries in many of the steep pasture fields which border the main channel network. Soil depths on the south facing slopes of the lower Start Valley were measured by augering along hillslope transects in the area indicated on Fig. 3 and shown in detail on Fig. 5. Soil depths varied from as little as 9 cm on the upper steep convex slopes to as much as 94 cm behind transverse hedgerows. These initial results suggested that a significant amount of material eroded from steep upslope locations may be deposited at the base of the slope behind hedgerows. To investigate this further, ^{137}Cs activities were measured in cores retrieved from locations upslope of field boundaries and Fig. 5 illustrates typical ^{137}Cs profiles and indicates the total ^{137}Cs inventories for seven cores. The basic premise behind using ^{137}Cs measurements for estimating rates of erosion and deposition, is that the total inventory at a particular point where erosion or deposition may have occurred is compared to that of a stable 'reference' location in order to establish the magnitude of the erosion or deposition involved (Walling & Quine, 1990). Within the vicinity of the study area, ^{137}Cs reference inventories in undisturbed soil profiles average *ca* 261 mBq cm^{-2} (corrected to 1992). From Fig. 5 it can be seen that both the total inventory and the shape of the profiles indicate that a substantial amount of deposition has occurred upslope of these hedge boundaries since 1954 (i.e. the start of ^{137}Cs fallout). For example, the total inventory for core 7 is over 400 mBq cm^{-2} greater than the local reference inventory and this difference can be accounted for by deposition of sediment-associated ^{137}Cs from upslope locations. Also, the peak in ^{137}Cs activity for core 7 at between 11 and 15 cm depth below the soil surface can be tentatively ascribed to the peak in ^{137}Cs fallout in 1963 (Fig. 4), suggesting an accumulation of >10 cm of material at this location since 1963. In the case of cores 1 and 3, the extended depths to which high concentrations of ^{137}Cs are found are again indicative of substantial amounts of deposition since the onset of ^{137}Cs fallout in the late 1950s.

A similar picture emerges from a consideration of the downcore organic matter and magnetic susceptibility profiles for cores taken from the transect marked on Fig. 5 (Fig. 6). High organic matter contents are recorded to a depth of *ca* 30 cm in the profile located immediately behind the transverse hedgerow, and these decline to background levels of under 4% in subsoil. In the case of frequency dependent magnetic susceptibility (Xfd), high values are recorded to depths of *ca* 30 cm on the steepest slopes, whereas in the core immediately upslope of the hedgerow high values are recorded to a depth of over 50 cm, below which levels fall sharply. These results further support the interpretation given above, based on the ^{137}Cs data, and again indicate a significant accumulation of sediment at the slope foot.

An estimate of the amount of soil deposited behind the hedgerows can be derived from the excess ^{137}Cs inventories of cores 1, 2 and 3 (Fig. 5). The average excess ^{137}Cs inventory of these three cores retrieved from behind the hedge boundary is 148.7 mBq cm^{-2} and this can be ascribed to the deposition of sediment derived from erosion at upslope locations (*cf.* Owens, 1994). Owens (1994) used a numerical mass balance model to calculate that the average ^{137}Cs content (decay corrected to 1991) of sediment deposited at these footslope sites since 1954 was *ca* 20 mBq g^{-1}. It is estimated that deposition has occurred over an area of *ca* 800 m^2 in this field, which has a total area of *ca* 100 000 m^2. If it is further assumed that this excess inventory ascribed to sediment deposition is representative of the entire area of deposition, then the total amount of topsoil that has accumulated upslope of the hedge boundary since 1954 is *ca* 60 t. This is equivalent to a mean annual soil erosion rate from the entire field of *ca* 16 t km^{-2} year^{-1}.

Floodplain sedimentation

Analyses of suspended sediment transport and sedimentation rates and patterns in the Start catchment, presented by Owens (1990) and Foster *et al.* (1993) have shown that suspended sediment concentrations can decline downstream by as much as 800% between Battleford Wood and Deer Bridge (see Fig. 3 for locations), suggesting that a significant quantity of sediment is being lost to channel and floodplain storage upstream of Deer Bridge. Other evidence appears to suggest that the Start Valley may have been a zone of net sediment accumulation throughout the 20th century. Fig. 7 maps the present day and historical extent of the wetland in the Start Valley as depicted on the Ordnance Survey maps of 1889, 1907, 1955 and 1965. It is clear from these maps that, whereas wetland was found only downstream of Deer Bridge in 1889, this currently extends up-valley almost as far as Battleford Wood. Historical records have also documented a significant and sustained increase in water level in the Ley since 1920, which may have been responsible for the rapid expansion of the wetland area after this time.

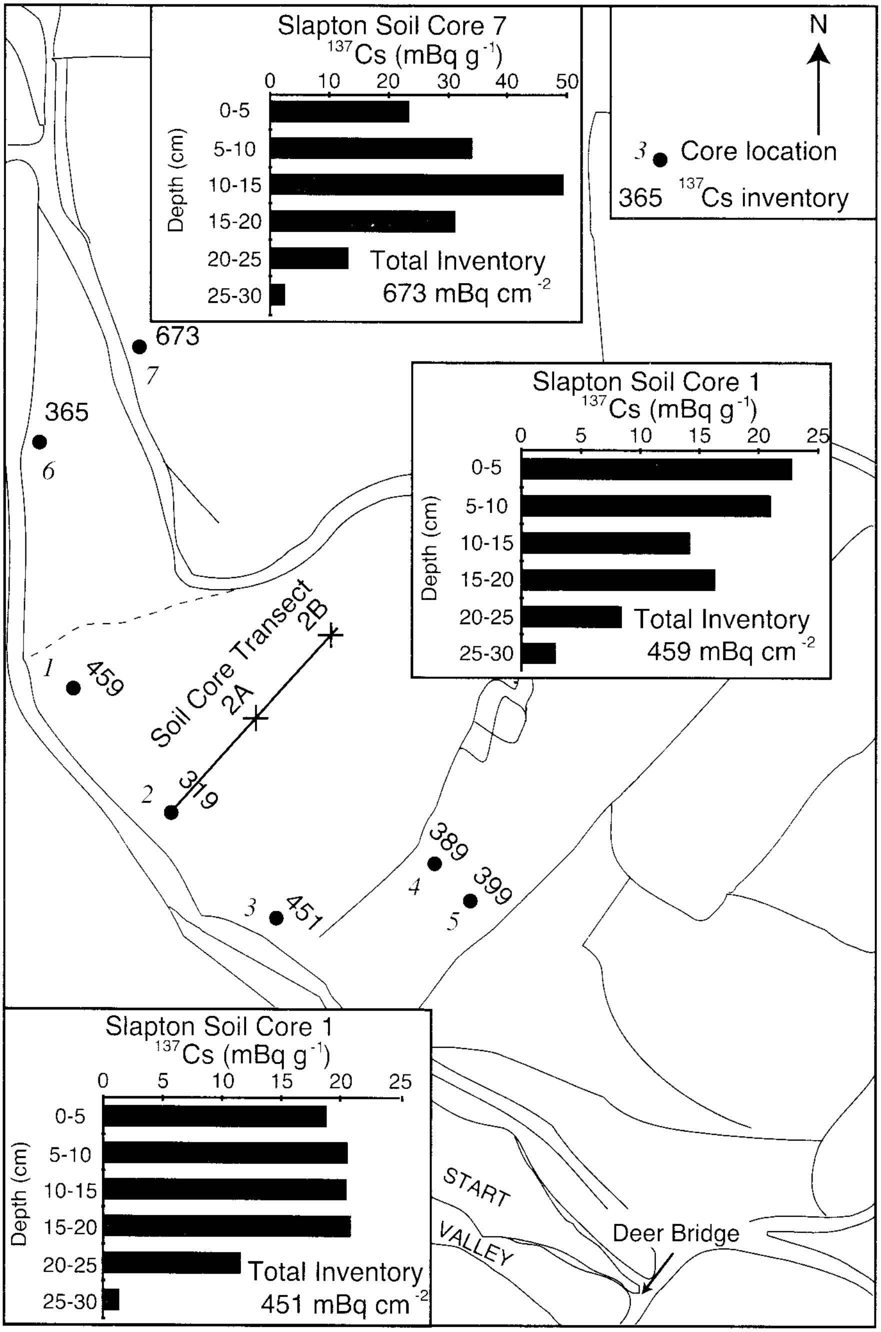

FIG. 5
Details of soil coring locations, representative ^{137}Cs profiles and ^{137}Cs inventories. (For location of site, see inset 'A' of Fig. 3).

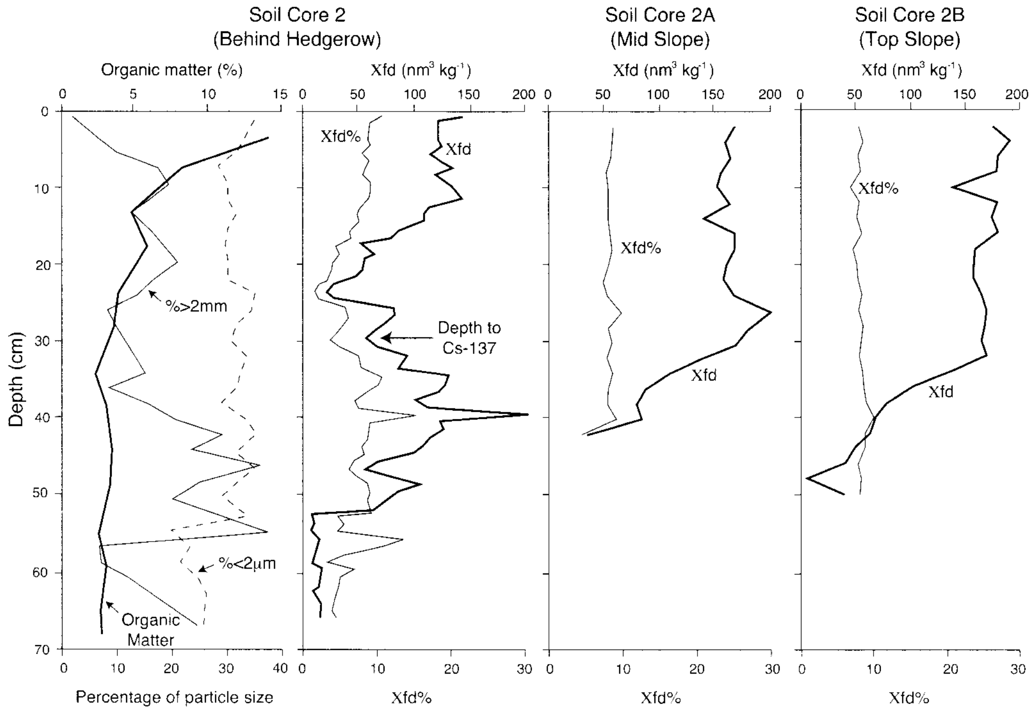

FIG. 6
Downcore variations in mineral magnetic, organic matter and particle size characteristics of pasture soils. The location of soil coring positions is identified on Fig. 5.

In order to examine further the magnitude of floodplain sedimentation, two cores (SV1 and SV2; see Fig. 3 for sampling locations) have been analysed for ^{137}Cs activity. Both cores contain ^{137}Cs to depths of over 50 cm and their total inventories are substantially greater than the local reference fallout inventory of 261 mBq cm^{-2} (Fig. 8). The high inventories of the floodplain cores reflect the excess ^{137}Cs deposited in association with suspended sediment during periods of overbank flow. The depth at which ^{137}Cs reaches a maximum activity in the floodplain sediment core provides a chronological marker horizon which can be equated with the peak of atmospheric fallout in 1963 (Fig. 4). In the case of core SV2, which was collected in 1991, the location of the ^{137}Cs peak at a depth of *ca* 37 cm from the surface implies a deposition rate of *ca* 1.3 cm year^{-1}. The deposition rate for core SV1 (collected in 1987) is almost the same (*ca* 1.4 cm year^{-1}).

Surveys of the Start valley undertaken between 1986 and 1988 revealed extensive deposition of sediment between Deer Bridge and Battleford. Seven valley cross sections were surveyed by Owens (1990) at locations indicated on Fig. 3. The survey showed that uncompacted sediments were found to depths in excess of 1.5 m in many places (Fig. 9) and the mean depth of sediment in the sampled area was estimated to be *ca* 0.79 m. Documentary evidence (such as Fig. 7) was used to establish that this sediment had

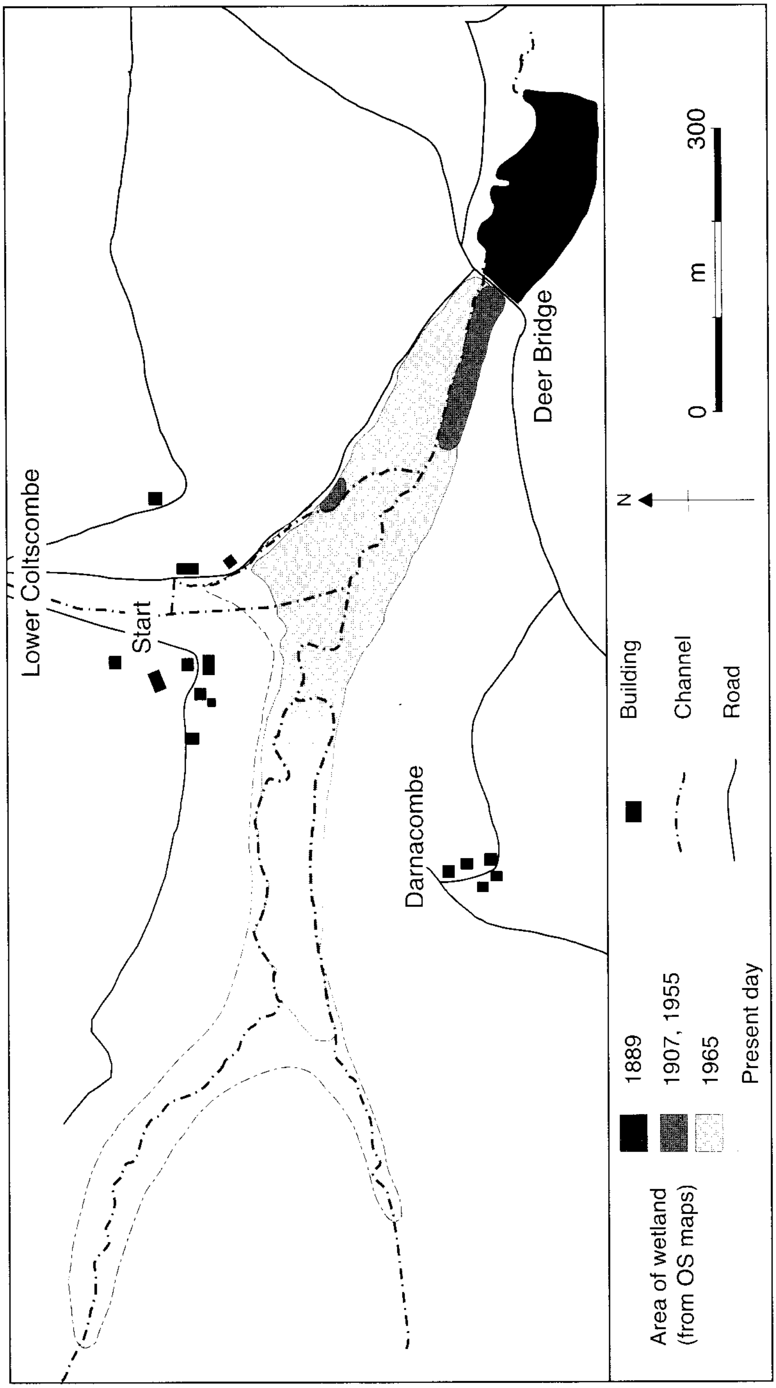

FIG. 7
Expansion of the wetland in the lower Start valley since 1889 identified from Ordnance Survey maps.

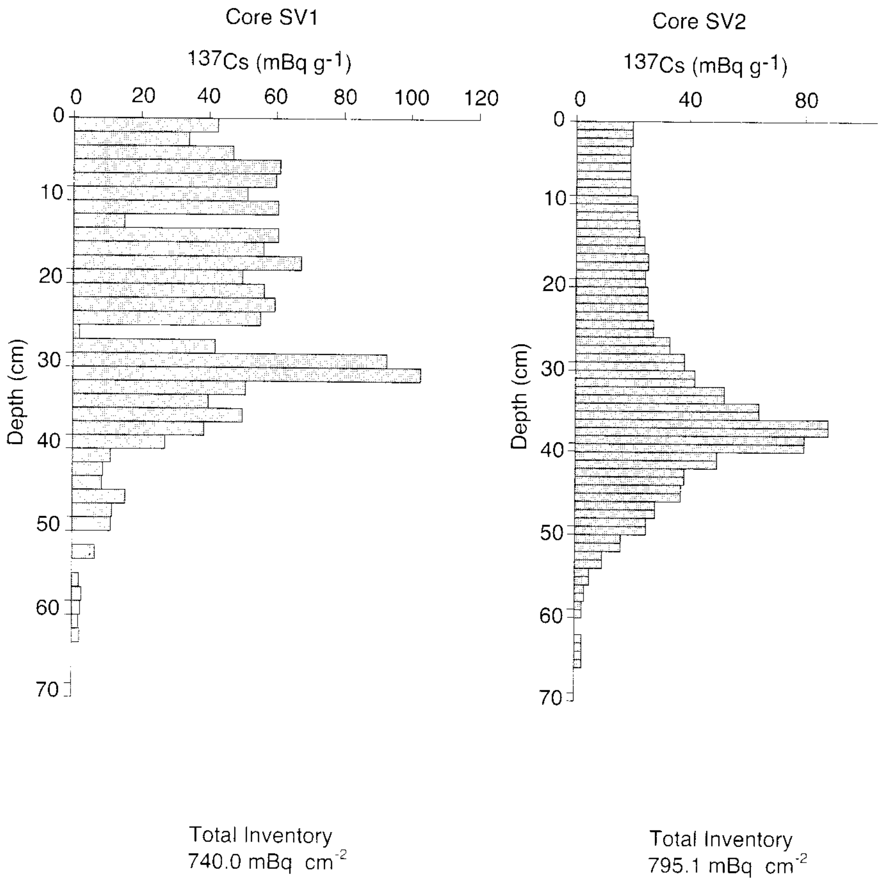

FIG. 8
^{137}Cs inventories and profiles for two floodplain sediment cores.
(Coring locations are identified on Fig. 3).

been deposited within the last 30 to 100 years. This gives a sedimentation rate between 0.79 and 2.6 cm year^{-1}, which agrees well with the values of 1.3 cm year^{-1} and 1.4 cm year^{-1} (since 1963) estimated from the ^{137}Cs depth distribution of two floodplain cores (SV1 and SV2, Fig. 8). The total volume of sediment stored in the valley was estimated by Owens (1990) to be 75,711 m^3, which is equivalent to 34,070 t of dry minerogenic sediment. Thus, between 341 and 1136 t of sediment has been deposited annually on the floodplain during the recent historical past. This represents a sediment input from the upstream catchment area of between 28 and 95 (mean 62) t km^{-2} year^{-1}.

A tentative sediment budget

It has been demonstrated above that, since 1954, sediment equivalent to an erosion rate from the upstream catchment of 62 t km^{-2} year^{-1} has accumulated on the floodplain of the Start valley and that the equivalent of *ca* 16 t km^{-2} year^{-1} of eroded topsoil has been stored behind field hedgerows. Adding the two values together increases the estimate of sediment mobilised within the catchment by *ca* 78 t km^{-2} year^{-1}. Furthermore, it has been estimated previously from the lake sediment record that the average sediment input to the Lower Ley since 1977 was *ca* 29 t km^{-2} year^{-1}. Although the time-base for this lake-based estimate of sediment yield and the estimate of equivalent 'yield' associated with floodplain and hedgerow storage are different, if it is assumed that the mean annual gross soil erosion rate in the Slapton catchments since 1954 can be represented by the sum of the two storage components (floodplain and upslope of hedgerows) and the lake-based estimate of sediment yield to the Lower Ley, a gross erosion rate of *ca* 107 t km^{-2} year^{-1} can be obtained. This estimate is higher than the average sediment yield for the period since 1954 obtained for the Old Mill catchment of *ca* 63 t km^{-2} year^{-1}, but it is consistent with the value for the same catchment over the last 15 years of *ca* 90 t km^{-2} year^{-1} (Foster & Walling, 1994) (*cf.* Fig. 2). There is only a very limited area of floodplain in the catchment of the Old Mill reservoir and the amount of sediment stored upslope of hedge boundaries is also likely to be less than in the Start catchment because of differences in field sizes between the two basins. The gross erosion rate in the Old Mill catchment is thus likely to be closer to the estimate of sediment yield obtained from the reservoir deposits.

From the calculations given above, a tentative sediment budget has been constructed for the Start catchment (Fig. 10). No estimate is made of within-channel storage (*cf.* Sutherland, 1990; Warburton, 1990; Walling & Quine, 1993). The budget suggests that 15% of the eroded soil has been stored behind hedgerows with 58% transferred to floodplain storage. Only 27% of the soil eroded from fields reaches Slapton Ley. The value of sediment output cited above is low compared to values estimated for most other catchments (e.g. Costa, 1975; Lambert & Walling, 1987; Sutherland, 1990; Walling & Quine, 1993) and reflects the large amount of material stored on the hillslopes and on the floodplain in this catchment. Other studies (e.g. Meade, 1982; Trimble, 1983; Roberts & Church, 1986; Phillips, 1991) have also demonstrated that in certain situations the output of sediment from the contributing catchment may be low due to storage effects.

Identification of Sediment Sources

In the previous section it was assumed that the majority of sediment is derived from the hillslopes. Using a sediment budget approach it was demonstrated that *ca* 58% of the sediment eroded from the hillslopes in the Start catchment is stored on the floodplain and that the output of sediment to the Lower Ley is *ca* 27% of the gross erosion. In this section ^{137}Cs, mineral magnetic and geochemical measurements of the sediment deposited on the floodplain and in the lake are examined in order to confirm that the hillslopes represent the dominant source of the sediment and to evaluate whether there have been any changes in sources since 1954. As the floodplain is located upstream of the Ley it seems logical to discuss the results obtained from these sediments before moving on to a discussion of the results obtained from the Lower Ley.

The Start floodplain

It is possible to infer whether the sediment deposited on the floodplain (and in the Lower Ley) is dominated by topsoil or subsoil sources by comparing the mineral magnetic properties of the sediment with representative catchment soils. From Fig. 6, for example, it is apparent that Xfd may be able to discriminate between topsoil and subsoil. On the other hand, Xfd% (Xfd expressed as a percentage of the total low

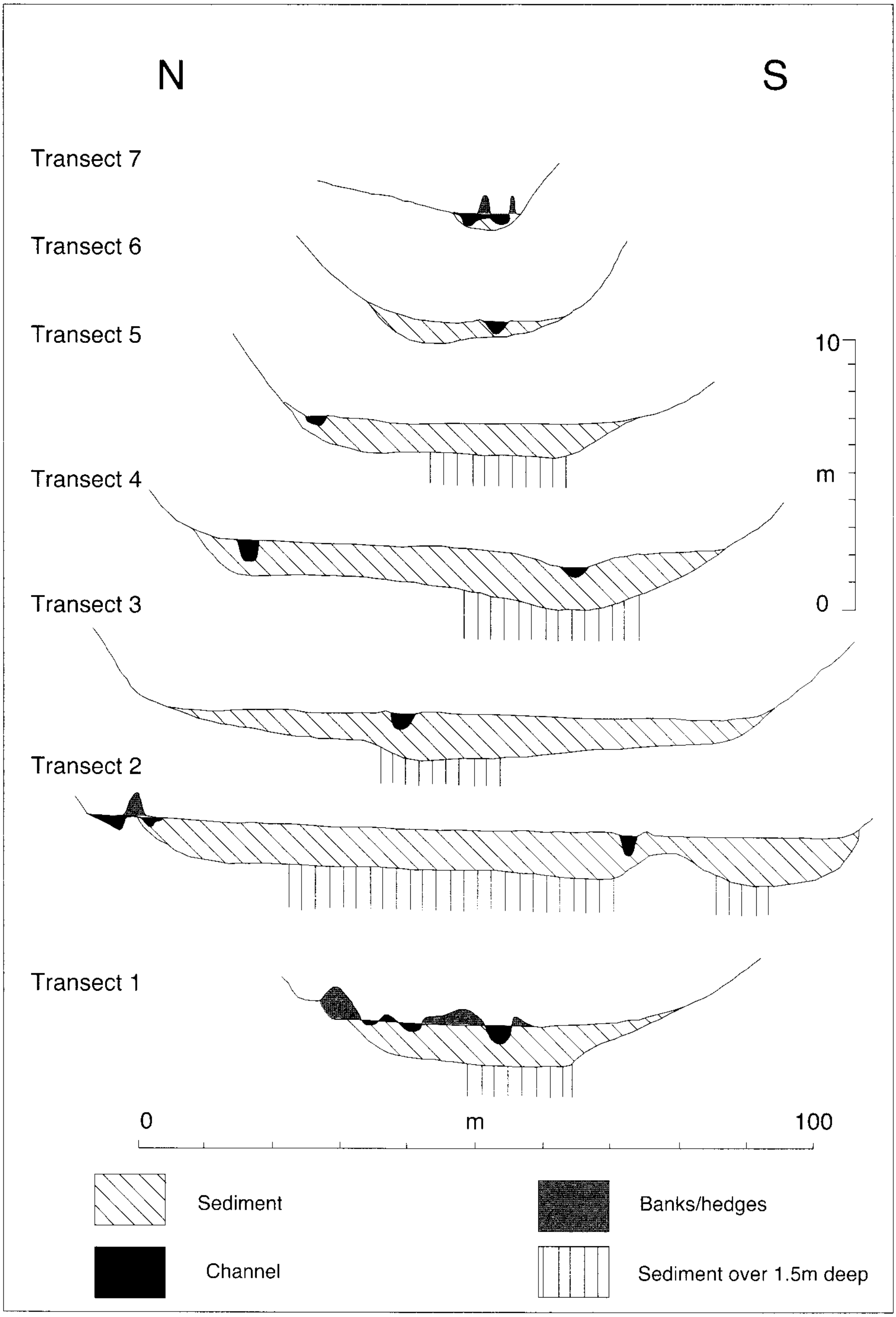

FIG. 9
Floodplain sedimentation in the lower Start valley
based on surveys of the transects located on Fig. 3 (after Owens, 1990).

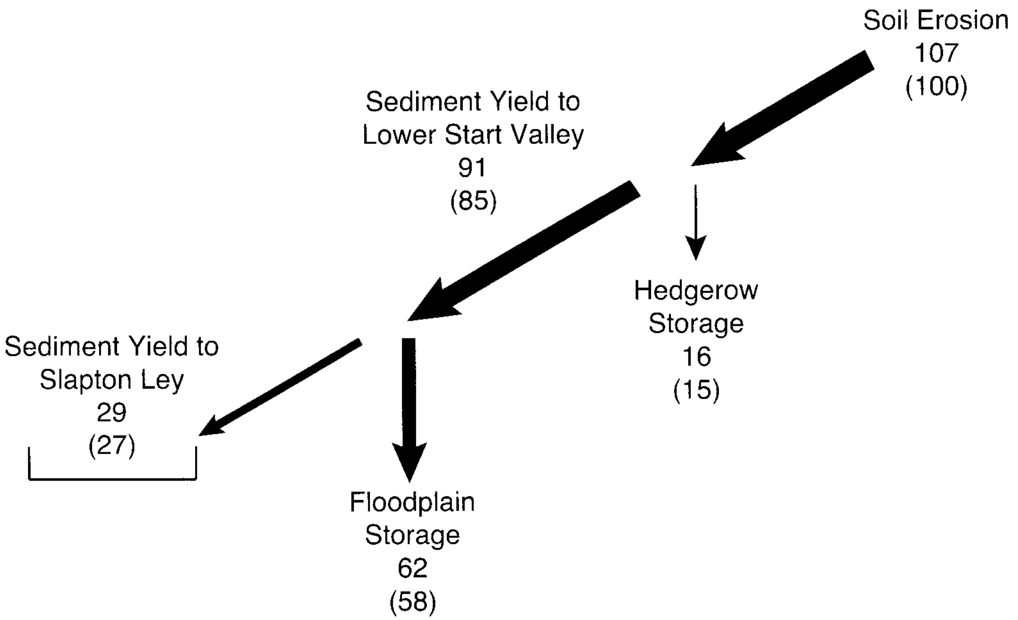

FIG. 10
A tentative sediment budget linking the Start catchment to Slapton Ley.
Percentages are given in parentheses.

frequency susceptibility) would not be an effective indicator of the contributions of topsoils and subsoils to the floodplain sediment. Although not shown in Fig. 6, the pattern for low frequency susceptibility (Xlf) is similar to that of Xfd, with topsoil values averaging *ca* 1.4 $\mu m^3\ kg^{-1}$ whilst subsoils average 0.2 $\mu m^3\ kg^{-1}$. Thus, both Xlf and Xfd could be used to identify the dominant source type and any changes over time.

Similarly, isothermal remanent magnetisation (IRM) acquisition curves have been measured for a range of topsoils and subsoils on the Denbigh and Manod series soils and are represented as envelope curves in Fig. 11. It is evident from these curves that catchment topsoils are dominated by a markedly different magnetic mineralogy (probably magnetite) from subsoils (probably haematite). Fig. 11 also shows the envelope IRM acquisition curves for sixteen samples taken at various depths from a floodplain core collected near to core SV2 (Fig. 3). It is clear from these data that the floodplain core includes the extreme end members of the potential source soils ranging from almost 100% subsoil to 100% topsoil dominance. The former is generally believed to be related to channel bank sources as there is no evidence of gully erosion in this catchment which would provide a similar mineral magnetic response in the floodplain sediment. The surface samples of the floodplain sediment core illustrated in Fig. 11 have similar IRM acquisition curves to topsoil, suggesting that topsoil is the dominant source of sediment recently deposited on the floodplain surface.

Temporal variations in sediment sources can be investigated by examining the depth distribution of certain diagnostic mineral magnetic properties and Fig. 12 presents the depth distributions of Xlf, Xfd, HIRM (the loss of magnetisation at a backfield of 0.1T after saturation when expressed on a mass specific basis) and the HIRM:Xfd ratio in the

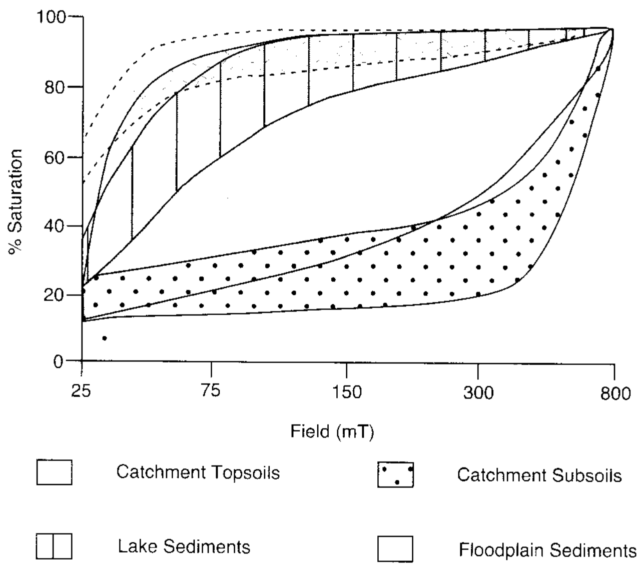

FIG. 11
IRM acquisition curves for subsoils, topsoils and floodplain and lake sediments.

floodplain sediment core mentioned above. Horizons representing the peak in measured ^{137}Cs fallout and the first occurrence of ^{137}Cs in 1954 are at *ca* 37–38 and 60–61 cm depth in the profile, respectively. Xlf values decline from above 0.2 $\mu m^3\ kg^{-1}$ at the surface to around 0.06 $\mu m^3\ kg^{-1}$ below 20 cm depth. Although more variable, a similar pattern is detected for Xfd which is generally higher in the upper 20 cm of the core. Individually high Xfd values are recorded at 39, 51, 59 and 65 cm depth and would seem to indicate a significant influx of topsoil to the floodplain at these levels. HIRM values show a reversal in the general pattern shown by the susceptibility parameters, with values below 0.4 $mAm^2\ kg^{-1}$ (with the exception of the surface sample) to a depth of 20 cm. HIRM slowly increases from 20 cm to a depth of 49 cm and then increases rapidly to values in excess of 0.8 $mAm^2\ kg^{-1}$ below 50 cm in the sediment column. The HIRM:Xfd ratio is close to zero in the upper 13 cm of the core, below which it increases and becomes more variable.

Since susceptibility parameters broadly increase with an increasing topsoil contribution and HIRM increases with a greater subsoil contribution, there is clear evidence that topsoil dominates the most recent period of floodplain sedimentation, with slightly increased subsoil contributions from 13 to 36 cm depth (approximately 1963) and a substantial increase in the subsoil contribution, probably as a result of channel bank erosion, before this date. The upper 13 cm of sediment probably represent a period of time from the mid 1970s to the late 1980s when this core was collected. Isolated reductions in the HIRM:Xfd ratio at depths of 39, 51, 59 and 65, suggest a significant influx of topsoil over limited periods of time, possibly associated with individual high magnitude storm events.

Having demonstrated above that the dominant source of the sediment deposited on the floodplain since the mid-1970s is topsoil, it should be possible to use ^{137}Cs

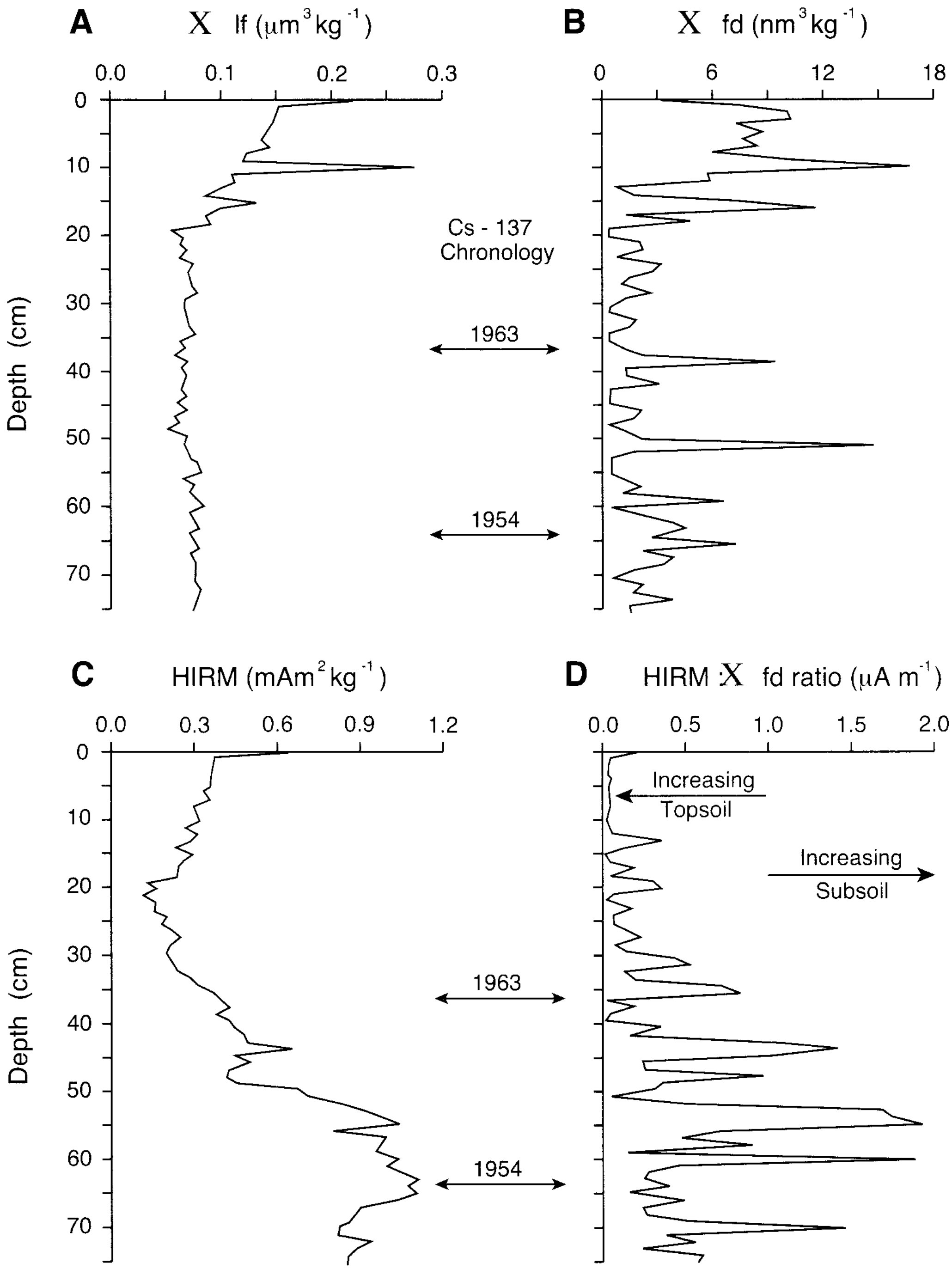

FIG. 12
Mineral magnetic properties of a floodplain sediment core collected in the Start Valley near core SV2 (see Fig. 3 for location).

measurements to identify whether the sediment is derived from pasture or cultivated fields. To examine this point further, the ^{137}Cs activities in representative samples of pasture and cultivated surface (top 1 cm) soils were measured and compared with those of surface sediment on the floodplain. Since there has been no significant fallout of ^{137}Cs in this region since the mid 1980s (there was no measurable Chernobyl fallout), the surface sediment accumulating on the floodplain since this time will only contain ^{137}Cs associated with sediment deposited during overbank flood events. The average ^{137}Cs concentration of pasture soils (n=10) is 27.5 mBq g^{-1} (range 23 to 37 mBq g^{-1}) and, for two cultivated soil profiles, the average concentrations in the plough layer were found to be 13 and 16 mBq g^{-1} (Owens, 1994). These data provide similar contrasts between ^{137}Cs concentrations in cultivated and pasture fields to those encountered in the catchment of the Old Mill reservoir, where the ^{137}Cs concentrations in cultivated topsoils average less than 10 mBq g^{-1}, whilst activities in pasture topsoils range from 24 to 36 mBq g^{-1} (Foster & Walling, 1994). On the Start floodplain, ^{137}Cs concentrations were measured in 27 surface sediment samples collected within an area of 100 m $\times$ 50 m, adjacent to coring point SV2 (Fig. 3) (Owens, 1994). Correcting for the mass of organic material produced in-situ on the floodplain surface (*ca* 30% of the mass of the sediment samples), the average ^{137}Cs concentration of the clastic sediment is *ca* 22 mBq g^{-1} (range *ca* 15 to 33 mBq g^{-1}). Even allowing for the potential enrichment or depletion of ^{137}Cs in sediment deposited on the floodplain due to particle size effects (*cf.* Walling & Woodward, 1992; He & Owens, 1995), it is evident that the average ^{137}Cs activity of the floodplain surface sediments more closely reflects the activities of soil samples collected from the surface of undisturbed pasture soils, rather than cultivated soils. This suggests that the dominant source of mobilised sediment in the Start catchment since the mid-1970s has been grazed pasture.

The Lower Ley

In addition to the mineral magnetic properties described in the previous section, the relationship between the HIRM:Xfd ratio and the percentage saturation acquired at a forward magnetic field of 300mT may also be used to differentiate between topsoil and subsoil, and Fig. 13 illustrates this relationship for samples taken at various depths from lake sediment core SL1. Although not linear, the relationship indicates that these parameters are closely related and that, as the HIRM:Xfd ratio decreases to below 0.1, samples are dominated by topsoil. Above a value of 0.3, samples are dominated by subsoil. Fig. 13 illustrates the presence of both topsoil and subsoil material in the lake sediment record, although topsoil appears to be the dominant source of the lake sediment.

Fig. 11 plots the envelope curves for IRM acquisition measurements on sediment samples taken at set depth intervals from core SL1 collected from the Lower Ley (Fig. 3). Again, in the majority of cases, the lake sediment samples more closely mirror the equivalent properties of catchment topsoils than of subsoils, suggesting that the former is the more likely source of the sediment in this lake core.

Temporal changes in the relative importance of topsoil sources to sediment delivered to the Ley can be assessed by examining the vertical distribution of mineral magnetic properties measured in lake sediment core SL1 as shown in Fig. 14. Summary statistics for all measured properties are given in Table 3. The average value for Xfd% is 5.28. Although this parameter is unsuitable for determining source type (i.e. topsoil or subsoil), this value is a strong indicator that eroded material from the surrounding

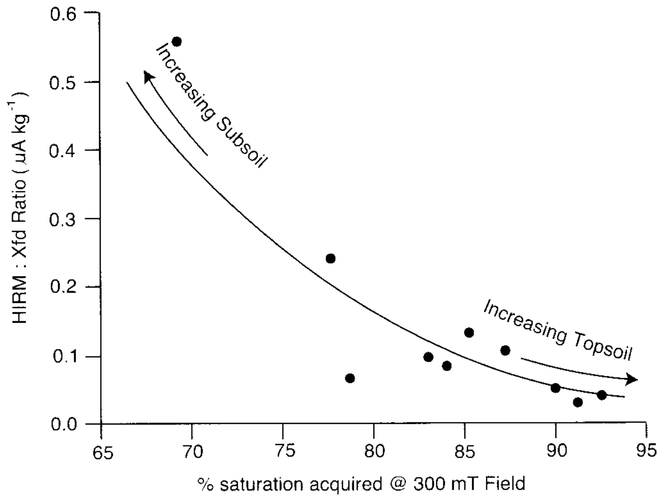

FIG. 13
The relationship between the HIRM:Xfd ratio and the percentage saturation acquired at a field of 300 mT for samples taken at various depths from lake sediment core SL1 (see Fig. 3 for location).

catchment is reaching the Lower Ley, as the high value for this parameter indicates the presence of secondary viscous magnetic minerals usually associated with fermentation processes in catchment soils under oxidising conditions (Thompson & Oldfield, 1986).

The plot of the HIRM:Xfd ratio versus depth in the lake sediment profile (Fig. 14vi) is perhaps the best indicator of changes in sediment source. Although most samples lie within the natural variability of catchment topsoils, the sample at 42 cm depth evidences an increased subsoil/channel bank contribution. This can be dated to approximately 1940–45, and corresponds with the initial period of major agricultural change and landscape disturbance identified by Heathwaite (1993).

The other mineral magnetic properties shown in Fig. 14 all display a similar trend, increasing gradually upcore. In the case of HIRM and Xfd, values have been adjusted for loss on ignition at 450°C and 850°C in order to eliminate the diluting effects of organic matter and carbonates, respectively. The S-Ratio, which is calculated from IRM (0.8T) and a backfield measurement of remanence at 0.1 tesla, ranges between 0.4 and 0.8 and also shows a slight increase upcore. It is tempting to argue that the upcore change in susceptibility and remanence parameters indicate a significant change in sediment source, with topsoil assuming increasing importance. Correction of these data for the effects of organic matter and carbonate content serves to enhance the upcore signal by removing the diluting effects of these two diamagnetic components. However, consideration of some of the physical and geochemical properties of the lake sediments, as shown in Fig. 15, complicates this simple interpretation.

The data presented in Fig. 15 are for a total chemical extraction, rather than a fractionation procedure as described by Heathwaite & O'Sullivan (1991) for Slapton Ley, and Foster & Walling (1994) for the Old Mill reservoir. The chronology was obtained by cross correlation of physical and geochemical characteristics between the

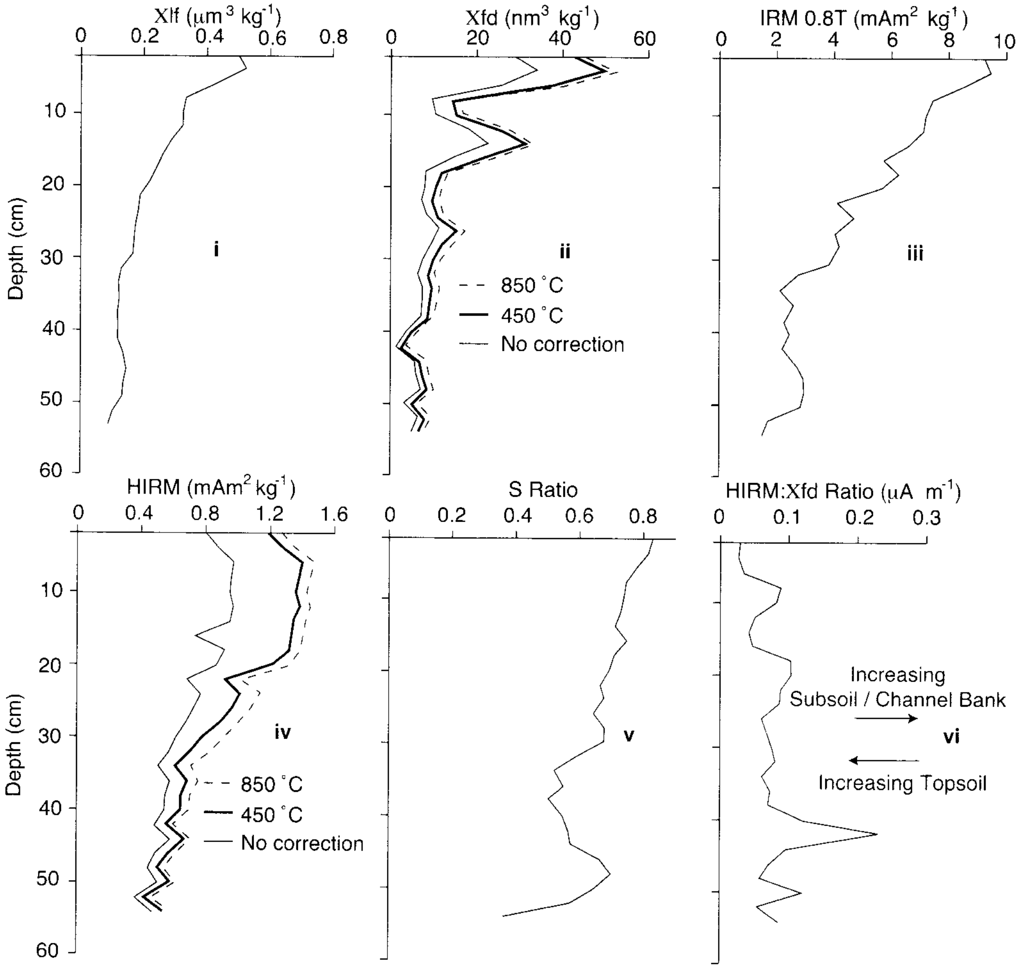

FIG. 14
Mineral magnetic properties of a sediment core retrieved from Slapton Lower Ley (core SL1; Fig. 3).

cores described here and those described and dated using ^{210}Pb analysis by Heathwaite & Burt (1993). Even though the core was over 70 cm long, only the post-1930 data (55cm) are displayed.

Although the study basin is located in a relatively remote rural location, there is evidence to suggest that both total Pb and Zn concentrations have increased substantially in the upper 60 cm of sediment. Whilst Zn is usually more soluble than Pb (Horowitz, 1991) the two patterns are closely correlated, suggesting that little post-depositional remobilisation of Zn has occurred. There are no known catchment sources which may have contributed heavy metals to the lake sediment column at Slapton Ley, other than road drainage from the numerous small lanes which cross the catchment. The upcore trend is similar to that attributed to the fallout of atmospheric contaminants

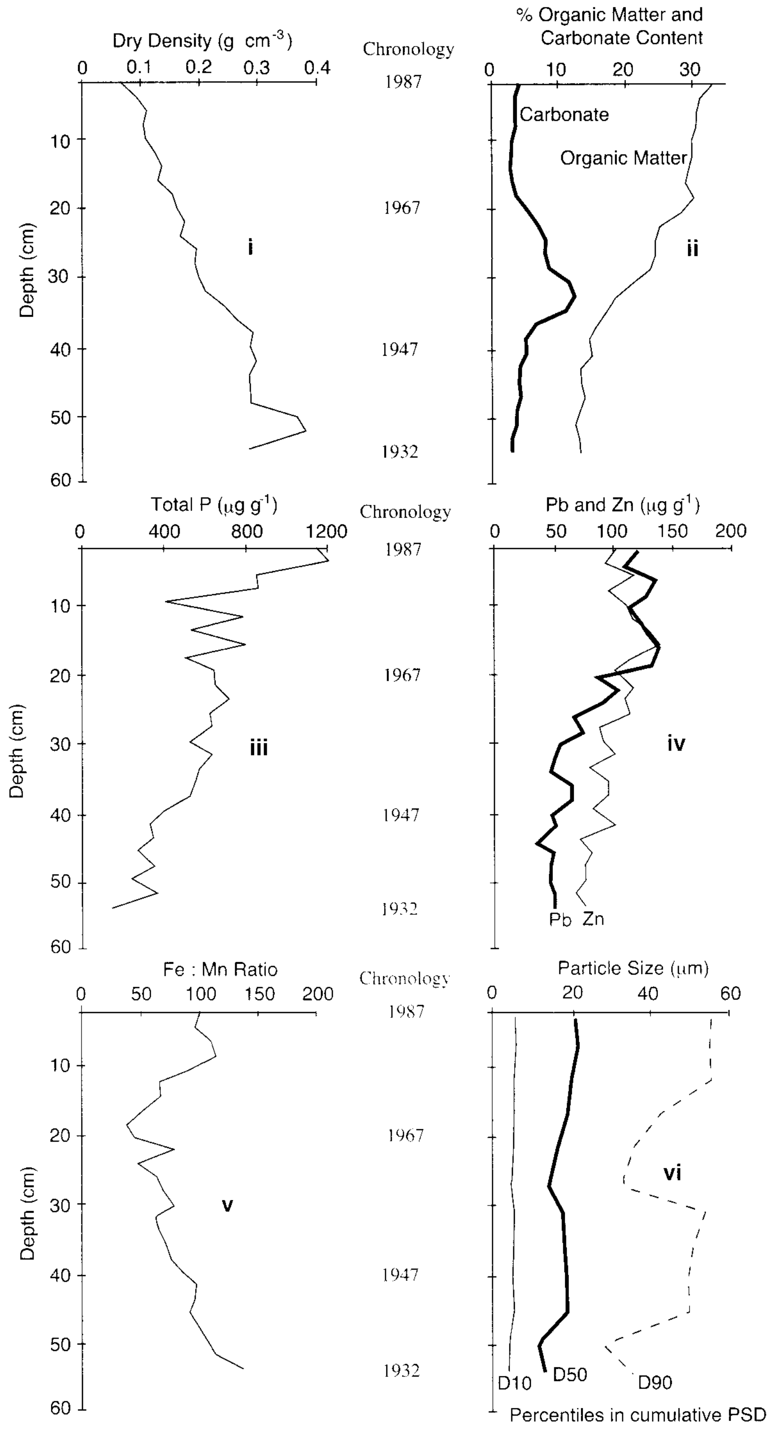

FIG. 15
Physical and chemical properties of a sediment core retrieved from Slapton Lower Ley (core SL1; Fig. 3).

reported elsewhere in the UK (Foster & Dearing, 1987; Battarbee, 1988; Foster & Charlesworth, in press). Whilst concentrations are considerably lower than those associated with contaminated reservoir sediments in Midland England (Foster *et al.*, 1991a) they are considerably higher than those found in lakes in more remote west coast sites in the UK such as the Scilly Isles (Foster *et al.*, 1991b).

The strong atmospheric pollution signal, as indicated by the Pb and Zn profiles, is likely to be associated with the deposition of highly magnetic carbonaceous particles and this negates the use of mineral magnetic measurements of lake sediments to infer changing sediment sources in the catchment through time (Foster & Dearing, 1987; Foster *et al.*, 1990b). This problem is less relevant to the interpretation of the floodplain sediment record, since the floodplain magnetic signal is much less sensitive to atmospheric flux inputs than the lake record. This is because the sedimentation rate (when expressed in g cm^{-2} $year^{-1}$) on the floodplain is more than double that in the lake, and the input of magnetic carbonaceous particles will be significantly diluted in the former. Since atmospheric contaminants do not contain secondary magnetic minerals, an average Xfd% exceeding 5 (Table 3) appears to provide the strongest evidence for the presence of catchment soil in the lake sediments.

It may also be possible to use ^{137}Cs measurements to identify sediment source. As with the floodplain sediment, the ^{137}Cs activity of the surface lake sediment should be associated with catchment inputs since there has been no significant recent atmospheric inputs. The depth distribution of ^{137}Cs in one of the sediment cores collected from the Lower Ley (core a in Fig. 3) is shown in Fig. 16i. The shape and total ^{137}Cs inventory of this profile are discussed in greater detail in the next section, and here attention is restricted to the ^{137}Cs concentrations, which increase upcore from values <10 mBq g^{-1} below *ca* 30 cm depth to between 50 and 70 mBq g^{-1} near the sediment surface. The ^{137}Cs concentrations of the surface lake-bottom sediments are considerably higher than any of the potential catchment sources and this precludes an interpretation of sediment source based on ^{137}Cs analysis alone. The high ^{137}Cs activities in the Slapton Ley sediments may reflect enrichment caused by sorting during delivery and the deposition of only very fine sediment particles in the Ley. Indeed, Fig. 15vi suggests that 90% of the sediment in the Ley has a diameter of less than 60μm. To date, no attempt has been made to model these enrichment effects, but the high activities in the Lower Ley sediments would, nevertheless, suggest that pasture topsoil is the more likely source.

To summarise the analysis presented above, topsoil sources, primarily pasture land, appear to dominate the most recent floodplain sediment, with contributions from subsoil sources (probably due to channel erosion) increasing with depth. The mineral magnetic data suggest that there have been periods of increased topsoil influx over limited periods of time, perhaps associated with individual storm events. The mineral magnetic data suggest that catchment topsoil has also reached Slapton Lower Ley. Whilst considerable downcore variability in the magnetic signal is recorded in the lake sediments, the trends in some physical and geochemical properties (i.e. heavy metal concentrations) complicate any interpretation of potential sediment source changes through time derived solely from the lake sediment record. Similarly, there are problems associated with the use of ^{137}Cs measurements to identify dominant sources and source changes (and some further problems are discussed below). However, the high ^{137}Cs concentrations of the lake sediment suggest that pasture topsoil is the most likely source.

The dominance of topsoil erosion from pasture fields as the main sediment source in recent times compares well with the known history of land use in the Slapton

TABLE 3. *Summary data for a Slapton Ley sediment core (core SL1)*

Variable	Mean	Standard deviation	Minimum	Maximum	Number of samples
Dry density (g cm^{-3})	0.21	0.11	0.1	0.5	35
Wet density (g cm^{-3})	1.07	0.10	0.9	1.3	35
DW ratio	0.19	0.08	0.052	0.380	35
Xlf	0.23	0.11	0.1	0.5	35
Xfd	13.37	11.22	0.7	43.1	35
Xfd%	5.28	2.89	0.5	10.1	35
$IRM_{(0.8t)}$	5.73	2.10	2.9	10.9	35
BKIRM	−4.13	2.00	−8.4	−1.4	35
SRATIO	0.69	0.10	0.5	0.8	35
HIRM	0.80	0.16	0.5	1.2	35
HIRM:Xfd	0.18	0.31	0.0	1.4	35
P (μg g^{-1})	510.47	255.96	112.0	1200.0	35
Pb (μg g^{-1})	95.22	17.45	68.09	138.55	35
Zn (μg g^{-1})	75.28	33.37	33.33	138.89	35
Mn (μg g^{-1})	0.24	0.07	0.0634	0.3548	35
Fe (μg g^{-1})	21.37	6.05	6.1	39.2	35
Fe:Mn	95.74	33.56	39.31	162.48	35
Cu (μg g^{-1})	60.53	15.77	16.82	89.72	35
Ni (μg g^{-1})	2.52	9.72	49.09	98.18	35
Al (μg g^{-1})	29.98	8.71	1.81	50.69	35
^{137}Cs (mBq g^{-1})	17.55	22.64	0.0	65.8	35
D10 (μm)	4.45	0.48	3.7	5.2	14
D50 (μm)	16.18	3.12	11.2	20.7	14
D90 (μm)	43.95	10.08	28.7	55.8	14
SPAN	2.40	0.27	2.1	2.9	14

catchments. In general, there has been an intensification of land use following the Second World War. Heathwaite (1993) and Heathwaite & Burt (1993) reported that the area of pasture land (both temporary and permanent) increased significantly after the war. In 1986, permanent pasture occupied *ca* 56% of riparian land use in the Start catchment, while cultivated land only occupied 3% of the riparian zone. The proximity of riparian pasture land to the stream will have increased its relative contribution to the suspended sediment load. Also, stocking densities associated with pasture land increased significantly in the post-war period. Heathwaite *et al.* (1990) have demonstrated, using rainfall simulation experiments, that runoff and sediment loss from overgrazed pasture is an order of magnitude greater than that from both lightly grazed and temporary pasture and is also significantly greater than that from cultivated land

EVALUATING THE SLAPTON LEY BOTTOM-SEDIMENT RECORD

In the light of the information presented above, it is important to assess the value of the lake sediment record from Slapton Lower Ley for estimating catchment erosion rates and for reconstructing changes in catchment processes. The examination of sediment delivery dynamics in the Start catchment provides strong evidence that only a small (<30%) proportion of the material eroded from the slopes actually reaches the Lower

Ley. While the use of the lake sediment record may provide a reliable means of calculating sediment yields to the lake, this method alone results in a significant underestimate of the erosion rate within the upstream catchment (Owens, 1990). When the effect of intermediate sediment storage behind hedge boundaries and on the floodplain is taken into account, the revised value is more closely comparable to that for the nearby catchment of the Old Mill reservoir. The problems associated with sediment storage are further complicated by the fact that storage is a dynamic process that changes over time (*cf.* Trimble, 1983; Church & Slaymaker, 1989). Sediment remobilised from intermediate storage areas in the lower part of the catchment may complicate any interpretation of downstream sediment fluxes in terms of geomorphic processes in the upper part of the basin.

The potential problems associated with the use of the lake sediment record in the Lower Ley for estimating sediment yields are further highlighted by examining the ^{137}Cs record contained within the sediments of Slapton Lower Ley and Old Mill reservoir. Fig. 16 presents ^{137}Cs profiles measured in a sediment core from each lake (core a, Fig. 3 in the case of the Lower Ley). Unlike the atmospheric fallout record depicted in Fig. 4, which shows a decline in ^{137}Cs fallout over the last 30 years, the ^{137}Cs profile from Slapton Ley shows increasing activity up-core, which may represent an increase in the ^{137}Cs content of recently deposited sediment. The profile shape appears to be generally consistent with other sites of relatively low sediment accumulation (Foster *et al.*, 1990a; Walling & He, 1993). In contrast, the ^{137}Cs activity in the sediments of the Old Mill reservoir rise rapidly to *ca* 100 mBq g^{-1} at a depth of 60–61.5 cm, which is taken to indicate the depth of the 1963 peak in bomb-derived fallout (see Fig. 4). After this well-defined 1963 peak, high activities are sustained upcore, since erosion of ^{137}Cs enriched topsoil, largely from heavily grazed pasture, has continued to supply ^{137}Cs to the reservoir (Foster & Walling, 1994).

The total inventories of the two cores range from less than 200 mBq cm^{-2} in Slapton Ley to over 1000 mBq cm^{-2} in the Old Mill reservoir. Although it is tempting to compare directly the ^{137}Cs inventories of these lakes with the background inventory for the region (261 mBq cm^{-2}), some care is required for two reasons. First, not all ^{137}Cs input to the lake from the atmosphere or the catchment will be deposited on the lake bed. The amount deposited will depend on the mechanisms controlling ^{137}Cs transfer to particulate material in the water column and the trap efficiency of the water body. Secondly, ^{137}Cs may not be uniformly deposited over the lake bed, since some areas accumulate sediment more rapidly than others ("focusing"). Focusing is likely to produce a lake sediment inventory greater than the local fallout inventory, whilst a low trap efficiency would lead to a lower value. Correcting the ^{137}Cs inventory for the trap efficiency of the Lower Ley, as described earlier, raises the value to 258 mBq cm- 2, which approximates the local fallout inventory. However, even with the correction for trap efficiency, it is evident that the ^{137}Cs inventory for the Slapton Ley sediment core is much less than that for the Old Mill reservoir. The ^{137}Cs inventory in the sediment of the Old Mill reservoir is more than four times greater than the local fallout inventory. The high sediment yields, as indicated in Fig. 2, appear to have been associated with a significant influx to the reservoir of ^{137}Cs derived from the erosion of catchment topsoils which has sustained high ^{137}Cs activities during a period of declining atmospheric influx. The Lower Ley, on the other hand, does not show the same pattern.

The comparison of the ^{137}Cs profiles and inventories for the two lakes clearly indicates that while the bottom sediment record of Old Mill reservoir is suitable for

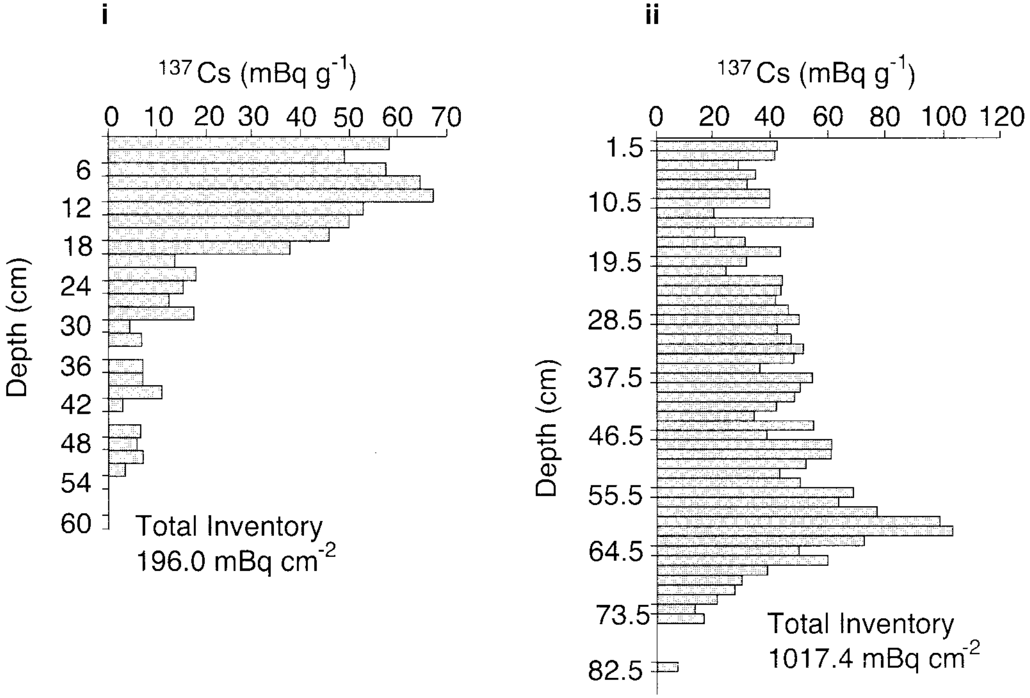

FIG. 16
^{137}Cs inventories and profiles of sediment cores retrieved from Slapton Lower Ley (i) and Old Mill Reservoir (ii).

estimating rates of, and temporal trends in, catchment erosion, that of Slapton Lower Ley is unsuitable. Not only does most of the eroded sediment not actually reach the Lower Ley, but there is also considerable uncertainty over the behaviour of the sediment once in the lake. The trap efficiency of the Lower Ley is not particularly high (76%) and, because of the very shallow nature of the water body (mean depth 1.55 m, Table 2), wind generated currents are likely to mix and disturb the bottom sediment. Thus, ^{137}Cs (and ^{210}Pb) measurements are likely to be of limited value for dating purposes in this lake. The absence of a reliable detailed chronology renders any attempt at estimating sediment yields to the Ley and palaeoenvironmental reconstruction difficult.

There are also problems associated with using the lake sediment record to identify the dominant sediment sources and source changes over time. Some of these problems have already been highlighted in the previous section, but further uncertainties can be highlighted by comparing the IRM acquisition curves for both the lake and the floodplain sediments (Fig. 11). The range associated with the curves for the lake sediment is significantly lower than that for the floodplain sediments. This is, perhaps, somewhat surprising since the age of the bottom of the lake sediment sequence is considerably older than that of the floodplain core, and the lake sediment might therefore be expected to include a wider range of source contributions given the land use history of the catchment (*cf.* Heathwaite, 1993). The most likely explanation is that selective sorting of the fluvial sediment passing through the Start floodplain and the marshy area immediately upstream of the Lower Ley (Fig. 3) results in the preferential deposition of coarser subsoil (which is haematite rich) and the transport to the lake body of finer (magnetite rich) topsoils. This in turn results in a bias of magnetic mineralogy towards topsoil derived materials.

The problems associated with examining source changes is also illustrated by the Iron:Manganese ratio (Fe:Mn), which is often used in palaeolimnological studies as an indication of changing redox conditions, since Mn is more mobile in sediment under strongly reducing conditions (Engstrom & Wright, 1984). Interpretation of the Fe:Mn ratio (Fig. 15) alone suggests that redox conditions have become more reducing in the lower 20 cm and the upper 15 cm of the sediment column. The particle size data presented in Fig. 15 indicate the diameter of particles at the 10th, 50th and 90th percentiles of the cumulative frequency distribution (D_{10}, D_{50} and D_{90} respectively). Decreases in all measures are identified at *ca* 25 and 50 cm depth in the core, suggesting an influx of finer sediment at this time. This pattern is inversely related to the carbonate profile and is directly related to the Fe:Mn ratio. The use of the Fe:Mn ratio as a palaeo-redox indicator in this lake requires some further consideration, since the trend appears to mirror the particle size distribution of the accumulating sediment. Thus, variations in the Fe:Mn ratio could reflect either changing sediment sources or changes in the particle size composition of the deposited sediment.

CONCLUSIONS

It has been shown that sediment yield estimates for the catchments draining to Slapton Ley, based on monitoring and interpretation of lake sediment records, are lower than would be expected from a comparison with the estimates obtained for the catchment of the nearby Old Mill reservoir. The evidence presented above suggests that the main reason for the apparently low sediment yield to Slapton Lower Ley is the significant accumulation of sediment in the floodplain of the lower Start catchment which traps 58% of the sediment moving down the Start stream. The quantity of sediment reaching the Start stream is itself reduced by deposition behind hedgerows and it is estimated that *ca* 15% of the total sediment mobilised within the catchment since 1954 has been stored in such locations.

By adding the sediment accumulation rate on the floodplain and behind hedgerows in the Start catchment to the estimated sediment yield to the Ley from the same catchment, an estimate of the gross erosion rate of 107 t km^{-2} $year^{-1}$ is obtained. This value is of a similar magnitude to that estimated by Foster & Walling (1994) for the Old Mill reservoir catchment over the last 15 years (90 t km^{-2} $year^{-1}$). It seems likely from historical evidence that significant quantities of sediment began to accumulate upstream of Deer Bridge after the rise in water level in the Ley in 1920s.

Mineral magnetic analysis of a floodplain sediment core suggests that topsoil has represented the dominant sediment source since the mid 1970s. Before this time, the contribution from subsoil sources was dominant, probably representing channel bank erosion. The mineral magnetic data also provide evidence that prior to the mid 1970s there were times of increased erosion from topsoil during limited periods. The ^{137}Cs activity of surface sediment samples on the floodplain more closely resembles that of pasture topsoil, suggesting that this is the dominant source of the recently deposited sediment. This observation agrees well with the documented land use history of the

Slapton catchments, which illustrate an increase in the area of permanent pasture (especially in the riparian zone) and in the stocking densities on this land. Previous studies have demonstrated that the sediment mobilised from heavily grazed pasture can be an order of magnitude greater than that from lightly grazed pasture or from cultivated land.

The mineral magnetic properties of the lake sediments have been compared with the same properties in catchment soils. Although the interpretation of the mineral magnetic properties of the lake sediments is complicated by the presence of metal contaminants and allochthonous material in the sediment column, it has been demonstrated that the sediments contain material derived from catchment soils. The HIRM:Xfd ratio appears to be one of the best discriminators between topsoil and subsoil sources in both the Slapton Ley and Old Mill catchments. In both bottom-sediment records, there is no evidence of a major and sustained change in sediment source through time, although sediment deposited in Slapton Ley dating from the 1940s appears to contain more subsoil; a feature which is attributed to the initial disturbance caused by post-war agricultural intensification. The Old Mill reservoir also contains evidence of subsoil erosion, but here it relates to a single high magnitude event in the 1980s. The ^{137}Cs concentrations associated with the lake sediment suggest that topsoil from pasture fields may be the dominant sediment source, although the high radiocaesium activities of recent lake sediments may be a function of selective transport and deposition of fine ^{137}Cs-enriched material in the Ley.

A lake-sediment based interpretation of catchment processes derived from an analysis of the Lower Ley record alone must therefore be treated with considerable caution for several reasons. First, the sediment yield to the Ley is less than 30% of the gross rate of soil erosion from the catchment surface and it is not accurately known when significant sediment storage began and how this has changed over time. Secondly, the shallow water depth of the Lower Ley means that the estimated trap efficiency is only 76% and that wind-generated currents are likely to have disturbed and mixed the deposited sediments. This places some doubt on the use of radionuclides for sediment dating in this lake. Thirdly, there is evidence to suggest that sediments in the Ley are dominated by fine silts, which indicates selective enrichment caused by sorting during delivery, a process which may influence radionuclide and chemical signatures in the lake.

Clearly, any attempt to use lake sediments for examining sediment (and solute) dynamics in the contributing catchment must be done in association with an understanding of contemporary and historical catchment processes and with an appreciation of the fate of the sediment once it reaches the lake. As many researchers have stressed (*cf.* Owens, 1990; Dearing & Foster, 1993; Butcher *et al.*, 1993; Owens & Slaymaker, 1993), not all lakes are suitable for interpreting processes operating in the upstream catchment.

Acknowledgements

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