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Use of ^{137}Cs in the study of soil erosion and sedimentation

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FOREWORD

Soil erosion and sediment deposition represent serious threats worldwide because of their impact on agricultural production and environmental conservation. Erosion affects the productivity of soil through loss of the nutrient-rich surface layers and the incorporation of potentially growth-limiting subsoil into the rooting zone. In many cases, erosion causes progressive decline in soil productivity, particularly so in agro-ecosystems that rely on indigenous fertility. The use of high-input technology such as large amounts of fertilizers, pesticides, and irrigation helps offset deleterious effects of erosion but has the potential to create pollution and health problems, destroy natural ecosystems, and contribute to high energy consumption and unsustainable agricultural systems.

Soil erosion causes not only on-site degradation of a precious natural resource, but also off-site problems of sediment deposition in residential areas and reservoirs, eutrophication of surface waters and pollution from various particle-adsorbed toxic agrochemicals.

Erosion and deposition are recognized to have occurred throughout the history of agriculture, and notwithstanding a half-century of research into its causes and effects, considerable uncertainty persists about extent, magnitude and actual rates, as well as on the economic and environmental consequences. When economic costs of soil loss and degradation and off-site effects are conservatively estimated into cost/benefit analyses of agriculture, it makes sound economic sense to invest in programs that are effective in the control of soil erosion.

The use of radionuclides in soil erosion/deposition research overcomes many of the problems associated with traditional approaches and is now being applied successfully in several developed countries. Among these, the ^{137}Cs technique allows the assessment of both soil loss and deposition in the same watershed from a single site visit without the need for long-term financial commitments. Caesium-137, an artificial radionuclide with a half-life of 30.2 years, is distributed across the earth's surface due to fallout from atmospheric nuclear tests and accidental releases from nuclear reactors. Strongly adsorbed by clay particles, it provides a unique tracer of soil movement.

In response to the United Nations Conference on Environment and Development convened in Rio de Janeiro in June 1992, the UN system launched a worldwide environmental programme called EARTHWATCH. The IAEA joined this initiative through a series of activities on environmental monitoring, impact assessment and environmental protection. Thus, in connection with Chapter 12, "Managing Fragile Ecosystems: Combating Desertification and Drought", of Agenda 21, two IAEA Divisions, the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture and the Division of Physical and Chemical Sciences, joined forces to plan, organize and implement activities on the assessment of soil erosion and sedimentation as a basis for soil conservation and environmental protection. A panel of experts on the use of isotopes in studies on soil erosion convened in November 1995 in Vienna to discuss the possibilities of exploiting radionuclide methodologies, and ^{137}Cs in particular, for the assessment of soil erosion and sedimentation in developing countries in which food security is at greatest risk. The state-of-the-art reports presented at that meeting are contained in this publication which, as the first comprehensive treatment of the subject, is expected to serve as an invaluable source of information to underpin future research on soil conservation and environmental protection. The responsible IAEA officer was F. Zapata. The assistance of D.J. Pennock and A.R.J. Eaglesham in the preparation of this publication is gratefully acknowledged.

CONTENTS

SUMMARY

Although current concern for the global environment focuses largely on problems of global warming and climate change, there is increasing realization that soil erosion represents a major constraint to sustainable development of agricultural production in a world characterized by a burgeoning population. Soil erosion is a natural process caused by water and wind, but the accelerative effects of human activities, most notably deforestation and poor agricultural practices, are of increasing concern. Soil erosion causes not only *on-site* effects associated with compromised soil productivity and loss of agricultural land, but there are also many *off-site* problems such as downstream sediment deposition, pollution of water courses with various adsorbed agrochemicals and eutrophication of water bodies. It is estimated that the world's arable lands are, on average, being eroded at a rate considerably in excess of that of soil formation, resulting in a net 7% depletion of soil resources each decade, with potentially serious implications for food security in many countries. Furthermore, the world's reservoirs are losing storage capacity at about 50 km^3 (approximately 1%) per year, as a result of sedimentation. Considering the central importance of reservoirs for domestic and industrial water supply, for irrigation schemes, and for hydropower production, and thus for economic progress in many developing countries, this trend is of significant concern.

To date, much of the loss of soil and agricultural land through erosion has been compensated by clearing new farm land, and by use of fertilizer and improved crop varieties to increase yields on existing land. However, the scope for maintaining such compensatory measures will decline in the future.

Against this background, there is an increasing need to assemble reliable information on rates of soil loss in different areas of the world. Such information is needed to precisely assess the magnitude of the problem, to evaluate influencing factors, to validate existing and new prediction models, and to investigate relationships with crop production. This need is, however, not readily met by classical methods of measurement of erosion, which have significant limitations. They do not give unbiased measurements of soil redistribution, and, more importantly, they do not address spatial patterns of erosion and deposition within fields. There is a need for location-specific measurements within the landscape, especially in areas where other erosion data are not available and where long-term experiments have not, nor cannot be, established.

The use of radionuclides overcomes many of the problems associated with the traditional approaches and they have the potential to provide the needed data. By labelling the soil, both the extent and the source of soil loss can be determined. Several radionuclides, mainly gamma emitters have been applied as tracers in field-erosion studies (^{59}Fe, ^{46}Sc, ^{110}Ag, ^{198}Au, ^{134}Cs, ^{51}Cr). Another group includes the environmental radionuclides, such as ^{137}Cs, ^{210}Pb, ^{7}Be, ^{240}Pu, ^{14}C, ^{32}Si, ^{26}Al and ^{36}Cl, which can be used to assess soil erosion and deposition patterns and related problems depending on the time scale involved.

The use of fallout radioactivity to estimate soil loss was first published in 1960, the transport of ^{90}Sr in runoff from "standard" erosion plots showed that tracer depletion was greatest where the most soil loss occurred. Research in the late 1960s showed that differences in distribution of fallout ^{137}Cs between vegetation types on a catchment in Mississippi were due to soil loss from the landscape. In the mid-1970s, the combination of data from a variety of soil and erosion conditions, with fallout radionuclides and added tracers, demonstrated a significant exponential relationship between soil loss and tracer loss, with the basic conclusion that ^{137}Cs would be a useful tool for measuring erosion.

Caesium-137 is an artificial radionuclide with a half-life of 30.2 years produced by nuclear fission. Widespread global distribution of ^{137}Cs into the environment began with atmospheric testing of high-yield atomic weapons in the 1950s and the early 1960s. To a lesser extent atmospheric explosions continued until 1980. The ^{137}Cs and other radionuclides were released into the

stratosphere, distributed globally, then moved back to the troposphere and to the earth's surface as fallout, the amount of deposition depending on the atmospheric concentration and rainfall.

Radioactive fallout has been monitored globally since the early 1950s. Strontium-90, identified as the most dangerous radionuclide in fallout due to its biological fixation in bones and the consequent link with bone cancer, was most closely followed, with a map of cumulative deposits published in 1967. Although ^{137}Cs deposition is less well documented, it is possible to construct its deposition pattern from the ^{90}Sr data.

Caesium-137 is by far the most widely used fallout radionuclide in soil erosion and sedimentation research by virtue of its strong adsorption to fine soil particles, a relatively long half-life, ease of measurement and well defined patterns of fallout input. Thus, in agro-ecosystems, its redistribution is a direct indication of erosion, transport and deposition of soil particles occurring during the period extending from the main phase of atmospheric deposition to the time of sampling. Assessment of ^{137}Cs redistribution is commonly based upon comparison of measured inventories (total activity per unit area) at individual sampling points, with an equivalent estimate of the inventory representing the cumulative atmospheric fallout at the site, taking due account of the differing behaviour of cultivated and uncultivated soils. Because direct long-term measurements of atmospheric fallout are rarely available, the cumulative input or reference inventory is usually established by sampling an adjacent undisturbed, putatively uneroded location, generally under permanent pasture, which provides an estimate of total fallout. Where sample inventories are lower than the local reference inventory, loss of caesium labelled soil and therefore erosion may be inferred. Similarly, sample inventories in excess of the reference level are indicative of addition of ^{137}Cs-labelled soil by deposition. The magnitude and direction of the measured deviations from the local reference level provide a qualitative assessment of soil redistribution. In order to derive quantitative estimates of rates of erosion and deposition from ^{137}Cs measurements, it is necessary to establish a relationship between the magnitude of the deviation from the reference inventory and the extent of soil loss or gain. Because empirical calibration data are rarely available, many workers have favoured the use of theoretical relationships or models to provide the necessary calibration function.

Although the basis for the use of the ^{137}Cs technique to document rates and patterns of soil loss is attractive in its simplicity, it is founded on several key assumptions and a number of potential limitations and uncertainties must be recognized and addressed in any application. However, limitations inherent in the use of fallout ^{137}Cs to estimate erosion are no greater than those associated with other techniques used by soil scientists and geomorphologists. If studies are designed to mitigate the effects of these limitations, then measuring the concentration of ^{137}Cs across the landscape can provide reliable and valuable information on erosion and deposition.

A significant expansion in the application of the ^{137}Cs approach has occurred recently, encompassing various locations ranging from glaciated mountain areas in Greenland, through the prairie and steppe regions of Canada and the Russian Federation and semi-arid areas of Spain, to tropical areas of Africa and Thailand. Therefore, the approach must now be seen as having global relevance.

It should be noted, however, that additional inputs of ^{137}Cs fallout to many parts of Europe, associated with the Chernobyl accident in April 1996, have complicated the interpretation of the ^{137}Cs inventories and may render the approach of limited value in such areas.

Although the validity and value of the ^{137}Cs approach has now been demonstrated by numerous studies in a number of environments, considerable scope remains to develop, refine and standardize the procedures employed and to explore additional applications. To date, most of the studies using this approach have been concerned with soil erosion by water, but there is clear potential to extend its application to redistribution of soil by tillage and wind erosion.

The data generated by ^{137}Cs measurements are ideally suited to coupling with GIS and spatial statistics, and for use in verifying computer-generated models for distributed erosion and soil loss Scope also exists for using estimates of soil loss derived from radiocaesium measurements as a basis for establishing medium-term soil-loss/crop-productivity relationships In addition, there is potential for extending the use of ^{137}Cs as a sediment tracer from consideration of soil redistribution within individual fields to investigation of the movement and storage of sediment within a drainage basin

Other fallout radionuclides, including unsupported ^{210}Pb and ^{7}Be have attracted much less attention, but there is increasing evidence that they offer considerable potential for use in soil-erosion research, individually and complementary to ^{137}Cs The International Atomic Energy Agency, through several mechanisms, is promoting further applications of fallout radionuclides in soil erosion and sedimentation studies

^{137}Cs USE IN ESTIMATING SOIL EROSION: 30 YEARS OF RESEARCH

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Abstract

^{137}Cs USE IN ESTIMATING SOIL EROSION: 30 YEARS OF RESEARCH

Significant amounts of fallout ^{137}Cs from nuclear weapons tests were introduced to the landscape during the 1950s and 1960s. Once ^{137}Cs reaches the soil surface it is strongly and quickly adsorbed by clay particles, and is essentially nonexchangeable in most environments. Thus, ^{137}Cs becomes an effective tracer of the movement of soil particles across the landscape. Over the past 30 years, researchers have shown that ^{137}Cs can be used to study soil movement. Early work used empirical relationships between soil loss and ^{137}Cs loss to estimate erosion. This was followed by the development of proportional and theoretical models to relate ^{137}Cs movement and soil redistribution. Most of the problems related to the ^{137}Cs technique are the same as those encountered with other techniques (i.e., sampling, measurement). The ^{137}Cs technique can make actual measurements of soil loss and redeposition in fields, fostering the formulation of better plans to conserve the quality of the landscape. This paper reviews the development of the ^{137}Cs technique to show how it can be used to understand erosion and soil movement on the landscape.

1. INTRODUCTION

Soil erosion is a natural process caused by water and wind. The accelerative effects of man's activities on erosion and the off-site damage caused, are major concerns around the world. The size of the problem and concern over degradation of the landscape are well documented [1, 2 ,3]. Economic effects of soil erosion along with off-site, downstream damage from eroded soil particles have also been described [3, 4, 5].

Measurements of soil erosion on the landscape using classical erosion techniques are difficult, time consuming, and expensive [6]. Empirical and theoretical mathematical equations/models have been developed. The most widely used is the Universal Soil Loss Equation (USLE), which is an empirical-based equation developed with data collected from soil erosion plots on "typical" soils of the United States east of the Rocky Mountains [7]. The USLE has been used and misused in the United States and around the World [8]. However, it is still the most widely used, powerful and practical tool for estimating sheet and rill erosion on the landscape. A Revised Universal Soil Loss Equation (RUSLE) is currently being used in the United States with applications to a wider range of conditions and locations than the original USLE [9]. There are many other efforts to model soil erosion and its off-site effects [10] that have had varying degrees of success and applications in management and research. One such effort is the Water Erosion Prediction Project (WEPP), which is a process-based, simulation model of soil erosion [11].

Over the past 30 years, researchers have studied the potential of using natural and man-made radioisotopes to study the erosion and sediment-deposition cycle. Several radioisotopes have been used. The potential for using fallout ^{137}Cs to provide independent measurements of actual soil erosion rates and patterns and sediment deposition is well documented [12, 13]. The purpose of this paper is to review the development of the ^{137}Cs technique for studying erosion and redeposition, based on a bibliography [14] of 1500 papers that show extensive use of the technique globally.

2. BACKGROUND

Most classical methods for estimating soil erosion are based on measuring soil loss from plots or at the edge of a field. They do not give unbiased measurements of actual soil movement, and, more importantly, they do not address spatial patterns of erosion and redeposition within fields. Mathematical models have the same limitations. There is a need to be capable of making measurements at any location on the landscape, especially in areas where other erosion data are not available and where long-term experiments have not, nor cannot be, established. Classical erosion measurement techniques and mathematical models cannot meet these criteria. Tracer techniques have the potential to provide the necessary type of data. However, such techniques can be difficult if tracer must be added to the environment. A tracer is needed that is naturally distributed across the landscape, easily measured, and readily adsorbed to soil particles.

Fallout ^{137}Cs from atmospheric nuclear weapons tests of the 1950s and 1960s is a unique tracer for the erosion and deposition cycle because no natural sources are in the environment. Yet, ^{137}Cs is globally distributed across the earth's surface due to fallout deposition from such tests and releases from nuclear reactors [15, 16]. Before 1952, releases were localized around weapon test sites or reactors. With the coming of high-yield thermonuclear weapons testing in November 1952 [17], ^{137}Cs was injected into the stratosphere and circulated globally [18]. Fallout rates decreased with distance from the northern temperate zone. Regional patterns and rates of fallout were linearly related to precipitation in latitudinal zones [18].

Local variation of fallout ^{137}Cs on the landscape can be significant. Studies have reinforced the need to make local measurements at undisturbed sites rather than by extrapolating from values determined at other locations [19, 20]. The rates of deposition of fallout ^{137}Cs have decreased since the maxima of the early 1960s, and since the mid-1980s have often been below detection limits [15]. Releases from nuclear reactors are usually local in nature. However, the Chernobyl accident in April 1986 caused regional dispersal of measurable ^{137}Cs [21] that affected the total global deposition budget [22]. Thus man's activities related to nuclear energy have distributed a unique radioactive element across the landscape surface in discernible patterns that can be used to trace natural events.

The chemistry of this unique tracer is well understood [18, 23]. Once ^{137}Cs reaches the soil surface it is strongly and quickly adsorbed by clay particles, and is essentially nonexchangeable in most environments [24, 25, 26]. Thus, ^{137}Cs becomes an effective tracer of the movement of surface soil. Distribution of ^{137}Cs in soil profiles at undisturbed sites shows an exponential decrease with depth [27, 28, 29], whereas plowed soils show uniform distribution throughout the plowed layer [30, 31]. Less than 1% of the ^{137}Cs is flushed in solution from a catchment immediately after deposition, and generally less than 0.1% moves in solution per year after the initial flush [32, 33]. Thus most movement of ^{137}Cs across the landscape is due to the physical processes of erosion and sediment deposition.

Accurately measuring ^{137}Cs in environmental samples is easy [34, 61]. In soil erosion studies, the challenge is to elucidate the changing patterns of distribution of ^{137}Cs-tagged soil particles on the landscape. The redistribution of ^{137}Cs between and within landscape elements provides information on soil erosion rates and patterns. Although biological and chemical processes move limited amounts of ^{137}Cs in unique environments, water and wind are the dominant factors moving ^{137}Cs-tagged soil particles between and within compartments of the landscape.

Thus, measurement of ^{137}Cs redistribution on the landscape provides estimates of long-term soil loss. Estimates are location-specific and can be made with minimum disturbance to study sites, giving both spatial patterns and rates of erosion from a single visit.

3. EARLY RESEARCH

The first publication of the use of fallout radioactivity to estimate soil loss was in 1960 by Menzel [35], who measured the transport of fallout ^{90}Sr in runoff from "standard" erosion plots. He concluded that ^{90}Sr loss was greatest from those plots that had the most soil loss. Although this study did not include ^{137}Cs, it showed that the movement of fallout radioactivity on the landscape was related to soil movement.

In 1963, Frere and Roberts [36] measured ^{90}Sr across a small cultivated catchment in Ohio as a function of slope position and shape, and concluded that the pattern was due to the redistribution of soil particles by erosion processes. Graham [37] added ^{85}Sr and ^{131}I to standard erosion plots, and concluded that soil particles affected nuclide removal by runoff water. And Yamagata, Matsuda, and Kodaira [38] concluded that runoff was a factor in the removal of ^{137}Cs and ^{90}Sr from catchments.

In 1965, Rogowski and Tamura published the first of three reports [39, 40, 41] on the movement of ^{137}Cs by runoff, erosion, and filtration from plots at the Oak Ridge National Laboratory in Tennessee, USA. They added ^{137}Cs as a tracer and followed its movement by measuring runoff, soil loss and ^{137}Cs loss at a flume at the end of erosion plots. The first publication [39] was based on the first 83 days of data collection. In follow-up publications in 1970, they discussed the environmental mobility of ^{137}Cs [40] and erosional behavior of ^{137}Cs [41]. They found a significant exponential relationship between soil and ^{137}Cs losses, and concluded that erosion was a major factor in removing ^{137}Cs. Although these studies were not based on fallout nuclear weapons tests, they showed that ^{137}Cs and soil movements were related, and could be used as a tool for estimating soil redistribution on the landscape.

It is interesting that in 1965 Wischmeier and Smith [7] first published the USLE (Universal Soil Loss Equation) in USDA Agriculture Handbook No. 262 on predicting rainfall-erosion losses for cropland east of the Rocky Mountains. The USLE, an empirical equation based on measured soil loss from standard erosion plots on "typical soils" east of the Rocky Mountains in the United States, received wide acceptance in the United States and around the world. The equation is used and misused [8] for areas where the empirical relationship developed for United States soils is probably not applicable. The early work of Rogowski and Tamura on using the ^{137}Cs to measure soil loss, however, has yet to be implemented as a tool for soil conservationists to study soil redistribution.

In another study at Oak Ridge, Dahlman and Auerbach [42] added ^{137}Cs to a grass plot (fescue meadow) and used its redistribution to estimate erosion. They also found an exponential relationship between soil and ^{137}Cs losses. These early studies with high levels of added ^{137}Cs raised the question of whether measurement of the much lower fallout levels could be used to estimate soil redistribution patterns across the landscape.

In 1968, Ritchie and McHenry began a series of studies to determine if fallout levels of ^{137}Cs could be used as a tracer of sediment movement and deposition across natural and agricultural landscapes, supported jointly by the United States Department of Agriculture and the U.S. Atomic Energy Agency (now Department of Energy). In 1970 [43, 44], they concluded that differences in distribution of fallout ^{137}Cs between vegetation types on a catchment in Mississippi were due to soil loss from the landscape. In 1972 [45, 46, 47], they designed an experiment to determine the relationship between losses of soil and of fallout ^{137}Cs in a catchment. Soil loss was estimated using the USLE and fallout ^{137}Cs loss was calculated as a percent compared with a non-eroded reference site. They found an exponential relationship between soil and ^{137}Cs loss, and, along with data from two other catchments [47, 48], concluded that most of the ^{137}Cs loss from the catchments was from the eroded areas.

In 1975, Ritchie and McHenry [49] combined their data with those from the earlier studies of Rogowski and Tamura [39, 40, 41], Menzel [35], Frere and Roberts [36], and Graham [37], and found a significant exponential relationship between soil loss and radionuclide loss. This was encouraging since the data used to develop this empirical relationship came from a variety of soil and erosion conditions, used different radionuclides, and varied from fallout levels to high levels added as tracers. Their basic conclusion was that ^{137}Cs would be a useful tool for measuring soil loss from the landscape.

While most of the early research in the 1970s was in the United States, in 1977 McCallan and Rose [50] used ^{137}Cs and ^{210}Pb to estimate erosion in a basin in Australia. The same year, Wise [51] published a review paper in England on the use ^{137}Cs and ^{210}Pb to measure denudation rates.

Simultaneously, McHenry and Ritchie [52] found that ^{137}Cs distribution in an agricultural field could also be used to show that most of the soil particles were being redeposited within the field rather than being lost from it. This opened a new area of interest in erosion, using the distribution of ^{137}Cs to determine spatial patterns of erosion within a field and areas of net loss and of net gain (deposition) within a landscape element.

In the 1980s, four major centers of research on the use of ^{137}Cs to study erosion were active. McHenry and Ritchie [12] continued their activities in the United States. In Australia, Campbell [53], Elliott [54], Loughran [55], and others used the low levels of ^{137}Cs in the southern hemisphere to measure erosion and sediment deposition. A group lead by de Jong [56] and his students [57, 58] used ^{137}Cs extensively to study erosion on the Canadian prairie. In England, Walling [59, 60, 61] developed a center at Exeter University for using ^{137}Cs to quantify changes in landscape geomorphology. These centers are still active in their research efforts and continue to provide new methods to use ^{137}Cs to quantify soil redistribution across the landscape.

4. EQUATIONS/MODELS

Empirical equations have been developed to explain the relationship between ^{137}Cs and soil loss. The studies vary from simultaneous measurement of losses of soil and of ^{137}Cs (radionuclide) from erosion plots, to correlation between soil loss from the plots and the reduction of ^{137}Cs in these plots, to correlation between estimates of soil loss from fields and the reduction of ^{137}Cs in the soils of these fields. Although important in showing a relationship between soil and ^{137}Cs loss, these studies have many limitations. The general form of these equations is $Y = aX^B$. Such empirical equations are affected by climate, soils, time since fallout, time period of development, and other landscape and environmental factors. Similar concerns for the application and misuse of the empirical-based USLE have been expressed [8]. Empirical equations are applicable only to the data domain used in their development. Using this approach to estimate soil erosion will require the development of an empirical equation (calibration curve) for each site or at best, for each region. Empirical equations are dependent on the time since fallout and time of fallout. While they may help explain and better define the role of different factors that affect the relationship between soil loss and radionuclide loss, the many limitations to their application reduce their usefulness for estimating soil loss on a large scale.

A second approach for using ^{137}Cs to study erosion is to assume that the loss of ^{137}Cs at a site is proportional to the loss of soil. The simplest form of this approach is to equate soil loss to ^{137}Cs loss ($Y = X$), where Y is soil loss in weight per area per time and X is ^{137}Cs loss in percent or weight. However, the X term is usually modified by depth distribution of ^{137}Cs, density of soil, decay corrections, and other coefficients and modifiers [62]. Kachanoski [63, 64] provided an empirical

verification of this approach by measuring ^{137}Cs concentrations in erosion plots at two different times and comparing the results of measured soil loss with measured ^{137}Cs loss. A major assumption with this model is that ^{137}Cs is instantaneously uniformly distributed in the soil profile. Since ^{137}Cs is deposited on the surface and strongly adsorbed, it requires mechanical mixing (plowing) to achieve uniform distribution. Thus, during times of fallout, these conditions are seldom met leading to excess removal of ^{137}Cs with surface erosion, causing overestimation of soil loss. Since fallout and erosion are both related to rainfall, there are concerns about erosion rates during times of heavy fallout. During these times, greater erosion rates would remove proportionately more ^{137}Cs from the surface layer of soil, leading to overestimation of long-term erosion rates. This problem is magnified if erosion rates are higher during maximum fallout, removing a disproportionate amount of the fallout. Usually the proportional method overestimates erosion rates for periods of heavy fallout. The proportional method will probably reflect actual erosion rates for a cultivated area that was undisturbed during the fallout period.

Another approach is theoretical models/mass accounting. Walling and Quine [61] have defined the theoretical models as "the aggregate effect of all redistribution processes operating over the period since the initiation of atmospheric fallout to establish site-specific calibration relationships." Getting all the data needed to run a "process" based model may be a concern in some regions. By determining the factors that influence ^{137}Cs movement, a ^{137}Cs balance for a catchment can be developed and the spatial pattern and loss of ^{137}Cs from the catchment or field can be calculated. Such studies thus allow an understanding of erosion and deposition patterns of soil particles, and have been used [60, 65, 66] to study erosion and deposition patterns on the landscape. These techniques give qualitative and quantitative information on erosion patterns. As with the other techniques, the balance approach requires a determination of the baseline level of ^{137}Cs for the study area. Several studies have cautioned against using fallout measurements to estimate total ^{137}Cs loads in soils of a watershed. Measurements of actual ^{137}Cs should be made at a noneroding site in the catchment. By comparing ^{137}Cs measurement at a study site with the baseline level, one can determine whether erosion (less ^{137}Cs present than at the baseline site) or deposition (more ^{137}Cs present than at the baseline site) has occurred.

While there are limitations to the use of fallout ^{137}Cs to estimate erosion, they are no greater than those associated with other techniques. Campbell et al. [67] suggest that the errors of the ^{137}Cs technique may be less than current techniques used by soil scientists and geomorphologists to study erosion. If we understand the limitations and design studies to reduce the effects of these limitations, then measuring the concentration of ^{137}Cs across the landscape can provide accurate and valuable information on erosion.

5. CONCLUSIONS

Thirty years of research have shown that the distribution of fallout ^{137}Cs on the landscape can be used to measure soil loss. Measurements of spatial patterns of ^{137}Cs can provide unique insights into soil movement and redeposition within a landscape element that other methods cannot provide. The ^{137}Cs method is often the only way to get actual measurements of soil loss and redeposition. As such, research should continue the development of the technique to better understand the changing landscape. Applications should also be encouraged in areas of the world where resources are limited for developing long-term erosion monitoring programs.

REFERENCES

[1] BROWN, L.R., WOLF, E.C., Soil erosion: Quiet crisis in the world economy, Worldwatch Paper 60 (1984) 51 pp.

[2] PIMENTEL, D., et al., World agriculture and soil erosion, Biosci. 37 (1987) 277-283.

[3] WALLING, D.E., "The struggle against water erosion and a perspective on recent research", Water Erosion, (K. Ivanov, Pechinov, D., Eds.), UNESCO Technical Document in Hydrology SC-89/WS-57 (1989) 39-60.

[4] CLARK, II, E.H., The off-site cost of soil erosion, J. Soil Water Conserv. **40** (1985) 19-22.

[5] COLACICCO, D., et al., Economic damage from soil erosion, J. Soil Water Conserv. **44** (1989) 35-39.

[6] LAFLEN, J.M., et al., WEPP A new generation of erosion prediction technology, J. Soil Water Conserv. **46** (1991) 34-38.

[7] WISCHMEIER, W.H., SMITH, D.D., Predicting rainfall-erosion losses for cropland east of the Rocky Mountains, Agr. Handbook No. 262 USDA, Washington, DC (1965).

[8] WISCHMEIER, W.H., Use and misuse of the universal soil loss equation, J. Soil Water Conserv. **31** (1976) 5-9.

[9] RENARD, K.G., et al., RUSLE Revised universal soil loss equation, J. Soil Water Conserv. **46** (1991) 30-33.

[10] FOSTER, G.R., Advances in wind and water erosion prediction, J. Soil Water Conserv. **46** (1991) 27-29.

[11] LAFLEN, J.M., et al., WEPP Soil erodibility experiment for rangeland and cropland soil, J. Soil Water Conserv. **46** (1991) 39-44.

[12] RITCHIE, J.C., McHENRY, J.R., Application of radioactive fallout cesium-137 for measuring soil erosion and sediment accumulation rates and patterns: A review, J. Environ. Qual. **19** (1990) 215-233.

[13] WALLING, D.E., QUINE, T.A., "Use of caesium-137 to investigate patterns and rates of soil erosion on arable fields", Soil Erosion on Agricultural Land (Broadman, J., Foster, I.D.I., Dearing, J.A., Eds.), John Wiley & Sons, London (1990) 33-53.

[14] RITCHIE, J.C., RITCHIE, C.A., Bibliography of publications of ^{137}Cesium studies related to erosion and sediment deposition. IAEA-TECDOC-828, IAEA, Vienna (1995) 125-201.

[15] CAMBRAY, R.S.,et al., Radioactive fallout in air and rain: Results to the end of 1988, U.K. Atomic Energy Authority Report AERE-R-13575 (1990).

[16] CARTER, M.W., MOGHISSI, A.A., Three decades of nuclear testing, Health Phys. **33** (1977) 55-71.

[17] LONGMORE, M.E., "The caesium-137 dating technique and associated applications in Australia— A review", Archaeometry: An Australasian Perspective, (Ambrose, W., Duerden, P., Eds.), Australian National University Press, Canberra, Australia (1982) 310-321.

[18] DAVIS, J.J., "Cesium and its relationship to potassium in ecology", Radioecology, (Schultz, V., Klement, A.W. Jr., Eds.), Reinhold, NY (1963) 539-556.

[19] KISS, J.J., de JONG, E., MARTZ, L.W., The distribution of fallout cesium-137 in Southern Saskatchewan, Canada. J. Environ. Qual. **17** (1988) 445-452.

[20] NOLIN, M.C., et al.., Short-range variability of fallout ^{137}Cs in an uneroded forest soil, Can. J. Soil Sci. **73** (1993) 381-385.

[21] PLAYFORD, K., et al., Radioactive fallout in air and rain: Results to the end of 1990, AEA-EE-0362, United Kingdom (1992).

[22] VOLCHOK, H.L., CHIECO, N. (Ed.), A compendium of the Environmental Measurement Laboratory's research projects related to Chernobyl nuclear accident, USDOE Rep. EML-460, EML, NY (1986)

[23] SCHULTZ, R.K., et al.., On the soil chemistry of cesium-137, Soil Sci. **89** (1960) 19-27.

[24] TAMURA, T., Consequences of activity release: Selective sorption reactions of cesium with soil minerals, Nucl. Safety 5 (1964) 262-268.

[25] CREMERS, A., et al.., Quantitative analysis of radiocaesium retention in soils, Nature **335** (1988) 247-249.

[26] LIVENS, F.R., RIMMER, D., Physico-chemical controls on artificial radionuclides in soil, Soil Use and Management 4 (1988) 63-69.

[27] BECK, H.L., Environmental gamma radiation from deposited fission products 1960-1964, Health Phys. **12** (1966) 313-322.

[28] RITCHIE, J.C., et al., Distribution of fallout and natural gamma radionuclides in litter, humus, and surface mineral soils under natural vegetation in the Great Smoky Mountains, North Carolina- Tennessee, Health Phys. **18** (1970) 479-491.

[29] CAMPBELL, B L , et al , Caesium-137 as an indicator of geomorphic processes in a drainage system, Aust Geographical Studies **20** (1982) 49-64

[30] BACHHUBER, H ,et al , Spatial variability of distribution coefficients of ^{137}Cs, ^{65}Zn, ^{85}Sr, ^{57}Co, ^{109}Cd, ^{141}Ce, ^{103}Ru, ^{95m}Tc, and ^{131}I in cultivated soil, Nucl Tech **72** (1986) 359-371

[31] LOUGHRAN, R J , et al , Soil erosion and sedimentation indicated by caesium 137 Jackmoor Brooke catchment Devon, England, Catena **14** (1987) 201-212

[32] EAKINS, J D , et al , "The transfer of natural and artificial radionuclides to Brotherswater from its catchment", Lake Sediment and Environmental History, (Haworth, E Y , Lund, J W G , Eds), University of Minnesota Press, Minneapolis, MN (1984) 125-144

[33] HELTON, J C , et al , Contamination of surface-water bodies after reactor accidents by the erosion of atmoshperically deposited radionuclides, Health Phys **48** (1985) 757-771

[34] RITCHIE, J C , McHENRY, J R , Determination of fallout Cs-137 and natural gamma-ray emitting radionuclides in sediments, Intern J Appl Radiat Isotopes **24** (1973) 575-578

[35] MENZEL, R G , Transport of strontium-90 in runoff, Sci **131** (1960) 499-500

[36] FRERE, M H , ROBERTS JR , H J , The loss of strontium^{90} from small cultivated watersheds Soil Sci Soc Am Proc **27** (1963) 82-83

[37] GRAHAM, E R , Factors affecting Sr-85 and I-131 removal by runoff water Water and Sewage Works **110** (1963) 407-410

[38] YAMAGATA, N , et al , Run-off of caesium-137 and strontium-90 from rivers Nat **200** (1963) 668-669

[39] ROGOWSKI, A S , TAMURA, T , Movement of ^{137}Cs by runoff, erosion and infiltration on the alluvial Captina silt loam, Health Phys **11** (1965) 1333-1340

[40] ROGOWSKI, A S , TAMURA, T , Environmental mobility of cesium-137, Rad Bot **10** (1970) 35-45

[41] ROGOWSKI, A S , TAMURA, T , Erosional behavior of cesium-137, Health Phys **18** (1970) 467-477

[42] DAHLMAN, R C , AUERBACH S I , Preliminary estimation of erosion and radiocesium redistribution in a fescue meadow ORNL-TM-2343 (1968), Oak Ridge National Laboratory, Oak Ridge, Tennessee

[43] RITCHIE, J C , et al , The use of fallout cesium-137 as a tracer of sediment movement and deposition Mississippi Water Resour Conf Proc (1970) 149-163

[44] RITCHIE, J C , et al , Distribution of cesium-137 in the upper 4 inches of soil in relation to vegetation type ASB Bulletin **17** (1970) 60

[45] RITCHIE, J C , et al , Estimating soil erosion from the redistribution of Cs-137 fallout Agronomy Abstracts 1973 Annual Meeting (1973) 129

[46] RITCHIE, J C , et al , Estimating soil erosion from the redistribution of fallout Cs-137, Soil Sci Soc Am Proc **38** (1974) 137-139

[47] RITCHIE, J C , et al , Distribution of Cs-137 in a small watershed in northern Mississippi, pp 129-133 *In* D J Nelson (ed), Proceedings of the third national symposium on radioecology USAEC CONF-710501-p1, US Atomic Energy Commission, Washington, DC (1973)

[48] RITCHIE, J C , et al , Fallout Cs-137 in the soils and sediments of three small watersheds Ecol **55** (1974) 887-890

[49] RITCHIE, J C , McHENRY, J R , Fallout Cs-137 A tool in conservation research, J Soil Water Conserv **30** (1975) 283-286

[50] McCALLAN, M E , ROSE, C W , The construction of a geochronology for alluvial deposits in the Condamine Plain and the estimation of the areal variation in erosion intensity in the Upper Condamine drainage basin Technical Report 2/77, Griffith Univ , Australia, (1977) 16 pp

[51] WISE, S , The use of fallout radionuclides Pb-210 and Cs-137 in estimating denudation rates and in soil erosion measurements Geography Department, King's College, London, Occasional Paper 7 (1977) 38 pp

[52] McHENRY, J R , RITCHIE, J C , Estimating field erosion losses from fallout Cs-137 measurements IAHS Publ No 122 (1977) 26-33

[53] CAMPBELL, B L , et al , Mapping drainage basin sediment sources using caesium-137 IAHS Publ No 159 (1986) 437-446

[54] ELLIOTT, G L , et al , Correlation of erosion measurement and soil caesium-137 content J Appl Radiat Isot **41** (1990) 713-717

[55] LOUGHRAN, R J , et al , Estimation of soil erosion from caesium-137 measurements in a small cultivated catchment in Australia J Appl Radiat Isot **39** (1988) 1153-1157

[56] de JONG, E , et al , Estimates of soil erosion and deposition from some Saskatchewan soils Can J Soil Sci **63** (1983) 607-617

[57] KACHANOSKI, R.G., Estimating soil loss from changes in soil cesium-137. Can. J. Soil Sci. **73** (1993) 515-526.

[58] PENNOCK, D.J., et al.., Distribution of cesium-137 in uncultivated black chernozemic landscapes. Can. J. Soil Sci. **74** (1994) 115-117.

[59] WALLING, D.E., BRADLEY, S.B., The use of caesium-137 measurements to investigate sediment delivery from cultivated areas in Devon, UK. IAHS Publ. No. 174 (1988) 325-335.

[60] QUINE, T.A., WALLING, D.E., Rates of soil erosion on arable fields in Britain: quantitative data from caesium-137 measurements. Soil Use Manage. 7 (1991) 169-176.

[61] WALLING, D.E., QUINE, T.A., Use of caesium-137 as a tracer of erosion and sedimentation: Handbook for the application of the caesium-137 technique. U.K Overseas Development Administration Research Scheme R4579, Department of Geography, Univ. Exeter, Exeter, United Kingdom (1993).

[62] WALLING, D.E., QUINE, T.A., "Use of caesium-137 to investigate patterns and rates of soil erosion on arable fields", Soil Erosion on Agricultural Land (Broadman, J., Foster, I.D.I., Dearing, J.A., Eds.), John Wiley & Sons, London (1990) 33-53.

[63] Kachanoski, R.G., Comparison of measured soil 137-cesium losses and erosion rates, Can. J. Soil Sci. **67** (1987) 199-203.

[64] KACHANOSKI, R.G., de JONG, E., Predicting the temporal relationship between cesium-137 and erosion rate, J. Environ. Qual. **13** (1984) 301-304.

[65] McHENRY, J.R., BUBENZER, G.D., Field erosion estimated from ^{137}Cs activity measurements, Trans. Am. Soc. Agric. Engr. **28** (1985) 480-483.

[66] FREDERICKS, D.J., PERRENS, S.J., Estimating erosion using caesium-137: II. Estimating rates of soil loss, IAHS Publ.# 174 (1988) 233-240.

[67] CAMPBELL, B.L., et al., "Use of isotopic techniques in hydrological and erosion-sedimentation studies in tropical and temperate zones of the Asian-Pacific region", International Geomorphology (Gardiner, V., Ed.), Part 1. John Wiley & Sons, London (1987) 751-766.

NEW PERSPECTIVES ON THE SOIL EROSION–SOIL QUALITY RELATIONSHIP

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Abstract

NEW PERSPECTIVES ON THE SOIL EROSION-SOIL QUALITY RELATIONSHIP

The redistribution of soil has a profound impact on its quality (defined as its ability to function within its ecosystem and within adjacent ecosystems) and ultimately on its productivity for crop growth. The application of ^{137}Cs -redistribution techniques to the study of erosion has yielded major new insights into the soil erosion-soil quality relationship. In highly mechanized agricultural systems, tillage erosion can be the dominant cause of soil redistribution; in other agroecosystems, wind and water erosion dominate. Each causal factor results in characteristic landscape-scale patterns of redistribution. In landscapes dominated by tillage redistribution, highest losses occur in shoulder positions (those with convex downslope curvatures); in water-erosion-dominated landscapes, highest losses occur where slope gradient and length are at a maximum. Major impacts occur through the loss of organically-enriched surface material and through the incorporation of possibly yield-limiting subsoils into the rooting zone of the soil column. The potential impact of surface soil losses and concomitant subsoil incorporation on productivity may be assessed by examining the pedological nature of the affected soils and their position in the landscape. The development of sound conservation policies requires that the soil erosion-quality relationship be rigorously examined in the full range of pedogenic environments, and future applications of the ^{137}Cs technique hold considerable promise for providing this comprehensive global database.

1. INTRODUCTION

The connection between soil redistribution and soil quality is implicit in many definitions of soil quality. For example, Larson and Pierce [1] define quality as the capacity of a soil to function, both within its ecosystem boundaries (e.g. soil map unit boundaries) and with the environment external to that ecosystem (particularly relative to air and water quality). The basic functions of a soil within the ecosystem are to sustain biological productivity, maintain environmental quality, and to promote plant and animal health [2].

Clearly, soil erosion has a range of ecosystem effects: on the soil itself at the point where erosion occurs; on the landscape where redistribution of soil occurs; and on adjacent ecosystems to which the soil is exported (primarily downstream aquatic ecosystems). Although all three scales of study are important, this review concentrates on the impact of erosion at the pedon and landscape scales; the primary focus is on the new insights into the soil erosion-soil quality relationship that have been gained by application of the ^{137}Cs redistribution technique.

Redistribution alters the chemical, biological, and physical composition of soil at each point in the landscape where it occurs (the pedon scale). These changes in composition may affect the ability of the soil to perform the ecosystem functions outlined above. The literature in soil science and related disciplines abounds in specific examples of the impact of redistribution on soil quality, yet few generalizations have emerged from this voluminous body of work. In most cases, at the point where loss occurs, there will be a decrease in the ability of the soil to function. The impact of soil deposition on function is even less clear: positive and negative impacts on soil quality have been observed. The link between these redistribution-related changes in soil quality and in crop productivity is also elusive.

Commonly, conclusions are based on what should happen to crop yields given the severity of soil-quality changes, rather than on what has been observed to occur.

The redistribution of soil materials also has a profound influence on the spatial pattern of soil quality indicators within the ecosystem boundary (the landscape scale). Redistribution can increase the range of variability within a given landscape unit; however, redistribution also imposes, or reinforces, a distinctive landform-soil property relationship that can be used to stratify landscapes into meaningful response units or experimental units. Hence, although redistribution may increase the overall range of variability, it can also create or exaggerate an overall spatial order within the ecosystem.

Soil transport by redistribution beyond the boundaries of the source ecosystem to adjacent ecosystems (the regional scale) is the final scale of relevance in examining impact on ecosystem function. The sediment itself and the chemical and biochemical components sorbed to it can be significant contributors of soil-derived pollutants to aquatic ecosystems. The effect of soil erosion on air quality, through deflation and transport by wind, can be of importance in specific regions (i.e. the dusts of north-central Africa), but tends to be a short-lived phenomenon elsewhere in the world.

A rigorous evaluation of the causes and impacts of soil erosion at all the scales of relevance is critical for the development of scientifically-sound land-use policies. The need for reliable data upon which to base these planning strategies is starkly illustrated in two recent articles. Pimentel et al. [3] argue that one-third of the world's arable land has been lost to erosion in the past 40 years; the cost of erosion losses in the U.S.A. alone totals $44 billion per year, and they suggest that these losses could be reduced to a sustainable levels with total expenditures of $ 8.4 billion per year. In his response to their study, Crosson [4] suggests that their estimate of arable land lost "rests on such thin underpinnings that it cannot be taken seriously" (p. 461). His estimates of the annual cost of erosion-induced productivity losses in the U.S.A. are in the range of $500 to $600 million (1986 dollars). Clearly we cannot expect policy-makers to develop sound conservation policies when we are unable to provide a more authoritative data set upon which to base decisions.

2. CHANGING CONCEPTS OF SOIL REDISTRIBUTION

The great contribution of soil-geomorphologists such as R. Ruhe and R. Daniels was to establish that soil redistribution is a natural process that has driven landscape evolution throughout time. The focus of this review is on the increases in soil loss and gain associated with human activity, or, as it is more commonly known, accelerated soil erosion.

2.1. Causes of soil erosion

Traditionally, reviews of the causes of "erosion" have focused almost exclusively on wind and water processes as the major determinants of soil redistribution. The physical processes of wind and water erosion, their relationship to soil and landform properties, the domains in which they operate, and the relative importance of each process in those domains have been exhaustively studied, and many fine reviews exist of this research [e.g. 5].

Recent research on tillage operations [6, 7, 8, 9] has, however, challenged the view that only wind and water erosion need to examined as the dominant causes of soil redistribution in all landscapes. Working at research sites in agricultural landscapes of Canada and Europe, these authors used a variety of techniques (natural and enriched ^{137}Cs redistribution, displacement of simulated clods, simulation modelling) to examine the relative importance of water and tillage erosion. Their

results strongly support the idea that tillage redistribution is a major cause of soil movement in agricultural landscapes.

Cultivation can displace soil upslope or downslope, depending on the direction of the operation; however, because downslope displacement is greater than upslope displacement, a net downslope displacement occurs. The rates of loss attributed to these practices (discussed below) can be high; however, the magnitude of the loss depends on the type and sequence of the tillage operation, as well as on the type of implement and the speed of operation [9].

Clearly, the impact of tillage redistribution is of greatest importance in highly mechanized agricultural systems - in other systems such as "slash and burn" described by Garcia-Oliva et al. [10], other causes of redistribution predominate. The recognition of the relative importance of a given erosion process (water, wind, or tillage) in a specific region is critical for explaining the landscape-scale spatial patterns of loss and gain, as well as for evaluating possible extra-ecosystem impact of soil redistribution.

2.2. Rates of soil redistribution as determined using ^{137}Cs techniques

Observations of rates of soil redistribution are available from a variety of sources. In many cases, they have been made on small research plots to generate data for the development and calibration of predictive erosion models such as the Universal Soil Loss Equation (USLE) or the forthcoming Water Erosion Prediction Project (WEPP). Traditionally, however, these plots were designed to examine only the soil-loss part of the redistribution continuum, hence they are limited in their usefulness when examining redistribution as a whole. Far too often the measured rates of soil loss from these research plots are uncritically extended to the landscape as a whole, without an evaluation of potential redistribution within the source landscape [11].

TABLE I. EXAMPLES OF RECENT VALUES FOR SOIL LOSS

Location	Field Type	Rate of soil loss in eroded postions of the field ($Mg\ ha^{-1}\ yr^{-1}$)	Reference
Mexico	Pasture and undisturbed forest	13	[10]
U.K., Belgium	Cultivated	10 to 20	[8]
Ontario, Canada	Cultivated	68 to 82	[9]
Saskatchewan, Canada	Cultivated	20 to 30	[15, 16]

The radionuclide ^{137}Cs was deposited on the soil chiefly as nuclear-bomb fallout in the 1950s and 1960s; peak deposition occurred in 1963 in the northern hemisphere, and some areas received more from the Chernobyl disaster in 1986. Upon deposition, ^{137}Cs is tightly bound by colloidal material at the soil surface. Redistribution rates of these mineral-^{137}Cs complexes is highly correlated with observed rates of soil redistribution [12]. The increasing use of ^{137}Cs is providing valuable sets of observations on redistribution rates within actual agricultural landscapes [13].

The most common research design used in ^{137}Cs studies has been to sample soils along transects or grids. After calculation of the change in ^{137}Cs concentration through time due to redistribution, usually by comparing the levels in the agricultural field to a nearby uneroded or reference site, a value for soil loss or gain at the specific sampling point can be determined. At each study site, a certain proportion of samples will show loss and some may show gain; the overall balance indicates the net export, or, less commonly, import, of soil.

^{137}Cs-derived rates of soil redistribution differ widely among landscapes, regions, and agricultural systems; however, as a generalization for mid-latitude regions, those portions of the landscape where soil loss occurs usually show average rates of 10 to 60 Mg ha^{-1} (Table I); typical average losses are around 15 t ha^{-1} yr^{-1} (although loss at specific points may be an order of magnitude greater). Note, however, that this average figure does not represent soil export from the study site; in many cases, much of the eroded soil is deposited within the source landscape, especially those dominated by tillage erosion.

Deposition rates are considerably more variable than erosion rates. Typically, deposition is concentrated in a small proportion of sampling points within a landscape [14, 15], but rates at specific points may be high.

For large areas of the tropics, including most of Africa and South America, ^{137}Cs results are not available. Lal [5] used existing figures for sediment transport in African river systems to estimate net erosion losses in upstream areas. Most of the African continent shows net erosion losses of < 10 (arid areas) to 50 Mg ha^{-1} yr^{-1}. The highest losses occur in the Maghreb region of NW Africa, with losses of > 75 Mg ha^{-1} yr^{-1}.

The rates of redistribution have greater relevance for soil quality if we convert them into depth of soil lost or gained. Using the bulk densities of a surface prairie soil presented in Pennock et al. [16], a 10 Mg ha^{-1} yr^{-1} soil loss from a soil with a bulk density of 1.07 (native prairie) translates to a loss of 0.093 cm yr^{-1}; the same rate of loss from a soil with a bulk density of 1.42 (a site cultivated for 80 years) corresponds to 0.070 cm yr^{-1}. The loss per year is not dramatic; however, over a period of cultivation, it may be substantial.

The sites discussed above are regionally typical agricultural landscapes, generally excluding representatives of high magnitude-low frequency (or catastrophic) erosion events. Sites affected by extreme events (e.g. high intensity rainfall, major wind erosion events) or locations within a field that have been selectively influenced by erosion processes (e.g. landscape positions with extensive gullying) are likely to show much higher rates of loss.

3. SOIL REDISTRIBUTION-SOIL QUALITY INTERACTIONS: THE PEDON SCALE

The impact of redistribution on specific points in the landscape (herein called the pedon scale) must begin with an understanding of the place of that pedon in the overall landscape. The action and interaction of soil processes that result in the properties observed in a given pedon do not occur at

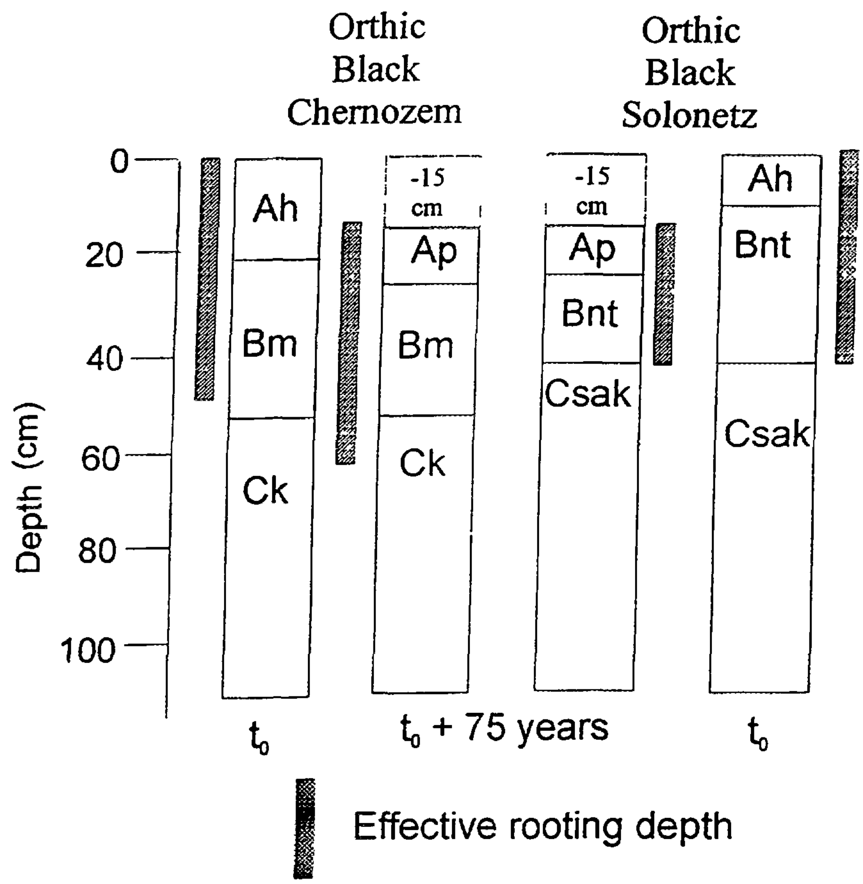

FIG. 1. Schematic diagram showing the impact of 75 years of soil loss and soil gain on the position of the plough layer and the rooting zone within the solum. The changes illustrated are based on annual losses of 20 t ha^{-1} $yr^{-1}$and equivalent soil gain due to deposition. The depth of cultivation is assumed to be 10 cm, and the rooting zone is 45 cm; both are characteristic of small-grain cropping systems in the Canadian prairies.

random - instead they are responding to a complex set of environmental conditions, which control the type and intensity of the pedogenic processes that occur at any given point in the landscape. The soil and biological processes affecting a given pedon are largely driven by microclimatic differences and the redistribution of water on the soil surface and within the soil. These hydrological and microclimatic differences cause the occurrence of distinctive pedogenic regimes within the landscape, and distinct soils arise in response to these regimes [16].

The need to consider landscape position occurs because of the possibility of confounding landscape effects (i.e. differences in soil properties due to the position of the pedon in the landscape) with erosion effects (i.e. differences in soil properties due to erosion among pedons at the same landscape position). Stone et al. [17] and Daniels et al. [18] examined the confounding influence of landscape position for Ultisols in North Carolina. Overall they found that the most severely eroded soils in the field were usually the least productive to begin with, and that the overall impact of erosion in these landscapes had been previously overestimated by 50%. Hence, we must always ensure that pedons are compared under the same pedogenic regime in the same landscape position, lest the action of erosion be confused with the position of the pedon in the landscape.

The impact of soil redistribution at the pedon scale can be divided into two types (Fig. 1). At sites where erosion is occurring, material is physically removed from the soil surface and transported elsewhere; any layer of fixed thickness within the soil (the cultivation layer, rooting zone) therefore incorporates an equivalent thickness of previously subsoil material. In depositional sites, only one clear impact occurs: the deposited soil buries the previous soil surface and thereby increases the thickness of the uppermost layer in the soil. Each of these three impacts (removal of surface soil material, incorporation of subsoil, deposition of soil) has distinct consequences for soil quality and will be examined separately.

3.1. Consequences of removal of the surface soil material

Erosion physically removes organic material and mineral material from the soil surface. An initial consideration is the potential for selective removal of materials versus bulk removal. In the former, materials are removed in amounts disproportionate to their relative amounts in the bulk soil; in the latter, the eroded material contains the same proportion of organic material and different particle size fractions as the soil from which it was derived. The distinction is important because of the possible occurrence of what has been termed fertility erosion - where erosion selectively removes soil organic matter (SOM) and fine particles (clay, silt), and leaves behind a coarser lag deposit. Because the soil nutrients and exchange sites are concentrated in the SOM and clay fractions, this selective loss of material has greater impact on fertility than the bulk loss would suggest.

Inherent differences in the potential for selective removal can largely be traced to the dominant erosion process. Tillage erosion results from the mechanical displacement of soil-surface material in a net downslope direction; the soil material moves as a mass, and the possibility for selective movement is minimal. In the water erosion process, the possibility for selective transport can occur in interill-dominated systems, but once a critical threshold is reached for a given soil type, detachment and transport is aselective [19]. In rill and gully erosion, detachment and transport is aselective, although separation may occur during deposition. The possibility for selective transport of SOM, fine separates and fine aggregates is perhaps greatest in wind erosion, where, in extreme cases, a coarse sand-gravel lag is left behind on the soil surface [20]. Hence the concept of fertility erosion, although valid in some environments, cannot be uncritically extended to all landscapes.

The loss of SOM from the surface through erosion is probably the single greatest impact of redistribution on soil quality. The use of the ^{137}Cs technique has allowed researchers to apportion the overall losses of SOM [or soil organic carbon (SOC), which is commonly used as a surrogate for SOM] to redistribution causes and to net mineralization causes. For the prairie soils of Canada, de Jong and Kachanoski [21] suggested that, at a range of sites, approximately 50% of the observed SOC losses was due to erosion. Pennock et al. [16] showed that the relative contribution of erosion and mineralization differed depending on the position of the pedon within the landscape. In shoulder positions (those with convex profile, or downslope, slope curvatures), they showed that an overall loss of 64 Mg ha^{-1} of SOC, of an original 117 Mg ha^{-1}, had occurred in 80 years of cultivation; 70% of this was due to redistribution. In footslope positions (those with concave profile curvatures), 45 Mg ha^{-1} of an original 129 Mg ha^{-1} had been lost; 18 Mg ha^{-1} (40%) of this loss was due to redistribution.

The consequences of the loss of SOM on soil quality are considerable. For example, Larson and Pierce [1] suggested the use of pedotransfer functions for soil-quality assessment; SOC appears in five of these (C.E.C., change in SOC itself, bulk density, water retention,and porosity increase). Furthermore, SOM is an important source of nutrients, especially nitrogen, particularly so where fertilizer input is lacking.

3.2. Consequences of the incorporation of subsoil

For layers of fixed thickness in the soil (i.e. rooting zone, depth of cultivation), the loss of material from the soil surface requires the concomitant inclusion of subsoil material of equivalent thickness to the surface losses (Fig. 1). Moreover, it is the nature of the contrast between the surface material and the incorporated subsoil material that determines the severity of the impact that loss has on soil quality and ultimately on soil productivity.

This statement can be illustrated with a simple example (Fig. 2). At the time of initial cultivation, the ploughed layers of an Orthic Black Chernozem (Typic Haploboroll) and of an Orthic Black Solonetz (Typic Natriboroll) were entirely composed of A horizon material (Fig. 1). The rooting layer of the spring wheat in the Chernozem is unconstrained by any impeding layer; in the Solonetzic soil, however, contact with the salt-rich C horizon effectively limits the actual depth of rooting.

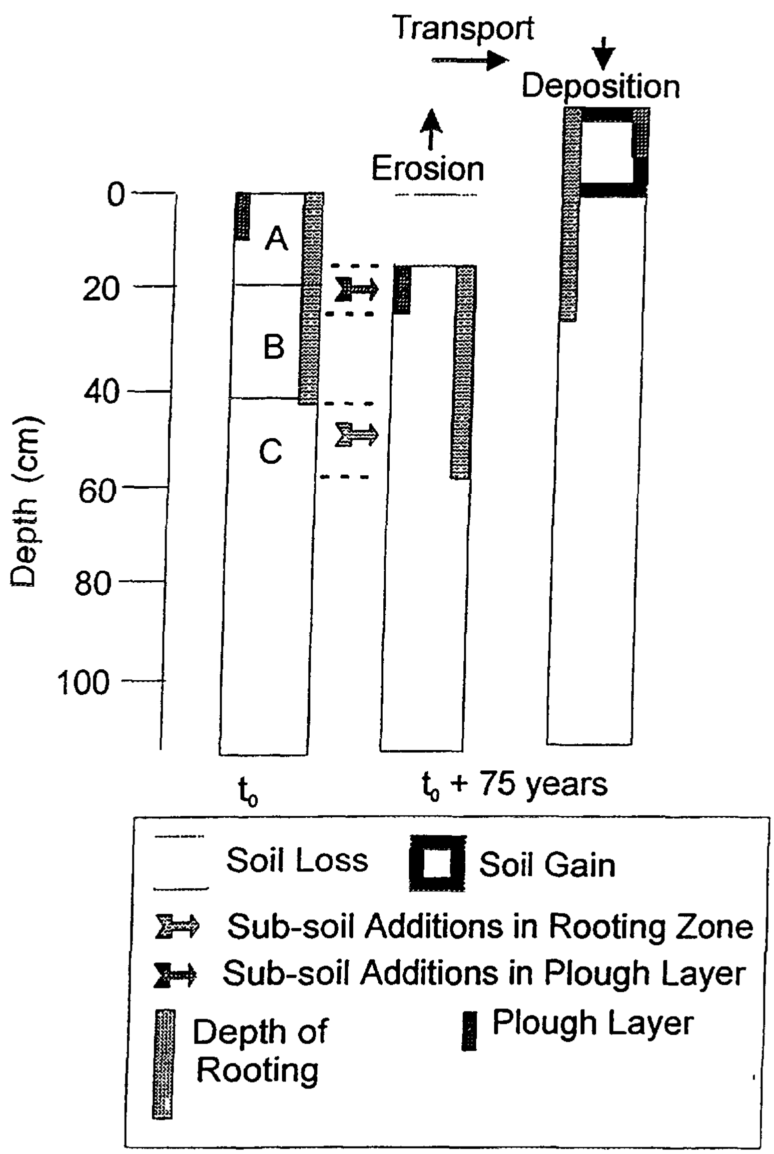

FIG. 2. Schematic diagram showing the differences in the impact of 75 years of soil loss on a Chernozemic (Haploboroll) solum and Solonetzic (Natriboroll) solum (see Fig. 1). The changes shown are based on average losses of 20 t ha^{-1} yr^{-1}, a 10-cm cultivation layer, and an optimum rooting zone of 45 cm.

Hence, even at the time of breaking, a minor potential productivity contrast exists between the two soils that is accentuated as erosion proceeds.

For both soils in this example, I assume that erosion is occurring at an equivalent rate of 20 Mg ha^{-1} yr^{-1}, which is typical of shoulder (convex downslope) positions in the Canadian prairies [15]. This translates to a loss of approximately 1 cm of soil every 5 years; hence, layers of fixed depth incorporate 1 cm of subsoil every 5 years to balance losses at the soil surface. For the cultivated layer, the incorporation involves mixing of 1 cm of subsoil every year into the remaining 9 cm of Ap; this results in a gradual dilution of the initial surface layer with subsoil.

For the thick Chernozemic soil, even 75 years of erosion does not greatly alter the characteristics of the cultivation layer and the rooting zone (Figs. 1 and 2); the 10-cm thick cultivated layer is still dominantly composed of former Ah horizon material; and the rooting zone is still dominantly within the B horizon. A considerable net export of organic material has occurred; however, the impact of these exports for crop productivity is unlikely to be major, given the lack of change within the rooting zone.

The consequences of erosion losses are much more severe for the Solonetzic soil. After 75 years of erosion, the Ap horizon is now found entirely within what was initially the Bnt horizon, although due to dilution and mixing, remnants of the former Ah will be detectable; the rooting zone, assuming it is limited by the salt-rich C horizon, is reduced by 15 cm. The decrease in the thickness of the effective rooting zone, the dense structure of the Bnt, and the deleterious sodium concentrations will all contribute to a major potential decrease in productivity; this decrease will be most apparent in dry years, because the thin rooting layer and lack of root penetration into the peds will greatly limit water uptake by plants.

An equivalent amount of erosion has occurred with both soils. For the Chernozemic soil, the consequences are negligible from a quality perspective, and probably also from a productivity perspective; for the Solonetzic soil, however, diminution in soil quality and potential productivity has occurred.

Overall, then, we expect that soils that greatly contrast in quality conditions between the surface soil and the subsoil will have the greatest potential for quality and productivity changes due to erosion; soils with a constant set of properties, or at least a gradual change in levels with depth, will show little or no impact of even substantial amounts of erosion.

The importance of the nature of the subsoil was recognized in the Productivity Index [1], which includes several subsoil properties known to limit root development, and can be used in a range of conditions. Use of the index also allows the vulnerability of a given soil to be assessed [11, 22]. A vulnerability curve, which shows the Productivity Index plotted against surface-soil removal, allows prediction of effects on productivity.

Soils that have a subsoil layer with known growth-limiting soil properties will show the greatest effects of surface loss and subsoil incorporation. As the depth to this layer decreases, the interaction between the layer and plants increases, as does the possibility for productivity limitation.

The soil layers or horizons with the greatest possible impact on productivity, and the reasons for this impact, are shown in Table II. In several of these layers the potential for effect on productivity is clear - in no case does soil quality increase due to the presence of a salt-rich layer or a fragipan in the plough layer or the rooting depth. In the case of plinthite, the layer itself is not limiting when found at depth in the soil; it becomes limiting as soil loss brings it closer to the surface and hardening of the layer to petroplinthite begins [22].

The argillic horizon (those enriched with clay relative to the overlying layer) is a problematic case. The argillic layer is commonly included as a problem subsoil in erosion studies [23]; however,

Stone et al. [17] in their work with Ultisolic soils found that inclusion of the argillic horizon into the cultivated layer due to surface soil loss actually improved overall productivity. They attributed this productivity increase to the higher AWC of these soils (due to higher clay contents); in drier years the higher AWC in turn increased yields over less-eroded landscape positions.

Soils with thin organic-rich layers, e.g. the leaf litter of forest soils or thin A horizons in non-forested soils, are also susceptible to soil quality and productivity changes due to surface soil loss. The example of Garcia-Oliva et al. [10] has been cited above; in the tropical deciduous forest/shifting cultivation agro-ecosystem they examined, the top 4 cm of the soil was critical as a nutrient reservoir. Overall, Lal [5] argues that in agro-ecosystems dominated by tropical soils, the impact of erosion can be especially critical because of the dependence of the agricultural systems on the thin, organically-enriched layer.

3.3. Consequences of deposition of soil

The position in the landscape where deposition occurs varies depending on the nature of the dominant erosional process. In tillage redistribution, the location of deposition is immediately downslope to the point of initiation; the possibility of transport off-site is low, although as Lobb et al. [9] indicated, tillage redistribution can deliver soil to locations where it can subsequently be

TABLE II. HORIZONS AND ASSOCIATED SOIL ORDERS WHERE THE INCORPORATION OF SUBSOIL MATERIAL IS LIKELY TO CAUSE MAJOR CHANGES IN SOIL QUALITY AND PRODUCTIVITY CONDITIONS.

Horizon	Characteristics and constraints	Soil Orders the horizons are commonly associated with
Salic	High salt concentration	Aridisols Mollisols
Fragic or Duric	Fragipan layer or layer cemented by iron, aluminum or silica; high resistance to root penetration	Spodosols Alfisols Ultisols Inceptisols
Natric	High sodium concentration and dense structure	Mollisols
Plinthite	High iron and aluminum oxide content; hardens upon drying; high resistance to root penetration	Oxisols Ultisols
Argillic	Increase in clay content relative to overlying soil; increases in root penetration resistance	Alfisols Ultisols
Oxic	High possible Al^{3+} concentrations in low-pH conditions	Oxisols
Spodic	High Al^{3+} or metal levels high in low-pH conditions	Spodosols

removed by channelized flow. Deposition of soil from the wind stream
most commonly occurs immediately downwind of the source of the soil; only the finest particles can be carried for considerable distances in the windstream [20].

The greatest potential for off-site impact occurs due to soil transport by channelized flow of water. Deposition of sediment transported by flowing water occurs where the energy available for transport decreases due to a decrease in gradient (a decrease in slope), a decrease in depth (e.g. where a channel widens or becomes unconfined), or an increase in surface roughness (e.g. where it encounters vegetation). Hence, deposition will occur within the field if one of those conditions is met; if the channel exists, then the soil may be transported out of the field to downslope water bodies.

The on-site effects of deposition (i.e. within the field where initiation of soil movement began) on soil quality are rarely of great consequence. A significant short-term impact can be the burial of seeds or seedlings, and hence a decrease in yield in that year. On-site deposition leads to a thickening of the soil surface at the point of deposition leading to the development of cumulic soils (Fig. 1). Pennock et al. [16] found that deposition of soil improved almost all the indicators of soil quality in a Boroll landscape in Saskatchewan. Again, however, generalization is risky - if the soil delivered from upslope is of significantly lower quality than the original soil, a decrease in quality of the surface layer would occur.

4. SOIL QUALITY-SOIL RESTRIBUTION INTERACTIONS: THE LANDSCAPE SCALE

In most non-level, cultivated landscapes, the spatial pattern of soil quality indicators at the surface is predominantly controlled by redistribution. Erosion and deposition are associated with distinctive segments of the landscape; in turn, the gain (or loss) of soil causes the occurrence of a distinctive suite of soil properties at the landscape segments with which they are associated.

As with soil deposition, the spatial pattern of redistribution in landscapes depends heavily on the nature of the dominant erosion process. Wind erosion is the only process that can remove significant amounts of soil from level landscapes, and there are examples of extremely high rates of such loss [24]. The highest losses due to water erosion occur in landscape positions where channelized flow (rills, gullies) occurs in the field. These positions are often concave in across-slope (or plan) curvature and have large, upslope contributing or catchment areas. Soil loss due to tillage is highest where the profile curvature of the slope is convex [6]. The difference between the position of highest soil loss due to channelized flow and due to tillage was used by Govers et al. [8] to assess the relative efficacy of the two processes in their study landscapes.

One of the consequences of the widespread use of ^{137}Cs redistribution has been the emergence of a well documented spatial pattern of soil redistribution in landscapes [8, 14, 15, 25]. Slope segments with convex profile curvatures (hereafter called shoulder elements [26]) experience the highest rates of loss; the segments with concave profile curvatures (footslopes) experience net soil gain. The role of the mid-slope or backslope elements (i.e. lacking significant plan or profile curvature) differs; for tillage erosion these elements are probably dominated by transport of soil from upslope, although infilling of small depressions in the slope will occur; if sufficient water velocity or depth exists, they can be areas of significant soil loss in a water-erosion dominated system [25].

The chronosequence of soil studied by Pennock et al. [17] allowed us to trace the evolution of this distinctive pattern. We examined soil redistribution using ^{137}Cs at four sites on a glacial till surface in Saskatchewan, Canada: a native site and sites with 12, 22 and 80 years of cultivation. In the native site, the distribution of ^{137}Cs was random and showed no association with landform [17]. After breaking of the land and 12 years of cultivation, a chaotic pattern of loss and gain occurred,

TABLE III: SUMMARY OF SELECTED SOIL QUALITY INDICATORS AT A NATIVE SITE AND AFTER 80 YEARS OF CULTIVATION IN A BOROLL DOMINATED LANDSCAPE IN SOUTHERN SASKATCHEWAN, CANADA [16]

	Shoulder elements		Low catchment area footslope elements		High catchment area footslopes and level depressional elements[a]	
	Native site	80-yr site	Native site	80-yr site	12-yr site	80-yr site
pH (0-15 cm)	7.4	7.9	6.6	7.6	7.2	7.7
Bulk density (g cm^{-3})	1.07	1.42	1.01	1.33	1.39	1.4
Ah/Ap thickness (cm)	14	12	22	15	11	26
Total N (Mg ha^{-1})	10.8	6.2	11.6	8.0	4.9	9.1
SOC (Mg ha^{-1})	117	53	129	84	57	113

[a]No native sites were sampled in this area and comparisons are based on the site with 12 years of cultivation

again with no discernable relationship to landform. After 22 years, however, a clear redistribution-landform relationship emerged - high soil loss in the shoulder positions, and deposition in both the low-catchment area and high-catchment footslopes. After 80 years of cultivation, the soil had been scoured out of the low catchment area footslopes and deposited only in high-catchment footslope areas.

We also examined the impact of redistribution on soil quality, and the importance of redistribution for the current pattern of quality indicators was clear (Table III). For soil pH and bulk density of the 0- to 15-cm layer, redistribution has narrowed the overall variability at the site. In both cases, the levels are approaching the values of the subsoil, indicating either the incorporation of subsoil or deposition of subsoil materials from upslope. The A-horizon differences illustrate further the problems with the use of topsoil discussed above: the naturally thin A horizons in the shoulders show little net loss, but the thicker A horizons in the footslopes show considerable losses; yet the highest ^{137}Cs losses have occurred in the shoulders. The A horizon cannot, however, drop below the cultivation depth (approximately 12 cm at this site), hence it cannot be used as a reliable indicator of absolute soil loss.

Considerable losses of soil N and SOC have occurred in the shoulder and low-catchment area footslope elements; considerable gains of these properties, and of A-horizon material generally, have occurred in the high-catchment area footslope positions. The impact of redistribution has been to reverse the spatial pattern of these properties found at the native site, where shallow-rooted wetland

vegetation and anaerobic conditions originally limited biological productivity in the high-catchment area footslope areas. Hence the current pattern of soil-quality indicators at least in the surface increment of the soil, strongly reflects the action of redistribution.

5. CONCLUSIONS AND PROGNOSES

Recent developments in soil-redistribution research, such as the use of ^{137}Cs and the increasing evidence of the importance of tillage, have provided new perspectives to examine the soil quality-soil redistribution relationship. Clearly, soils show a range of vulnerability to loss; curiously, however, much of the research has been concentrated on soils such as the Mollisols, whose vulnerability levels are, overall, probably quite low. Hopefully the wider application of relatively inexpensive techniques such as the ^{137}Cs approach will allow the quality-redistribution relationship to be assessed on soils with higher vulnerability to redistribution, especially those in tropical developing countries.

A dichotomy also occurs between the developed and developing worlds in terms of the prognosis for redistribution itself. In many areas of the developed world, the increased use of herbicide-based weed control has led to increasing adoption of reduced tillage or no-till cultivation systems. Regardless of the cause of erosion, reductions in tillage and increases in the residue cover following field operations will slow the rate of soil redistribution; in a tillage-redistribution dominated system, it may almost eliminate accelerated erosion.

A positive prognosis does not, however, exist for many areas of the developing world. Population pressures in many developing countries may lead to increased utilization of marginal land and to greater use of mechanized tillage systems; both may lead to increases in accelerated erosion. Hence, while the principles of effective erosion control are well understood and are being applied in many developed countries, the socio-economic constraints inherent in the agricultural systems of many developing countries is likely to limit the adoption of these vital control principles.

REFERENCES

[1] LARSON, W.J., PIERCE, F.J. "The dynamics of soil quality as a measure of sustainable production", Defining Soil Quality for a Sustainable Environment. (DORAN, J.W., COLEMAN, D.C., BEZDICEK, D.F., STEWART, B.A., Eds.). SSSA Special Publication Number 35. Soil Science Society of America, Inc. and American Society of Agronomy, Inc., Madison, Wisconsin, USA, (1994) 37-51.

[2] DORAN, J.W., PARKIN, T.B., "Defining and assessing soil quality", Defining Soil Quality for a Sustainable Environment. (DORAN, J.W., COLEMAN, D.C., BEZDICEK, D.F., STEWART, B.A., Eds.). SSSA Special Publication Number 35. Soil Science Society of America, Inc. and American Society of Agronomy, Inc., Madison, Wisconsin, USA, (1994) 3-21.

[3] PIMENTEL, D., et al., Environmental and economic costs of soil erosion and conservation benefits, Science (Wash.), **267** (1995) 1117-1123.

[4] CROSSON, P., Soil erosion estimates and costs, Science (Wash.) **269** (1995) 461-464.

[5] LAL, R., Erosion-crop productivity relationships for soils of Africa, Soil Sci. Soc. Am. J. **59** (1995) 661-667.

[6] LINDSTROM, M.J., et al., Quantifying tillage erosion rates due to moldboard plowing, Soil Tillage Res. **24** (1992) 243-255.

[7] GOVERS, G., et al., The role of tillage in soil redistribution on hillslopes, Eur. J. Soil Sci. **45** (1994) 469-478.

[8] GOVERS, G., et al., The relative contribution of soil tillage and overland flow erosion to soil redistribution on agricultural land. Earth Surface Processes and Landforms (1995) (in press).

[9] LOBB, D.A., et al., Tillage translocation and tillage erosion on shoulder slope landscape positions measured using ^{137}Cs as a tracer, Can. J. Soil Sci. **75** (1995) 211-218.

[10] GARCIA-OLIVA, F., et al., Long-term net soil erosion as determined in an undisturbed and perturbed tropical deciduous forest ecosystem, Geoderma **68** (1995) 135-147.

[11] JOHNSON, R.R., Putting soil movement into perspective. J. Production Agric. **1** (1988) 5-12.

[12] KACHANOSKI, R.G. Comparison of measured soil 137-cesium losses and erosion rates, Can. J. Soil Sci. **73** (1987) 515-526.

[13] RITCHIE, J.C., McHENRY, J.R., Application of radioactive fallout Cesium-137 for measuring soil erosion and sediment accumulation rates and patterns: a review, J. Environ. Qual. **19** (1990) 215-233.

[14] MARTZ, L.W., de JONG, E. Using cesium-137 to assess the variability of net soil erosion and its association with topography in a Canadian Prairie landscape, Catena **14** (1987) 439-451.

[15] PENNOCK, D.J., de JONG, E. Spatial pattern of soil redistribution in Boroll landscapes, Southern Saskatchewan, Canada, Soil Sci. **150** (1990) 867-873.

[16] PENNOCK, D.J., et al., Landscape-scale changes in indicators of soil quality due to cultivation in Saskatchewan, Canada, Geoderma **64** (1994) 1-19.

[17] STONE, J.R., et al., Effect of erosion and landscape position on the productivity of Piedmont soils, Soil Sci. Soc. Am. J. **49** (1985) 987-991.

[18] DANIELS, R.B., et al., Soil erosion has limited effect on field scale crop production in the Southern Piedmont, Soil Sci. Soc. Am. J. **53** (1989) 917-920.

[19] GOVERS, G., Selectivity and transport capacity of thin flows in relation to rill erosion, Catena **12** (1985) 35-49.

[20] FRYREAR, D.W., "Wind erosion: mechanics, prediction, and control", Advances in Soil Science, Volume 13 (SINGH, R.P., PARR, J.F., STEWART, B.A., Eds.), Springer- Verlag, New York, (1990) 187-200.

[21] de JONG, E., KACHANOSKI, R.G., The importance of erosion in the carbon balance of Prairie soils, Can. J. Soil Sci. **68** (1988) 111-119.

[22] ESWARAN, H., et al.,. "Role of Plinthite and related forms in soil degradation", Advances in Soil Science, Vol. 12 (LAL, R., STEWART, B.A., Eds.), Springer-Verlag, New York, (1990) .

[23] LARSON, W.E., et al., The threat of soil erosion to long-term crop production, Science (Wash.) **219** (1983) 458-465.

[24] SUTHERLAND, R.A., et al., Cesium-137 estimates of sediment redistribution by wind, Soil Sci. **151** (1991) 387-396.

[25] LOUGHRAN, R.J., et al., A caesium-137-sediment hillslope model with tests from south-eastern Australia, Zeitgrift fur Geomorphologie **33** (1989) 235-250.

[26] PENNOCK, D.J., et al., Landform classification and soil distribution in hummocky terrain, Saskatchewan, Canada, Geoderma **40** (1987) 297-315.

DEPOSITION, TRANSFER AND MIGRATION OF ^{137}Cs AND ^{90}Sr IN SWEDISH AGRICULTURAL ENVIRONMENTS, AND USE OF ^{137}Cs FOR EROSION STUDIES

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Abstract

DEPOSITION, TRANSFER AND MIGRATION OF ^{137}Cs AND ^{90}Sr IN SWEDISH AGRICULTURAL ENVIRONMENTS, AND USE OF ^{137}Cs FOR EROSION STUDIES.

Intensive atmospheric tests of nuclear bombs in the late 1950s and early 1960s resulted in fallout on Sweden of 3 kBq/m^2 ^{137}Cs and 2 kBq/m^2 ^{90}Sr. To determine how soil characteristics influence radionuclide transfer to red clover, pot experiments with ^{137}Cs and ^{90}Sr were made with 178 Swedish mineral soils; significant negative correlations were obtained the with levels of P, K and Ca. To quantify impact in field conditions, experiments with artificial depositions on microplots were started in 1961. Transfer to barley on 12 topsoils combined with sandy and clay subsoils, and to grass on two contrasting pastures, was followed over two decades. The subsoil type was found to be important.

Fallout of ^{137}Cs from the Chernobyl accident, up to 200 kBq/m^2 in some areas of Sweden, was studied between 1986 and 1994. As in the microplot experiments, transfer of ^{137}Cs to grass was higher than to arable crops. Transfer rates were high in the first year(s), and then decreased differently from year to year, as shown by a new Tar (i.e. annual reduction rate in nuclide transfer) concept. The use of Chernobyl fallout to investigate soil redistribution on arable fields is briefly discussed; a frame-scrape soil-sampling procedure is proposed to improve the accuracy and precision of the ^{137}Cs technique for evaluation of soil erosion.

1. INTRODUCTION

With the advent of the atomic age, radiotracers became a common research tool. For agricultural scientists, isotopic labelling provided the ability to follow the fate of applied fertilizers in soil-plant systems. Tracer techniques have been used in root studies to determine uptake of nutrients and water from different depths in the soil profile [1], and to elucidate the fate of pesticides and other pollutants.

The release of fission products and transuranic elements by detonated nuclear bombs and nuclear accidents, has stimulated research on the behaviour of radionuclides in terrestrial and aquatic ecosystems. In Sweden, extensive pot experiments and long-term field experiments have been carried out with the long-lived fission radionuclides ^{137}Cs and ^{90}Sr. After the Chernobyl accident, field surveys and "real" field studies on the behaviour of, especially, ^{137}Cs were carried out [2].

In this paper, we briefly review these investigations, especially transfer and migration of ^{137}Cs, and, for comparison, ^{90}Sr, under Swedish field conditions. Some aspects of the use of ^{137}Cs in soil-erosion studies are considered. A frame procedure for soil sampling is described, for use in a pilot study for calibration of the ^{137}Cs-technique on a silty soil within a Chernobyl-fallout area.

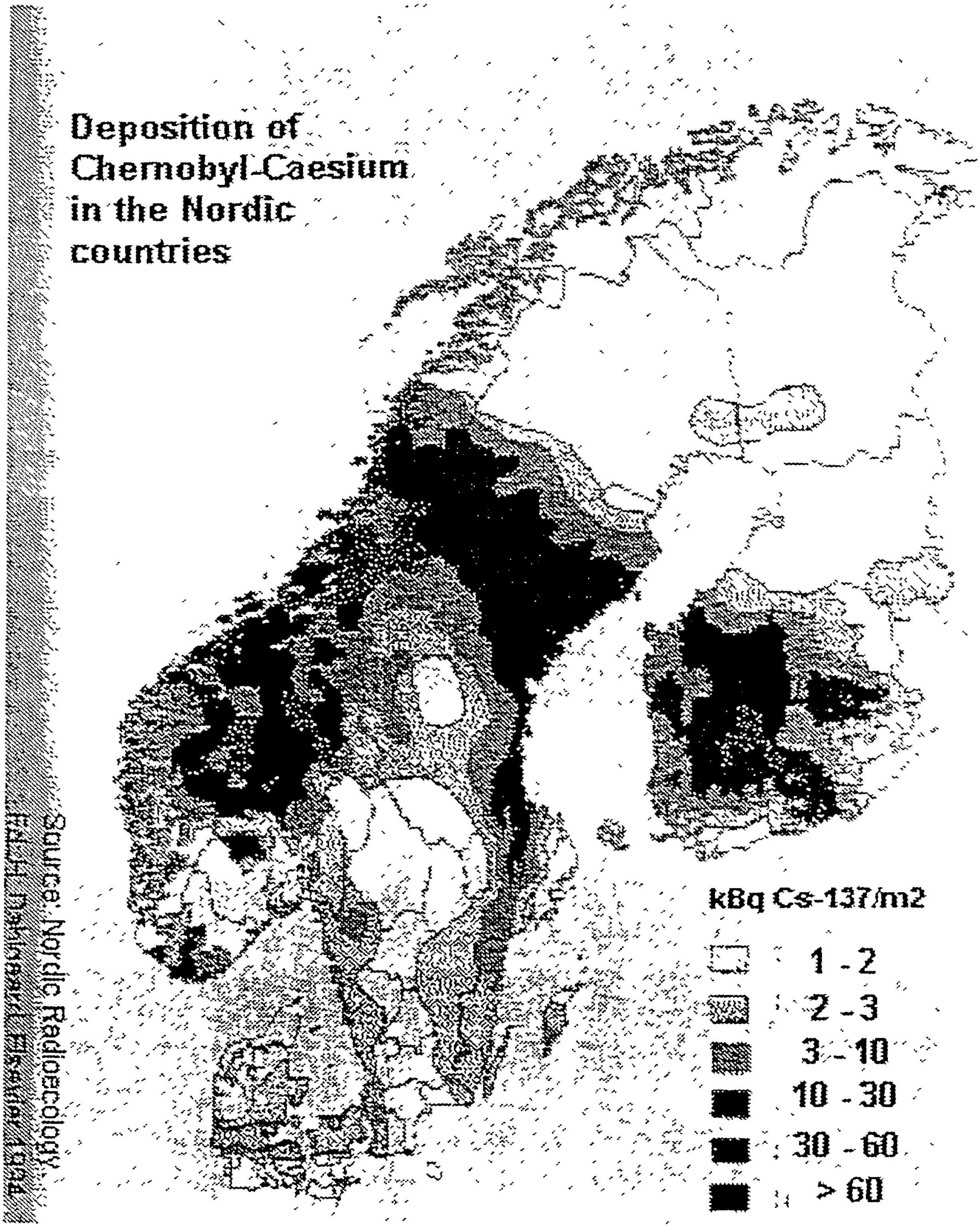

FIG. 1. Ground deposition of ^{137}Cs from Chernobyl, kBq/m^2, in nordic countries Denmark, Finland, Norway and Sweden (T. Selnäs in Dahlgaard, 1994).

2. RADIOACTIVE FALLOUT IN SWEDEN

2.1. Nuclear bomb tests

Tests of thermonuclear weapons have been conducted since 1945. Intensive tests during 1954-58 and 1961-62 resulted in radionuclide contamination of the atmosphere that persisted globally for several years. In the northern hemisphere, mean fallout values are estimated at 2.8 kBq/m^2 of ^{137}Cs and 2 kBq/m^2 of ^{90}Sr [3]. The mean deposition on Sweden from the test at Novaja Zemjla alone was estimated at 3 kBq/m^2 of ^{137}Cs [4].

2.2. The Chernobyl accident

On 26 April 1986, two explosions occured in a reactor at the Chernobyl power plant, situated 120 km north of Kiev in the Ukraine. The core was exposed, with release of large amounts of fuel particles containing fission nuclides and transuranics. Radionuclides associated with larger particles were deposited near the site, whereas smaller particles (approximately 1 mm) were, with the heat of the explosion, lifted to an altitude of $>$1,000 m and carried away in the wind.

During April 26-30 and May 8-10, wind direction was towards Scandinavia. The heaviest fallout occurred during the first phase, estimated to range from 10 to $>$80 kBq/m^2 in some areas of north and mid Sweden, with maxima in the Gävle community of $>$200 kBq/m^2 (Fig. 1). The inventory of ^{137}Cs for Sweden as a whole was about 4.25 x 10^{12} kBq, about 5 % of the total release from the Chernobyl reactor [4]. It is notable that while the ratio of ^{137}Cs / ^{90}Sr was about 1.5 in bomb-test fallout, deposition from Chernobyl contained only about 1% of ^{90}Sr compared to ^{137}Cs. The latter also contained ^{134}Cs in amounts that give a ^{134}Cs / ^{137}Cs ratio of 1.6 [4].

3. SOIL-PLANT TRANSFER OF ^{137}Cs AND ^{90}Sr IN POT EXPERIMENTS

In the late 1950s and early 1960s, pot experiments using 178 Swedish mineral soils were carried out at the State Experimental Research Institute, Uppsala. The aim was to identify soil characteristics that influence the transfer of ^{137}Cs and ^{90}Sr from soil to red clover [5, 6]. With the aid of multiple regression analysis and the equation $Y = A * X1^{b1} * X2^{b2}$ x ... Xn^{bn}, (where Y is the transfer unit, A is the intercept, X1, X2 .... Xn are soil factors and b1, b2 .... bn are coefficients to be estimated), significant correlations were found for transfer of ^{137}Cs and ^{90}Sr with soil factors.

The transfer of ^{137}Cs to red clover was negatively correlated with exchangeable potassium (K_{AL}) and non-exchangeable potassium (K_{RES}) (Fig. 2), and with exchangeable calcium (Ca_{AL}) (R^2 = 0.35). The transfer of ^{90}Sr was found to be negatively correlated also with exchangeable calcium (Ca_{AL}), soil pH, cation exchange capacity (CEC) and labile phosphorus (P_{AL}) (R^2 = 0.87).

4. SOIL-PLANT TRANSFER OF ^{137}Cs and ^{90}Sr UNDER FIELD CONDITIONS

Comparisons of radionuclide transfer to different field-grown crops are meaningless without referencing plant activity to total inventory in the soil. This concept [7], and its TFg-value [8], has been used at the Department of Radioecology, Uppsala, in field microplot studies with nuclides experimentally applied to the plough layer of arable soils and to the surface of grassland sites:

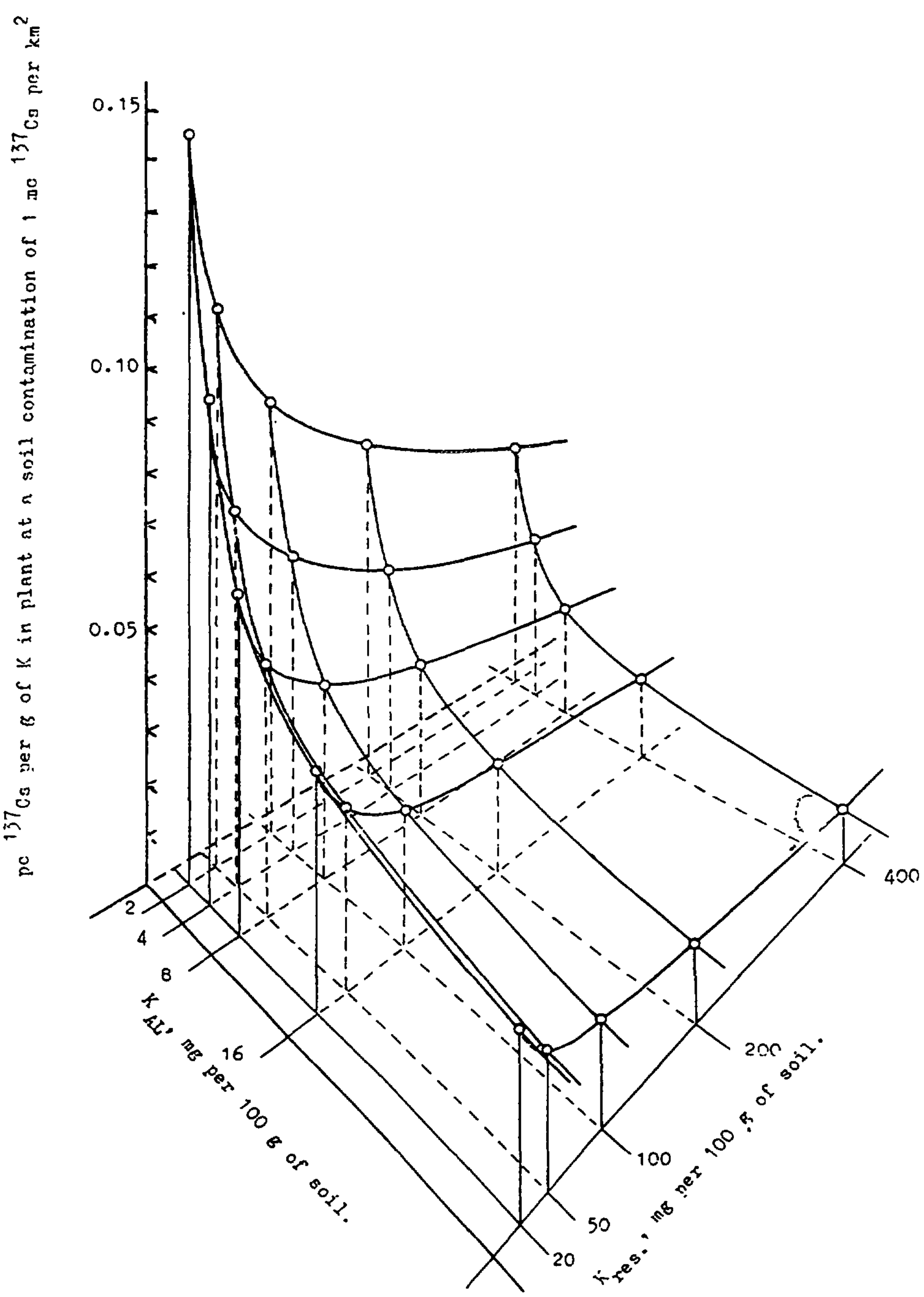

FIG. 2. Plant absorption of ^{137}Cs from soils differing in content of exchangeable potassium (K_{AL}) and residual potassium (K_{RES}). The diagram is based on data obtained in pot experiments with 178 Swedish soils.

$$\text{TFg} = \frac{\text{Activity in plant (Bq kg}^{-1}\text{ dry wt.)}}{\text{Total deposition (Bq m}^{-2}\text{)}} \qquad (1)$$

The TFg, recalculated to the time of contamination, is expressed as the fraction of activity per kg dry matter recovered from a deposition of 1 Bq/m^2.

Decreasing rates of transfer to crops, independent of physical decay, are observed in most terrestrial environments due to declining availability. An ecological half-life, **Tec**, similar to that of radioactive decay, can be calculated from the general exponential equation:

$$Y = Y_0 * \exp(A*t) \qquad (2)$$

As found in pasture experiments with ^{137}Cs after the Chernobyl accident [2], the annual reduction in nuclide transfer was not exponential (A is not a constant in Eq. 2) on grassland sites, at least not during a lag period after deposition. Instead an equation of the type

$$f(t) = \exp(A*t^N + B) \qquad (3)$$

can be used [9], where A, N and B are constants and t is time (years). The constants are obtained by a least square fit of observed annual mean TFg values. From Eq. 3 an inverse, denoted **Tar**, can be calculated and used as an expression for the annual reduction rate in nuclide transfer. Contrary to the **Tec** concept, the **Tar** concept depends only on the real reduction in nuclide transfer from year to year.

4.1. Microplot experiments

4.1.1. Transfer to grass

In April 1961 two contrasting types of Swedish pastures were artificially contaminated with ^{90}Sr and ^{137}Cs [10]. One was a permanent pasture on a sandy soil and the other a grazing ley on a clay soil. Results of the two experiments for the period 1961-1981 are shown in Table I.

There was more transfer on the permanent pasture than on the grazing ley. Even after 20 years, the nuclides were retained in the soil and were available for uptake. The TFg values varied from year to year due to unequal rooting, and showed a decreasing trend over time. Although there was more leaching of ^{90}Sr than of ^{137}Cs, the transfer of ^{90}Sr was higher than that of ^{137}Cs.

4.1.2. Transfer to barley

Soil from the plough layer (0-20 cm) of 12 Swedish topsoils were homogenously contaminated with carrier-free solutions of ^{137}Cs and ^{90}Sr, and placed on plots on two contrasting subsoils, a sandy subsoil of 1-m depth and a clay subsoil [11]. Results are shown for barley grain in Table II for the period 1961-80.

The TFg values were 5- to 10-fold higher for ^{90}Sr than for ^{137}Cs. For both nuclides, TFg varied with year due to unequal release of K and Ca from the uncontaminated subsoils [1]. For the same reason, the long-term trends also differed between ^{137}Cs and ^{90}Sr. As regards the influence of top-soil characteristics, the TFg for ^{137}Cs decreased with increasing contents of clay and exchangeable K, but increased with increasing contents of organic matter. The Tfg for ^{90}Sr decreased with increasing pH and CEC, and with exchangeable contents of Ca and P. The results were thus consistent with those from the pot experiments described above.

5. MIGRATION of ^{137}Cs AND ^{90}Sr IN SOIL PROFILES

5.1. Microplot experiments

5.1.1. Pasture experiments

Leaching of the two radionuclides was determined in 1967 in soil profiles at both pasture sites, and was repeated in 1981 at one of the sites [10]. As expected, ^{90}Sr was more mobile than ^{137}Cs (Tables III and IV). No large effect of fertilization was observed, except for one of the NPK-

treatments on the permanent pasture/sandy soil, where acidification by annual application of ammonium sulfate increased leaching of ^{90}Sr.

TABLE I. MEANS OF TFg OF ^{137}Cs AND ^{90}Sr IN GRASS ON PERMANENT PASTURE/SANDY SOIL AND ON GRAZING LEY/CLAY SOIL

Year	Permanent pasture sandy soil		Grazing ley clay soil	
	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr
	($m^2\ kg^{-1}$ DW x 10^{-3})			
1961	22.2	73.0	9.25	23.2
1662	6.85	50.4	0.71	15.1
1963	3.48	33.0	0.41	11.8
1964	31.1[a]	24.8	7.93[a]	9.9
1965	15.3	21.9	1.37	9.7
1966	7.16	18.7	0.80	8.7
1967	2.48	18.4	0.35	6.6
1968	1.86	18.3	0.24	6.1
1969	1.10	13.7	0.10	5.1
1970	0.68	15.3	0.11	5.5
1971	0.83	14.6	0.18	5.7
1972	0.96	10.9	0.18	5.4
1973	0.70	11.8	0.10	3.8
1974	0.74	12.8	0.22	4.5
1975	0.72	13.7	0.08	4.2
1976	0.78	10.8	0.06	2.8
1977	0.67	10.3	0.06	3.6
1978	0.82	12.2	0.13	3.5
1979	0.82	12.0	0.10	3.5
1980	0.53	12.6	0.12	4.8
1981	0.44	10.7	0.10	3.6
72-81	**0.72**	**11.8**	**0.12**	**4.0**

[a]Recontaminated in 1964.

5.1.2. Lysimeter experiment

Migration in soil profiles of ^{137}Cs and ^{90}Sr was determined with a lysimeter experiment started in 1962 [13], with three topsoils placed on a sandy subsoil and a clay subsoil (Table V). The percentage of activity migrating from the three plough layers to the two subsoils over 20 years was higher for ^{90}Sr than for ^{137}Cs. The migration of ^{90}Sr was greater to the clay subsoil than to the sandy subsoil; the difference may depend on deeper rooting in the former than in the latter subsoil. There was no consistent effect of applying K-fertilizer at 124 kg K/ha/yr.

TABLE II. TFg OF ^{137}Cs AND ^{90}Sr IN BARLEY GRAIN, AVERAGED OVER 12 TOP-SOILS, ON SUBSOIL I (SAND) AND II (CLAY)

	^{137}Cs		^{90}Sr	
Year	I	II	I	II
	(m^2 kg^{-1} DW x 10^{-3})			
1961	0.030	0.054	0.58	0.46
1962	0.038	0.044	0.27	0.21
1963	0.050	0.065	0.56	0.46
1964	0.028	0.045	0.33	0.28
1965	0.041	0.057	0.42	0.32
1966	0.048	0.074	0.33	0.32
1967	0.035	0.063	0.18	0.10
1968	0.023	0.032	0.34	0.22
61-68	**0.036**	**0.054**	**0.38**	**0.30**
1969	0.047	0.042	0.48	0.17
1970	0.066	0.053	0.52	0.25
1971	0.047	0.036	0.47	0.22
1972	0.046	0.048	0.55	0.19
69-72	**0.052**	**0.045**	**0.50**	**0.21**
1974	0.066	0.030	0.54	0.28
1975	0.058	0.034	0.40	0.19
1976	0.045	0.028	0.32	0.15
1977	0.034	0.024	0.54	0.23
1978	0.024	0.019	0.52	0.23
1979	0.028	0.022	0.41	0.21
1980	0.029	0.023	0.44	0.22
74-80	**0.041**	**0.042**	**0.45**	**0.22**
61-80	**0.041**	**0.042**	**0.43**	**0.25**

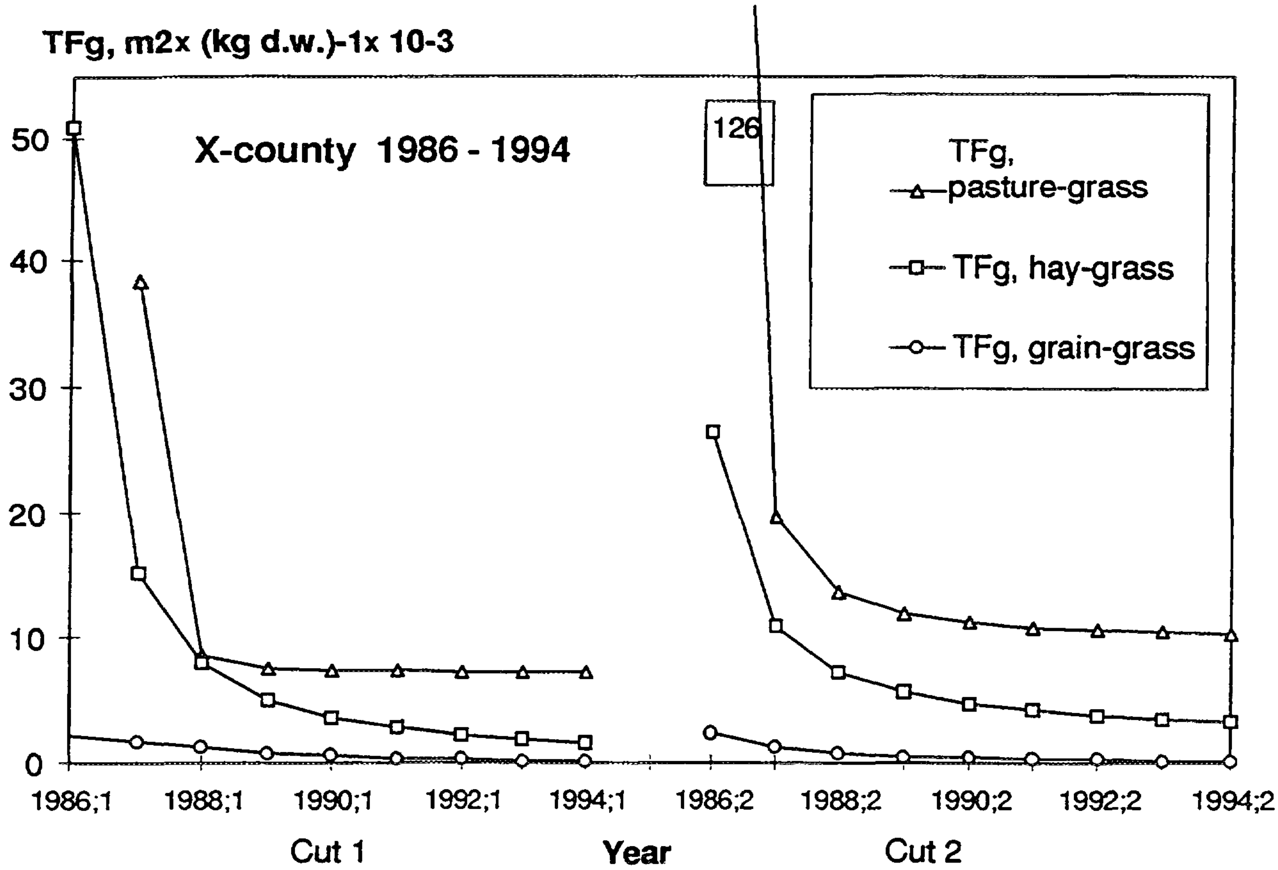

FIG. 3. Annual changes in the X-county of ^{137}Cs transfer to two cuts of pasture grass, hay grass and grain-grass. Mean values for this crop have been used for a least square fit according to Eq.3.

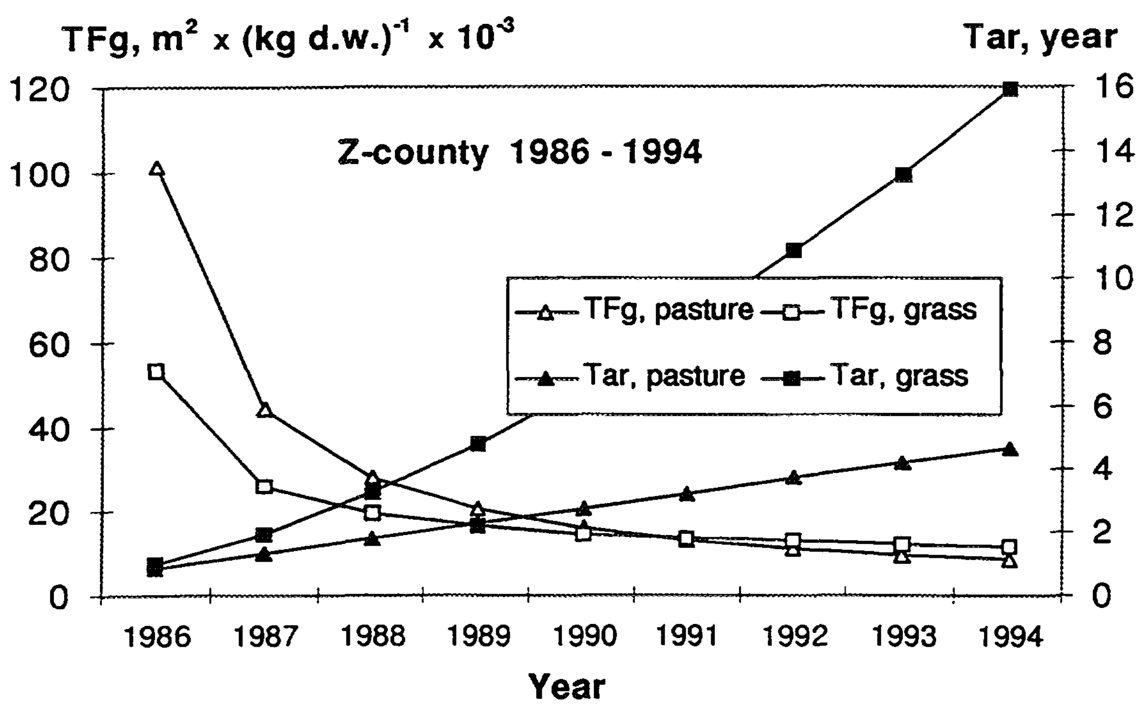

FIG. 4. Annual change in the Z-county of ^{137}Cs transfer to pasture and hay grass. Mean values for this crop have been used for a least square fit according to Eq. 3. The Tar-*values, as calculated from this equation, show the change in half-time of ^{137}Cs transfer with year.*

TABLE III. MEDIAN DEPTH OF ACTIVITY IN THE SOIL PROFILE ON PERMANENT PASTURE/SANDY SOIL IN 1967.

Nuclide	Range for NPK treatments (cm)	Range for lime treatments (cm)	Mean (cm)
^{137}Cs	1.7 - 2.6	1.8 - 2.1	1.9
^{90}Sr	3.8 - 10.3	4.1 - 5.7	5.6

TABLE IV. MEDIAN DEPTH OF ACTIVITY IN THE SOIL PROFILE ON GRAZING LEY/CLAY SOIL IN 1967 AND IN 1981.

Nuclide	Year	Range for PK treatments (cm)	Range for N treatments (cm)	Mean (cm)
^{137}Cs	1967	3.0 - 3.2	2.6 - 3.8	3.0
	1981	5.0 - 5.7	5.0 - 5.6	5.3
^{90}Sr	1967	5.0 - 5.7	5.2 - 5.3	5.2
	1981	8.4 -10.2	9.0 - 9.2	9.1

5.2. After Chernobyl

The leaching of ^{137}Cs was also determined in soil profiles at Swedish sites affected by fallout from Chernobyl [12]. Results from four of these sites are shown in Table VI. The radionuclide migrated downwards more in the peat soil than in the three mineral soils. However, most of the ^{137}Cs remained in the surface 5 cm even after 8 years.

TABLE V. FRACTION OF TOTAL ACTIVITY TRANSFERRED FROM THE TOPSOIL TO THE SUBSOIL DURING 20 YEARS

Subsoil type	Topsoil type	^{137}Cs, NO_3-N -K[a]	^{137}Cs, NO_3-N +K[b]	^{90}Sr, NH_4-N -K	^{90}Sr, NH_4-N +K
		(%)			
Sand	Sand	0.41	0.08	8.8	15.6
	Silt	0.25	0.13	5.6	7.1
	Clay	0.18	0.20	6.2	7.2
Clay	Clay	0.27	0.10	12.9	19.2
	Silt	0.08	0.18	11.2	15.2
	Clay	0.30	0.06	10.8	12.4

[a]No K-fertilization.
[b]124 kg K/ha /year.

TABLE VI. DISTRIBUTION OF ^{137}CS ACTIVITY WITH DEPTH DOWN TO 25 cm IN ONE PEAT AND THREE MINERAL SOILS 6-8 YEARS AFTER THE CHERNOBYL ACCIDENT OF 1986

Depth soil 1994	Peat soil 1992	Sandy soil 1994	Silty soil 1994	Clay
(cm)	(percent per cm)			
0-1	6.5	28.9	11.0	17.2
1-2	14.5	38.8	12.2	25.9
2-3	16.1	15.0	22.9	21.2
3-4	16.7	6.9	15.1	19.3
4-5	15.0	3.5	13.3	7.9
5-7.5	2.4	1.5	5.3	1.7
7.5-10	3.1	0.2	1.9	0.3
10-15	1.7	0.4	0.9	0.4
15-20	1.3	0.1	0.4	0.1
20-25	0.4	-	0.2	0.1

6. USE OF ^{137}Cs FOR SOIL-EROSION MEASUREMENT

Soil erosion is a global problem [14] and a serious threat to sustainable agriculture. There is less erosion with annual-crop rotations than with cereal monocultures. In Sweden it has been comparatively unimportant, due to its soils and climate, however, counter-measures are required on

some silty and sandy soils, from which considerable erosion has occurred, contributing to nutrient loading of aquatic systems. In fact, much of the work in Sweden on erosion has been related to water quality. Recent results clearly show that soil particle erosion is of importance for the transfer of phosphorus to aquatic systems. Therefore new studies on erosion of agricultural land under Swedish conditions are necessary, and are presently being initiated by the Department of Soil Sciences. The utilization of the Chernobyl and bomb fallout in this research is being developed in a joint project with the Department of Radioecology.

Some areas with silty and sandy soils were rather heavily contaminated by fallout from the Chernobyl accident [10], making them the logical choice as sites for research. As a first step in the application of the ^{137}Cs-technique for soil erosion studies, a site with high Chernobyl fallout of ^{137}Cs has been chosen, just 70 km from our University in Uppsala. The first two objectives are as follows.

1. To investigate sampling methods required to determine the activity of ^{137}Cs per unit area in a silty soil, heterogenously or homogenously mixed within the plough layer.
2. To determine the activity of ^{137}Cs in the soil in various parts of cultivated fields to evaluate patterns of erosion and accumulation of soil since 1986.

Step 1 will be carried out in a uniform and levelled field not exposed to erosion in order to develop sampling techniques and investigate small-scale spatial variation in ^{137}Cs activity.

Step 2 will then be carried out in the same field, using a similar sampling technique, in a sloping area that is exposed to erosion, to investigate the extent of redistribution of ^{137}Cs activity.

The Department of Radioecology is in possession of an Ortec computer-aided germanium detector system, housed in a specially designed low-background laboratory. The facility has been used extensively since the Chernobyl accident for measurement of radiocaesium (^{137}Cs, ^{134}Cs) activities in various soil, plant and animal samples. In the proposed research, 330-mL plastic beakers will be filled with soil samples and measured for their activity of both ^{137}Cs and ^{134}Cs.

With experience gained from the pilot experiments, large-scale investigations of soil erosion, using the new ^{137}Cs-technique, are proposed for the west and south of Sweden. Since mainly bomb-source-^{137}Cs is to be found there, ^{137}Cs-activity measurements will require larger soil volumes.

7. A SPECIAL FRAME TECHNIQUE FOR SOIL SAMPLING

The Department of Soil Science has long and extensive experience in sampling for the determination of depth, soil mass and content of various components in the tilled surface layer of cultivated soils. This experience will be valuable for calibration and interpretation of ^{137}Cs-data.

Sampling will be done from the soil surface to a depth of a few cm below the plough layer, using a frame-scraper sampling technique [15, 16]. A steel frame, 0.5 m^2 in area, is driven into the soil. All soil within this area is sampled and weighed. Complementary core samples are taken to sufficient depth to include all ^{137}Cs present in transects of the slope in order to cover a larger area of the field. After mixing, subsamples are removed for determination of ^{137}Cs activity per unit weight. This allows a good estimation of the activity per unit area. Sampling is done in 3x3 = 9 points in a grid with a distance of 15-20 m between sampling points. On the slope, complementary points in a grid will be sampled down to the depth of the radionuclide. The pattern of soil erosion and accumulation will be evaluated according to [17].

REFERENCES

[1] HAAK, E., Nutrient uptake from subsoil by cereals. In Agricultural Yield Potentials in Continental Climates. Proc. 16th Coll. Int. Potash Institute, Bern (1981).

[2] ROSÉN, K., et al., "Transfer of radio-caesium in sensitive agricultural environments 1986-1994 after the Chernobyl fallout in Sweden", Ten Years Terrestrial Radioecological Research Following the Chernobyl Accident (Proc. Symp. Vienna 1996) (1996).

[3] UNITED NATIONS, Ionizing radiation: Sources and biological Effects. United Nations Scientific Committee on Effects of Atomic Radation 1982. Report to General Assembly, with annexes. New York (1982).

[4] EDVARSON, K., "Fallout over Sweden from the Chernobyl accident", The Chernobyl Fallout in Sweden(MOBERG, L.. Ed.), The Swedish Radiation Protection Board, Stockholm (1991).

[5] FREDRIKSSON, L., Studies on plant accumulation of fission products under Swedish conditions. IV. Influence of exchangeable and nonechangeable potassium on and of exchangeable calcium in soil on the absorption of ^{137}Cs by red clover in pot experiments with 178 Swedish soils. FOA 4 rapport A 4321-4623, Stockholm (1963).

[6] FREDRIKSSON, L.,et al., Studies on plant accumulation of fission products under Swedish con-ditions. IX. Plant uptake of Sr-90 and Ca-45 as influenced by soil chemical properties. FOA 4 rapport C 4378-28, Stockholm (1968).

[7] ERIKSSON, Å. Fissionsprodukter i svensk miljö. Rapport från Instutionen för Radiobiologi, SLU-IRB-40. Uppsala (1978) (Fission products in Swedish environments; in Swedish).

[8] IAEA, Handbook of parameter values for the prediction of radionuclide transfer in the terrestrial and freshwater environments. 2nd draft. March 1987, Vienna (1987).

[9] ERIKSSON, Å., A database model for calculation of transfer of ^{90}Sr and ^{137}Cs in complex agricultural en-viroments. Report SLU-REK-76. Department of Radioecology, Swedish University of Agricultural Sciences, Uppsala (1994).

[10] HAAK E., LÖNSJÖ, H., "Long-term transfer of ^{137}Cs and ^{90}Sr to grass on contrasting types of Swedish pastures", Ten Years Terrestrial Radioecological Research Following the Chernobyl Accident (Proc. Symp. Vienna,1996) (1996).

[11] LÖNSJÖ, H., HAAK, E. "Soil factors influencing the long-term transfer of ^{137}Cs and ^{90}Sr to arable crops. Results from experimental studies under Swedish field conditions", Ten Years Terrestrial Radioecological Research following the Chernobyl Accident (Proc. Symp. Vienna, 1996) (1996).

[12] ROSÉN, K., et al., Migration of radiocaesium in grassland soil profiles after the Chernobyl fallout in Sweden (in preparation).

[13] WILKENS, A-B, et al., *In-situ*-studier av migrationsparametrar för strontium och cesium, Etapp 1. Studsvik/NW-84/869 (1984).

[14] BROWN, L.R.,WOLF, E.C., Soil erosion: Quiet crisis in the world economy, Worldwatch Paper 60 (1984) 51 pp.

[15] ANDERSSON, S., HÅKANSSON, I., Markfysikaliska undersökningar i odlad jord. XIV, Grundförbättring **16** (1963)1-26.

[16] HÅKANSSON, I. 1990. A method for characterizing the state of compactness of the plough layer, Soil Tillage Res. **16** (1990)105-120.

[17] WALLING, D.E., QUINE, T.A., Use of Caesium-137 as a Tracer of Erosion and Sedimentation: Handbook for the Application of the Caesium-137 Technique, UK Overseas Develop-ment Administration Research Scheme. Department of Geography, University of Exeter (1993).

USE OF ^{137}Cs AND OTHER FALLOUT RADIONUCLIDES IN SOIL EROSION INVESTIGATIONS: PROGRESS, PROBLEMS AND PROSPECTS

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Abstract

USE OF ^{137}Cs AND OTHER FALLOUT RADIONUCLIDES IN SOIL-EROSION INVESTIGATIONS: PROGRESS, PROBLEMS AND PROSPECTS

Accelerated erosion and soil degradation currently represent serious problems for the global environment. Against this background there is a need to assemble reliable information on the rates of soil loss involved. Existing techniques for documenting rates of soil loss possess many limitations and there is increasing interest in the potential for using fallout radionuclides, particularly ^{137}Cs, to obtain such information. An example of the application of the ^{137}Cs approach to a cultivated field at Rufford Forest Farm, Nottinghamshire, UK, is presented to illustrate its value. The key advantages of the approach are that it provides a means of assembling retrospective estimates of medium-term (ca. 40 years) rates of soil loss and the spatial pattern of erosion and deposition involved, on the basis of a single site visit. There are, however, currently a number of problems and uncertainties associated with the use of ^{137}Cs in soil erosion investigations, and these are reviewed and needs for further research identified. Potential developments of the approach, including the use of other fallout radionuclides such as unsupported ^{210}Pb and ^{7}Be are also considered.

1. THE CONTEXT

Although much of the recent concern for the global environment has focussed on problems of global warming and climatic change, there is also growing evidence that accelerated erosion and associated soil degradation represent a major problem for the sustainable development of agricultural production in a world characterized by a rapidly expanding population. Recent assessments of the global soil-erosion problem afford considerable cause for concern. For example:

- Brown [1] reports that each year the world is currently losing 23 x 10^9 tonnes of soil from croplands in excess of new soil formation. This is equivalent to a depletion of the global soil resource by 7% each decade.
- ISRIC [2] indicates that the soils of an area covering more than 8% of the land surface of the globe (i.e. $> 10^9$ ha) have now been degraded by water erosion.
- Buringh [3] estimates that the global loss of agricultural land due to soil erosion is now of the order of 3 x 10^6 ha per year.
- Pimental et al. [4] report that of the 11.6 x 10^6 ha of forest cleared annually, more than half can be attributed to agricultural soil degradation and subsequent expansion of agriculture onto new land.
- Brown and Young [5] estimate that current rates of soil loss from croplands result in an annual loss to the global grain output of 9 x 10^6 tonnes.

To date, much of the loss of soil and agricultural land identified above has been compensated by clearing of new land for crop production and by use of fertiliser and improved crop strains to increase yields on existing land, but the scope for maintaining such compensation measures will clearly

decline in the future. In addition to *on-site* costs associated with reduced soil productivity and loss of agricultural land, there is also increasing evidence that the *off-site* costs of soil erosion related, for instance, to increased sediment transport in rivers, may be of equal, if not greater, importance. Mahmood [6], for example, has reported that the world's reservoirs are currently losing storage at a rate of about 50 km^3 per year as a result of sedimentation. This is equivalent to a storage loss of approximately 1% per year. Taking account of the central importance of reservoirs for domestic and industrial water supply, for irrigation schemes, and for hydropower production, and thus for economic progress in many developing countries, such losses of storage are of considerable concern. Annual replacement costs are conservatively estimated at about US$6 x 10^9 per year and the new reservoir sites needed to replace lost storage are increasingly difficult to find.

Against this background, there is an increasing need to assemble reliable information on rates of soil erosion or soil loss in different areas of the world. Such information is, for example, needed to assess the magnitude of the problem, to evaluate the key factors influencing rates of soil loss and to investigate erosion-crop productivity relationships. This need is, however, not readily met by existing methods of measuring soil erosion, such as erosion plots, which possess many important limitations in terms of cost, representativeness and the reliability of the resulting data [7, 8]. These methods are also generally unable to provide the detailed spatially distributed data required to verify the new generation of distributed erosion and sediment yield models and to interface with current developments in the application of GIS and geostatistics to this field. Recent work in exploring and exploiting the possibilities for using fallout radionuclides, and more particularly ^{137}Cs, to document rates and patterns of soil redistribution can, however, be seen as overcoming many of the limitations associated with existing techniques for monitoring soil erosion and as offering considerable potential for meeting the needs outlined above.

2. THE USE OF ^{137}Cs MEASUREMENTS

2.1. The basis

The potential for using ^{137}Cs measurements to investigate rates and patterns of soil loss was originally recognised by Ritchie and McHenry in the USA [9] and the basis of the approach is now well documented [10, 11, 12, 13, 14]. In essence, the approach is founded on the fact that radiocaesium released into the stratosphere as a by-product of past atmospheric testing of thermonuclear weapons during the 1950s and early 1960s reached the land surface as fallout and was in most environments rapidly and strongly adsorbed by the surface soil. Its subsequent redistribution can be attributed to the erosion, transport and deposition of soil particles and measurements of the current distribution of ^{137}Cs within the landscape provide a means of establishing rates of erosion and deposition, and the spatial patterns involved, during the period since the main phase of atmospheric fallout. Assessment of ^{137}Cs redistribution is commonly based on comparison of the measured inventories (total activity per unit area) at individual sampling points, with an equivalent estimate of the inventory representing the cumulative atmospheric fallout at the site, taking due account of the different behaviour in cultivated and non-cultivated soils. Because direct long-term measurements of atmospheric fallout are rarely available, the cumulative input or reference inventory is usually established by sampling adjacent undisturbed, uneroded locations, generally under permanent pasture, which can provide an estimate of total fallout inputs. The magnitude and direction of measured deviations from the local reference level provide a qualitative assessment of sediment redistribution.

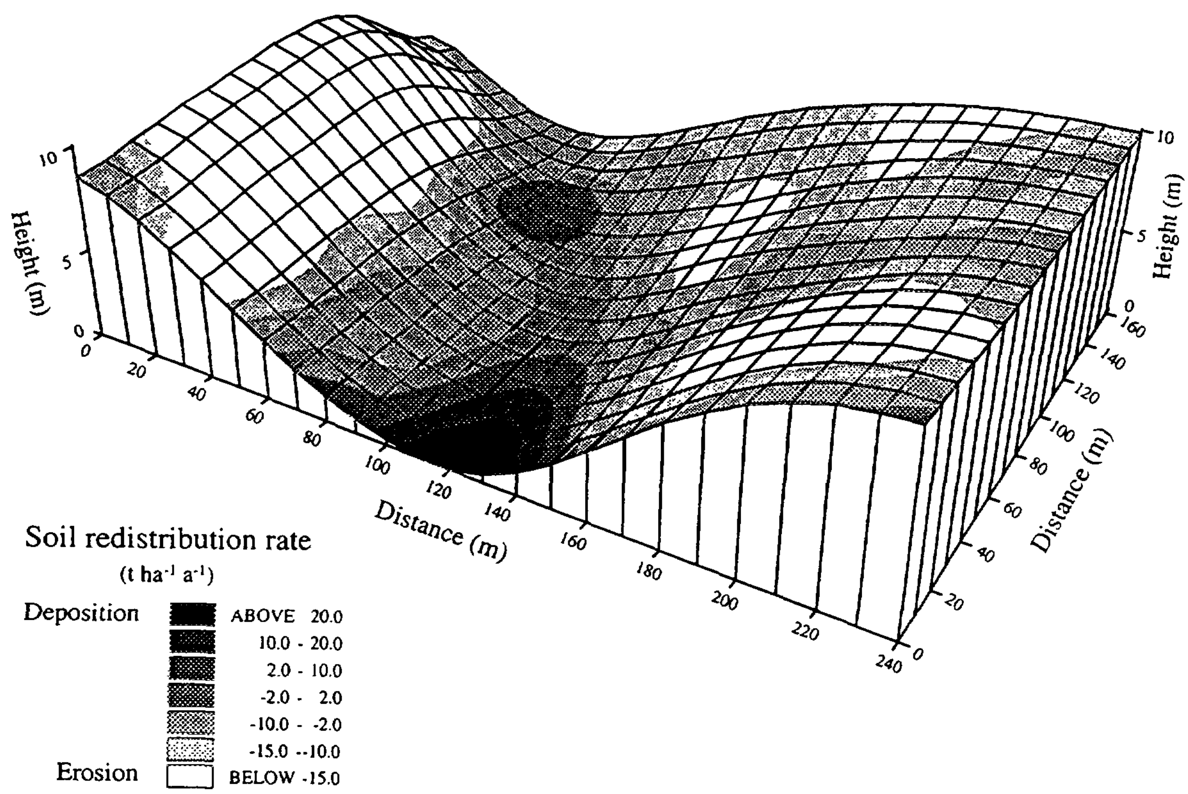

FIG. 1. Medium-term (35 years) erosion and deposition rates within a field at Rufford Forest Farm, Nottsinghamshire, UK, estimated using ^{137}Cs measurements.

To derive quantitative estimates of the rates of erosion and aggradation involved, it is necessary to establish a relationship between the magnitude of the deviation from the reference inventory and the extent of soil loss or gain [15]. Because empirical calibration data are rarely available, many workers have favoured the use of theoretical relationships or models to provide the necessary calibration function. Such models can be used to simulate the effect of a range of long term erosion and aggradation rates upon the ^{137}Cs inventory of soil profiles, and the resultant data can be used to derive the calibration relationship [15, 16].

2.2. An example

The advantages and potential value of the ^{137}Cs approach to documenting medium-term (i.e. ca. 40 years) rates and patterns of soil erosion can be usefully demonstrated by introducing an example from a study of a 3.8 ha cultivated field at Rufford Forest Farm, Nottinghamshire, UK, reported by Walling & Quine [10]. This area, which is underlain by brown sand soils of the Cuckney 1 association, is primarily used for arable cultivation. Sugar beet is widely grown and soil erosion has frequently been observed in the area [17]. A 20m x 20m grid was used as a basis for collecting soil cores from the field and a total of 117 cores was obtained using a motorized percussion corer (38 cm^2) inserted to a depth of 60 cm. The reference cores were obtained from an area of uneroded, undisturbed grassland located 1.7 km from the study field. After collection, all cores were air dried and lightly ground and the ^{137}Cs content of the material passing through a 2 mm sieve was determined by gamma spectrometry using an HPGe coaxial detector. A value of 3200 Bq m^{-2} was obtained for

TABLE I. SPATIALLY INTEGRATED ESTIMATES OF SOIL REDISTRIBUTION IN THE FIELD AT RUFFORD FOREST FARM ILLUSTRATED IN FIG. 1.

Component		Estimate
Gross erosion rate	($t\ ha^{-1}\ yr^{-1}$)	12.2
Eroding zone		
Mean erosion rate	($t\ ha^{-1}\ yr^{-1}$)	13.8
Fraction of total area	(%)	89
Fraction of total area with erosion rates		
$>2\ t\ ha^{-1}\ yr^{-1}$		81
$>4\ t\ ha^{-1}\ yr^{-1}$		72
Aggrading zone		
Mean aggradat'n rate	($t\ ha^{-1}\ yr^{-1}$)	16.1
Fraction of total area	(%)	11
Net erosion rate	($t\ ha^{-1}\ yr^{-1}$)	10.5
Sediment delivery ratio	(%)	86

TABLE II. SOME ADVANTAGES OF THE ^{137}Cs TECHNIQUE FOR ESTIMATING RATES OF SOIL LOSS AND DEPOSITION

(1) Estimates relate to individual points within the landscape and information relating to both rates and spatial patterns of soil redistribution can be assembled

(2) The technique is capable of providing spatially-distributed data which are compatible with recent advances in physically-based distributed modelling

(3) The estimated rates of soil redistribution reflect the integration of all landscape processes (e.g. water and wind erosion, tillage effects etc.)

(4) Estimated rates of soil redistribution relate to the past 40 years and thus provide estimates of longer-term average rates of erosion and deposition. Short-term measurements may be unrepresentative

(5) There are no major scale constraints apart from the number of samples that can be processed. Areas studied can range from a few m^2 to small drainage basins (e.g. 5 ha)

(6) Application of the technique does not involve major disturbance of the landscape under study

(7) Estimates can be obtained on the basis of a single site visit

(8) Estimates based on contemporary sampling are retrospective and therefore avoid the need for establishment of long-term monitoring programmes

the local reference inventory. Deviations of the inventories associated with the individual sampling points within the field, from the reference value, were calculated, and a calibration model was used to derive estimates of the rates of erosion and deposition occurring within the field over the past 35 years. The resultant pattern of soil redistribution documented for the field, which is presented in Fig. 1, reflects the action of a range of erosion processes, including both water erosion and the effects of soil tillage.

In addition to providing an assessment of the spatial pattern of soil redistribution within the study field, the individual point estimates of erosion and deposition rates derived from the ^{137}Cs measurements can be spatially integrated to produce a range of measures of the overall status of erosion and deposition within the field (Table I). The values of both the gross erosion rate and the mean erosion rate for the eroding sites permit clear assessment of the severity and potential on-site impact of erosion within the area under investigation. Furthermore, assessment of both the net soil loss and the sediment delivery ratio permits an evaluation of the potential for off-site problems posed by sediment leaving the field and entering local watercourses.

The example outlined above is based on measurements of the total inventory of individual soil cores, since this minimises the number of samples requiring gamma assay and therefore reduces the analytical demands. Further development and refinement of the approach could, nevertheless, usefully involve consideration of the depth distribution of radiocaesium in the soil profile, since such information can afford the basis for improved interpretation of the erosional history of the study site, particularly in areas of intensive land use [18].

The information generated for the field at Rufford Forest Farm from ^{137}Cs measurements, which is presented in Fig. 1 and Table I represents essentially unique data that would be effectively impossible to assemble by any other means. Use of erosion plots would, for example, provide information only on the net soil flux at the lower end of the bounded plot and would be unable to document the *spatial pattern of* erosion and deposition within the field. Equally, they would not document the effects of soil redistribution by tillage. Furthermore, although the medium-term and temporally-lumped nature of the erosion rate estimates provided by the ^{137}Cs measurements could be seen as a limitation, it must be recognised that short-term measurements could be unrepresentative and that long-term monitoring is likely to prove both costly and labour intensive and in many instances impractical. In addition, the ^{137}Cs approach affords a unique opportunity to secure *retrospective* information for a particular site and to acquire the *spatially distributed* data required to develop and validate the new generation of distributed soil-loss models currently being developed [19]. These and other key advantages of the use of ^{137}Cs to monitor rates and patterns of soil loss are summarized in Table II.

3. CURRENT PROGRESS

Although the potential for using ^{137}Cs as a tracer in soil erosion investigations was recognised at a relatively early stage in the United States of America [9, 20], wider application of the approach was relatively slow. It is only in more recent years that its potential has been more generally exploited. Figure 2 provides a schematic representation of the expansion of such exploitation over the past 30 years by plotting the activity of individual research groups who have made extensive use of the approach. Figure 2 is neither comprehensive nor precise, since some groups will have been excluded and the periods of activity may be incorrect. Nevertheless, it clearly demonstrates the very significant expansion in the application of the approach in recent years. Such applications have

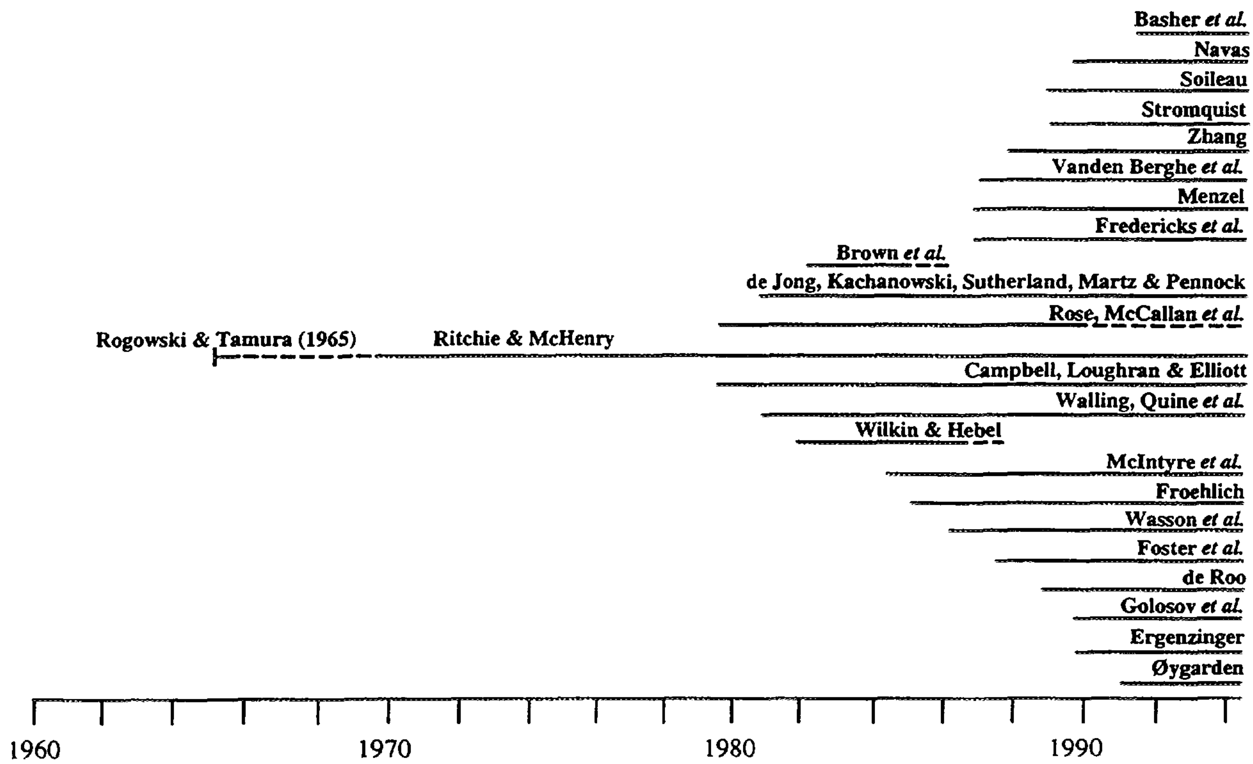

FIG. 2. The evolution of the use of ^{137}Cs in soil-erosion studies.

encompassed a wide variety of locations throughout the world (Fig. 3), ranging from glacierized mountain areas in Greenland [21] and mountain areas in Sweden [22], through the prairie and steppe regions of Canada and the Russian Federation [23, 24, 25, 26] and semi-arid areas of Spain [27], to tropical areas of Africa [28] and Thailand [29]. Therefore, the approach must now be seen as having global relevance [30, 31].

4. PROBLEMS AND UNCERTAINTIES

Although the use of ^{137}Cs measurements to document rates and patterns of soil erosion must now be seen as well established and proven, and as providing a valuable alternative to traditional approaches, a number of limitations and uncertainties must be recognised. These are briefly reviewed.

4.1. Global and regional patterns of ^{137}Cs fallout

Use of ^{137}Cs measurements to document rates and patterns of erosion requires that existing inventories should be sufficiently high to permit accurate assessment of radiocaesium redistribution during the period since the main period of weapons testing. Measurement precision is particularly important in this context, since it is difficult to obtain reliable measurements of ^{137}Cs activity when inventories are low. Although a detailed assessment of the global pattern of ^{137}Cs inventories in undisturbed soils, which would be representative of fallout inputs, has yet to be undertaken, it is

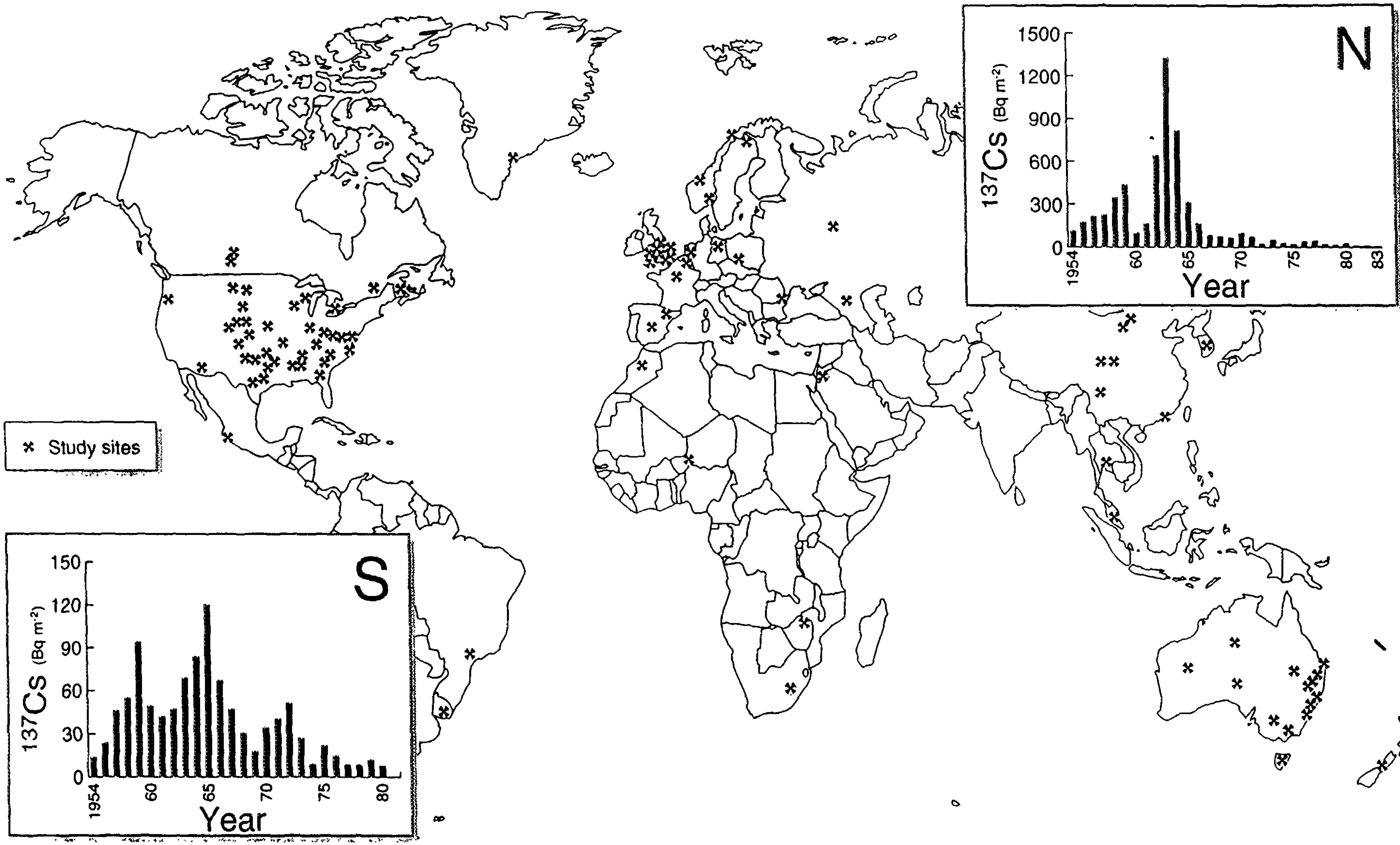

FIG. 3. Locations where ^{137}Cs has been used successfully in soil-erosion and related studies and typical fallout records for the northern (New York, USA/Milford Haven, UK) and southern (Adelaide/Brisbane) Australia) hemispheres.

known that such inventories are much lower in the southern hemisphere than in the northern hemisphere (cf. Fig. 3) and that inputs to equatorial areas were probably considerably lower than those in the mid-latitude areas of Europe and North America, where most work on exploiting the potential of ^{137}Cs measurements has been undertaken. Table III presents generalised information on the global distribution of the fallout of ^{90}Sr, another fission product of weapons testing, based on data reported by Larsen [32]. In view of the common origin of both strontium-90 and caesium-137, the global pattern of fallout of both radionuclides can be expected to be similar.

Table III indicates that in equatorial areas and over large regions of the southern hemisphere, ^{137}Cs inventories are likely to be <30% of those recorded in the mid-latitudes of the northern hemisphere. There have, nevertheless, been many reports of the successful application of ^{137}Cs measurements in areas of the southern hemisphere with relatively low inventories such as Australia and southern Africa [33, 34], but uncertainty remains over the viability of the approach in arid regions and some equatorial areas.

4.2. Chernobyl fallout: problems and opportunities

The use of ^{137}Cs measurements for soil-erosion assessment is generally based on the assumption that it is possible to assess the redistribution of radiocaesium occurring during the period extending from the main period of weapons test fallout in the late 1950s and the 1960s to the present, and to use this information to estimate rates of erosion and deposition. This basis will be compromised in areas that received significant amounts of Chernobyl-derived ^{137}Cs fallout in 1986. Such areas include large parts of northern, eastern and western Europe. In the first place, it will no longer be possible to assume that the documented redistribution reflects the the net effect of soil erosion processes operating over a period of ca. 40 years. Some of the ^{137}Cs inventory will have been present in the soil only since 1986. Although it was possible to distinguish the bomb- and Chernobyl-derived components of the total ^{137}Cs inventory at the time of the Chernobyl incident by measuring the ^{134}Cs activity (^{134}Cs was associated only with Chernobyl fallout and exhibited a fixed ratio to ^{137}Cs), this is no longer possible due to the short half life of ^{137}Cs (2.2 years) which is now below the level of detection at most locations. Secondly, the main input of Chernobyl fallout was restricted to a short period immediately after the accident and was in many places characterised by marked spatial variability due to the interaction of the plume with local air mass and precipitation dynamics [35]. This variability introduces problems in terms of establishing a local reference level against which the inventories for individual cores can be compared in order to assess the gain or loss of radiocaesium and thus the rate of soil redistribution.

Although the addition of Chernobyl fallout will inevitably complicate the interpretation of ^{137}Cs measurements in many areas, some potential undoubtedly exists to make use of the two phases of fallout input to derive additional information on the erosional history of a site. Chernobyl inputs could be incorporated into theoretical calibration procedures aimed at interpreting the inventory values for bulk cores, but in most cases it may prove more useful to consider the depth distribution of radiocaesium within the soil, which may in turn reflect both input phases. Where Chernobyl-derived ^{137}Cs inventories are very much greater than bomb-derived inventories, such that the latter may be effectively ignored, it should prove possible to use the redistribution of Chernobyl-derived ^{137}Cs to assess soil redistribution during the period since 1986.

TABLE III. LATITUDINAL VARIATION OF BOMB-DERIVED ^{90}Sr INVENTORIES AT THE END OF 1983, BASED ON LARSEN [32]

Latitude band	Mean ^{90}Sr inventory Northern hemisphere	Southern hemisphere
	(Bq m^{-2})[a]	
0-10	953	526
10-20	1370	491
20-30	2075	841
30-40	2862	967
40-50	3867	1124
50-60	3585	672
60-70	2084	455
70-80	897	276
80-90	409	154

[a] Inventory values have been estimated from the cumulative ^{90}Sr deposition on the land and ocean surfaces of individual latitudinal belts.

4.3. Local variability of ^{137}Cs fallout and establishment of local reference inventories

As indicated above, most procedures involving the use of ^{137}Cs measurements to estimate rates of soil redistribution are based on a comparison of measured inventories for individual soil cores with a local reference inventory. In most investigations it is assumed that this local reference inventory will be effectively constant over a small study area. This assumption can be readily justified theoretically in terms of the extended period of input associated with bomb fallout, such that local variability associated with individual precipitation events is likely to disappear when the inputs associated with a large number of precipitation events are averaged. However, more attention undoubtedly needs to be given to justifying this assumption empirically and assessing the potential magnitude of local variability in fallout inventories. This in turn requires consideration of potential sources of sampling variability, in order to distinguish true spatial variability from variability introduced by measurement precision and sample collection [36, 37, 38]. The latter could be seen as effectively adding confidence limits to any estimate of the local reference inventory, such that this should be represented by a range rather than an absolute value. Equally, where there is clear evidence of true spatial variability of the local reference inventory, it will be necessary to consider whether this is essentially random or if there is a systematic trend. In the former case the confidence limits associated with the estimate of the local reference inventory will need to be increased, whereas in the latter case appropriate spatial statistics may be used to represent the pattern or trend involved. Where random spatial variability exists, it is

important to consider the number of samples required to obtain a reliable estimate of the mean and variance of the reference inventory at the required level of confidence. Results presented by Owens and Walling [36] indicate that confidence limits associated with measurement precision and sampling variability are likely to be of the order of $\pm 10\%$ and $\pm 5\%$ respectively at the 95% level of confidence.

4.4. Behaviour of ^{137}Cs within the soil profile

Use of ^{137}Cs measurements to estimate rates of soil redistribution depends heavily upon the Assumption that radiocaesium fallout is rapidly and strongly adsorbed by the upper horizons of the soil and that its subsequent redistribution therefore reflects movement of soil particles. There have been a number of reports of the mobility of Chernobyl-derived radiocaesium in the receiving soils that could cause this assumption to be questioned. However, it is important to recognise that most of these reports relate to upland areas with acid, highly organic soils with limited capacity to adsorb radiocaesium. Furthermore, the concentrations of radiocaesium in precipitation associated with Chernobyl fallout were frequently orders of magnitude greater than those associated with bomb fallout, which occurred over a period of many years rather than few days, and may therefore not provide a meaningful replication of the response of soils to bomb fallout.

Most agricultural soils, which will be investigated in soil erosion studies, can be expected to conform to the assumptions of rapid and strong fixation of radiocaesium associated with bomb fallout and there have been many laboratory and field investigations that have confirmed such behaviour. Livens and Loveland [39], for example, cite the work of several investigators as demonstrating the highly efficient extraction of radiocaesium from dilute (0.001*M*) solutions by clay minerals. The radiocaesium concentrations in the solutions are several orders of magnitude greater than those associated with rainfall during the period of weapons testing fallout. The effects of soil texture and the magnitude of the clay fraction must also be considered, but other studies indicate that the proportions of fine particles commonly found in mineral soils do not limit radiocaesium adsorption. Livens and Baxter [40] examined a range of soil types and found that radiocaesium has been adsorbed by all the mineral soils investigated. Strong adsorption is also reflected by the low rates of vertical migration of ^{137}Cs evident for many soil types in both field and laboratory experiments [41, 42] and in the depth distributions of the weapons testing ^{137}Cs characteristic of undisturbed soil profiles.

Figure 4 illustrates typical ^{137}Cs depth distributions for a selection of soils investigated by the author. These encompass a textural range from clay to sand in the UK (Figs. 4(a) to (e)) and an environmental range from temperate through semi-arid to subtropical, worldwide. All exhibit a sharp decline in ^{137}Cs activity with increasing depth and in all cases more than 75% of the total inventory is found in the top 15 cm, indicating that downward translocation is minimal. Furthermore, the total inventories of the UK soils are in close agreement with existing evidence regarding total fallout amounts [43]. These profile characteristics again support the assumption that in most environments the majority of mineral soils have the capacity to adsorb and immobilize fallout. Further work is, however, required to investigate the behaviour of highly weathered tropical soils with respect to the fate of radiocaesium fallout inputs.

4.5. Preferential mobility of ^{137}Cs in response to grain size effects and the organic fraction

When using ^{137}Cs measurements to estimate rates of soil erosion or deposition, it is frequently assumed that there is a simple relationship between the percentage increase or decrease of the radiocaesium inventory relative to the local reference value and the mass of soil eroded or deposited. Thus, in the case of the *proportional method,* which is frequently used to convert measurements of the percentage reduction in the total ^{137}Cs inventory to an estimate of the erosion rate, the soil loss is assumed to be directly proportional to the amount of ^{137}Cs removed from the plough layer [15]. A 50% reduction in the ^{137}Cs inventory would be taken as indicating that a depth of soil equivalent to 50% of the depth of the plough layer had been eroded during the period since the commencement of fallout. The assumption of proportionality is, however, an oversimplification of reality, since the surface lowering by erosion may be associated with preferential mobilisation of specific size fractions or the organic fraction. It is well known that the radiocaesium fixed within a soil will be preferentially associated with the finer fractions, and if there is selective erosion of these finer fractions the proportional method will overestimate the rate of surface lowering. Equally, if the coarser fractions

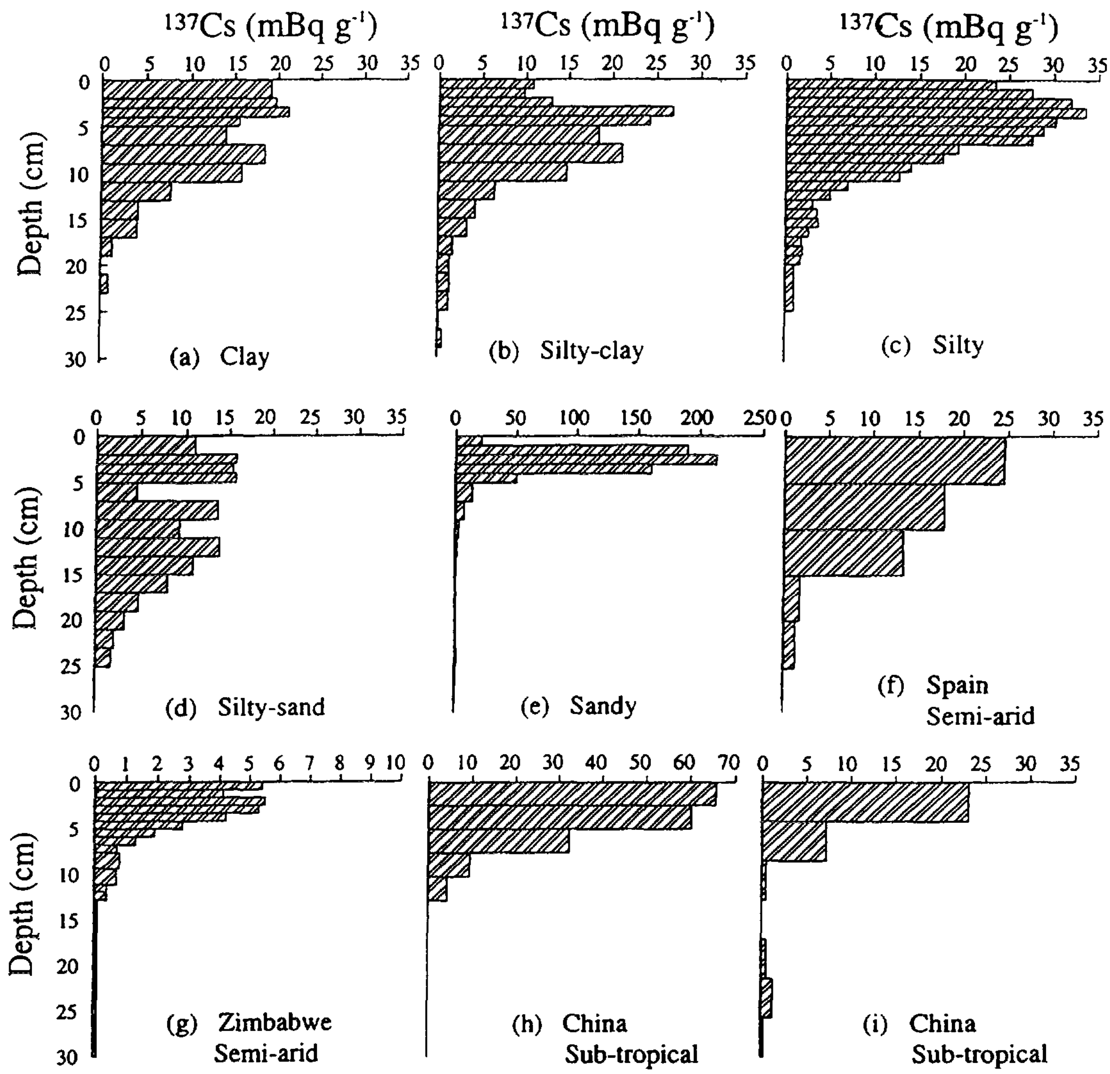

FIG. 4. Typical ^{137}Cs profiles associated with undisturbed soils: (a) to (e): soil-textural variation in the UK; (f) to (i): environmental variation worldwide.

are preferentially mobilised, the rate of surface lowering is likely to be underestimated. Similarly, depending on whether the organic fraction is enriched or depleted in radiocaesium relative to the mineral soils, preferential removal of this fraction would again cause the erosion rate to be over- or underestimated respectively. In many situations, material mobilized by erosion will be eroded in the form of aggregates containing primary particles of a range of sizes and both mineral and organic particles [44]. Under such circumstances, the potential for selective erosion is likely to be limited. Nevertheless, there is a need for increased attention to this facet of the behaviour of radiocaesium in eroded soil and for incorporation of the enrichment ratio concept [45], which has been extensively used in studies of sediment-associated contaminant transport, into the interpretation of ^{137}Cs measurements.

The implications of selective mobilisation and transport are probably more significant in the use of ^{137}Cs measurements to estimate rates of deposition or aggradation, since selective deposition of coarser particles will frequently occur. If, as is likely, the resulting deposits are characterised by lower radiocaesium concentrations than the parent soil, application of simple proportionality assumptions will lead to underestimation of the deposition rates involved. An improved understanding and representation of the effects of particle size in the adsorption of radiocaesium, such as attempted by He and Walling [46], is required to provide a basis for improved interpretation of ^{137}Cs measurements in soil erosion investigations.

4.6. Establishing improved 'calibration' relationships between measured inventories and rates of soil loss or deposition

Although ^{137}Cs measurements can readily provide *qualitative* information concerning the redistribution of soil within a field or landscape, there will be a requirement in most studies to convert such measurements into *quantitative* estimates of erosion and deposition rates. This will commonly involve application of a 'calibration' relationship that relates the percentage increase or decrease of the radiocaesium inventory at the measuring point, relative to the local reference value, to the rate of erosion or deposition involved. Walling and Quine [15] have reviewed many of the uncertainties and inconsistencies associated with the wide range of calibration relationships employed in existing investigations, and the scale of the problem is clearly demostrated in Fig. 5, which is based on their work and which plots a number of these calibration functions on common coordinates.

Estimates of the erosion rate associated with a particular level of ^{137}Cs can vary by more than an order of magnitude, according to the calibration relationship used. Some of this variability is undoubtedly related to local conditions, since variations in cultivation practices, and particularly plough depths, will be reflected in different relationships. Furthermore, for a given rate of soil loss, the reduction in the ^{137}Cs inventory might be expected to vary according to the relative importance of sheet and rill erosion. In some cases relationships have been incorrectly derived, but much of the variability evident in Fig. 5 is a reflection of the uncertainty surrounding the precise nature of the calibration relationship and the major controlling factors.

Existing calibration relationships essentially fall into two categories. The first involves empirical relationships between measured or estimated soil loss or deposition and measurements of ^{137}Cs depletion or gain. The second employs theoretical models or accounting procedures to derive the relationship. Both categories possess limitations. In the first case, data suitable for deriving empirical relationships are very limited for most areas of the world. In the second, there is a need to represent accurately the long-term behaviour and fate of radiocaesium fallout in the soil of the study area. The inadequacy of the simple proportional model in terms of representing the grain size selectivity of

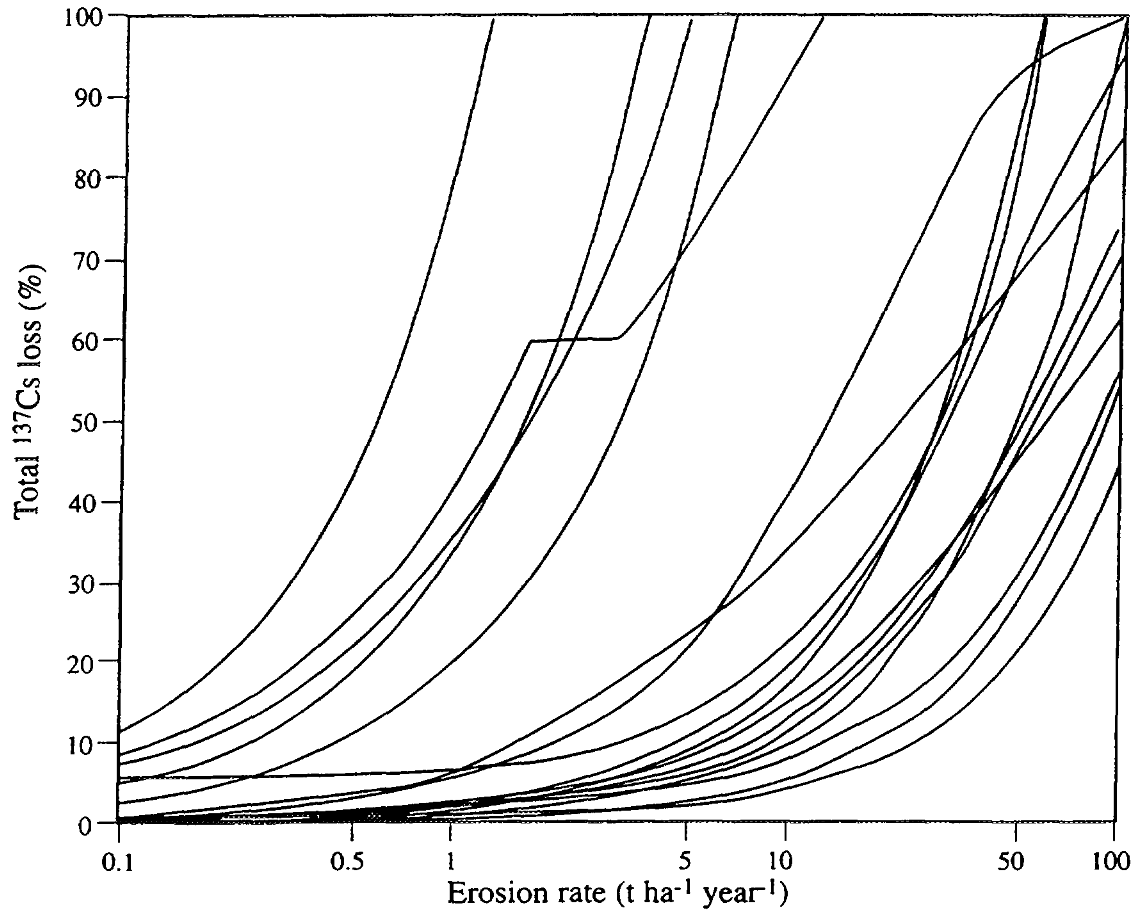

FIG. 5. A selection from the range of calibration relationships between the percentage of the total ^{137}Cs inventory lost from a soil profile and the long-term erosion rate used by various workers. (based on Walling and Quine [15]).

erosion, transport and deposition processes has already been highlighted above, but these and other considerations can be readily incorporated into more comprehensive theoretical models and accounting procedures [15, 16].

Much of the uncertainty and inconsistency surrounding calibration relationships evident in Fig. 5 has been reconciled by the development of improved theoretical models and accounting procedures [15, 16] and by the careful assessment of data obtained from erosion plots [47, 48]. Provided that care and critical appraisal are exercised, calibration problems should not be seen as a major impediment to the wider application of ^{137}Cs measurements in soil-erosion investigations. The author has favoured the application of theoretical accounting procedures that are able to represent the combined effect of all redistribution processes operating over the period since the initiation of atmospheric fallout and to take account of the known history of land management at the site, to establish site-specific calibration relationships [15, 34]. Where independent evidence of longer-term erosion rates exists, use of these procedures has resulted in close agreement of the estimates produced [49]. Nevertheless, more work is undoubtedly required to make use of available long-term erosion plot experiments in validating and developing empirical calibration relationships, to refine theoretical procedures, for example by incorporating the particle-size selectivity of erosion and deposition processes and by experimental investigations [e.g. 50, 51] and to combine these two approaches.

4.7. Past fallout behaviour

When interpreting ^{137}Cs measurements in terms of soil-redistribution processes and when attempting to develop comprehensive representations of the fate of radiocaesium in agricultural soils for use in developing theoretical accounting models, one of the greatest sources of uncertainty relates to the precise fate and behaviour of bomb-derived radiocaesium at the time of deposition during the late 1950s and early 1960s. For example, it is important to know the likely thickness of the surface layer of soil enriched with radiocaesium fallout. If this was extremely thin, a small amount of surface erosion could remove the recently deposited ^{137}Cs, whereas if the thickness was greater a substantial proportion of the recent input would remain for subsequent incorporation into the soil by tillage activity. Equally, it is important to relate the pattern of fallout receipt during the year to the precise timing of tillage and erosion events, since the proportion of the recent fallout removed by erosion will depend on whether it still remains at the surface or is incorporated into the plough layer. It is impossible to recreate the conditions of the late 1950s and 1960s, but additional evidence of the likely behaviour and fate of contemporary fallout could be obtained from carefully designed experiments and from collation of available records of the magnitude and timing of fallout inputs.

4.8. Physiographic constraints on the application of ^{137}Cs measurements in soil erosion investigations

It is important to recognise that ^{137}Cs measurements are primarily applicable to investigations of sheet and rill erosion, which involve gradual surface lowering. In the case of rill erosion, subsequent tillage will redistribute and smooth the surface soil such that its net effect in terms of the radiocaesium content of the soil is effectively similar to that of sheet erosion. Caesium-137 measurements are of limited value in investigating gully erosion, since the depths of incision are very much greater than the depth of soil labelled with radiocaesium. Nevertheless, ^{137}Cs measurements can be used in gully erosion investigations to assist in establishing the chronology of incision and deposition, since the surface layers of sediment deposited after the late 1960s are likely to contain little or no radiocaesium. Equally, when tracing the source of sediment transported by a river, the ^{137}Cs content of the sediment can provide evidence as to the likely source of the sediment [52, 53]. Where sheet and rill erosion represent the dominant sources, radiocaesium concentrations are likely to be relatively high, whereas if the sediment originates primarily from gully erosion the concentrations are likely to be very low.

Problems of low fallout inventories in some areas of the world highlighted above may also limit the applicability of ^{137}Cs measurements in certain physiographic zones. These are likely to include many of the desert areas of the world. In addition, several assumptions of the approach could be violated in areas where a substantial proportion of the precipitation falls as snow and accumulates through the winter season. The effects of drifting in redistributing snow will also introduce spatial variability of fallout receipt, such that it will be more difficult to establish a local reference inventory and variations in radiocaesium inventories across an area could reflect variations in input rather than erosional redistribution. Accumulation of drifting snow in hollows and its removal from ridge tops could, for example, falsely suggest the existence of depositional areas in the former and eroding areas on the latter.

4.9. Costs and operational constraints and the need for upscaling

The various advantages of the ^{137}Cs approach to soil-erosion assessment listed in Table 2 underpin its increasing use. In particular, the potential for obtaining retrospective measurements of soil erosion and deposition on the basis of a single site visit represents a very important advantage. Similarly, the potential for obtaining detailed distributed data matches the requirements of contemporary developments in the application of distributed erosion and sediment yield models. Nevertheless, there are significant cost and operational constraints on its use. More particularly, the gamma spectrometry analysis required to establish the ^{137}Cs inventories of bulk cores or the ^{137}Cs content of depth incremental samples from sediment cores are costly in terms of detector time. Because of the relatively low levels of radiocaesium activity involved, count times for individual samples are typically of the order of 10,000 to 30,000 s. This in turn limits the number of samples that can be processed, since equipment costs generally preclude the establishment of more than a small number of detectors. Collection of substantial numbers of bulk cores can also represent a time consuming exercise in areas characterised by dense dry soils, but this limitation can be overcome by use of motorised percussion corers.

Because of the limitations on sample numbers imposed by analytical constraints, and the spatial variability of soil erosion that precludes using a few radiocaesium measurements to derive estimates of soil loss for a large area, most investigations making use of ^{137}Cs measurements have focussed on small areas. For example, in the case of the field at Rufford Forest Farm, Nottinghamshire, UK, studied by Walling and Quine [10] and shown in Fig. 1, a total of 117 bulk cores were collected from the 3.8 ha field using a 20 m x 20 m grid. Similarly, the reconnaissance survey of soil erosion in Australia reported by Loughran et al. [33], which allocated 500 ^{137}Cs analyses per state, focussed on the detailed investigation of a small number of representative slope profiles. There is clearly a need to develop means of scaling up the use of ^{137}Cs measurements to provide data from larger areas. This could be achieved by using the point-specific information provided by ^{137}Cs measurements as 'ground truth' in extrapolation procedures [11]. These procedures could involve the development of GIS erosion models for use with Digital Elevation Models (DEMs), such that the ^{137}Cs measurements could be used to calibrate the model that could then be applied to a wider area using topographic data. Similarly, there is potential to couple the use of ^{137}Cs measurements and satellite imagery, such that the former could provide ground truth for areal extrapolation procedures based on the latter [30, 54].

5. FUTURE PROSPECTS

Although the ^{137}Cs approach has been employed in an increasing number of soil erosion investigations in recent years, considerable scope remains to refine the procedures employed and to exploit its potential more fully. To date, most of the studies employing this approach have been concerned with soil erosion by water, but there is clearly potential to extend its application to redistribution of soil by tillage [55, 56] and to wind erosion [57]. Where it is possible to initiate longer-term investigations, it should also be feasible to extend the approach to include resampling of soil inventories to permit comparison of values for known dates and thus estimate the erosion rates for the associated intervening periods. Care would, however, need to be exercised to ensure that the period between measurements was sufficiently long to produce significant differences in recorded

inventories, bearing in mind the precision errors typically associated with gamma assays. This strategy has the attraction of avoiding the need to establish the reference inventory for a site, but it no longer affords the potential to obtain retrospective estimates of soil redistribution.

The distributed data generated by ^{137}Cs measurements are also ideally suited to coupling with GIS and spatial statistics [58] and for use in verifying distributed erosion and soil loss models [59]. Scope also clearly exists for using estimates of soil loss derived from radiocaesium measurements as a basis for establishing medium-term soil loss / crop productivity relationships. In addition, there is considerable potential for extending the use of ^{137}Cs as a sediment tracer from consideration of soil redistribution within individual fields to investigation of the movement and storage of sediment within a drainage basin. Walling and Bradley [60] have, for example, shown how ^{137}Cs measurements can provide the basis for establishing the sediment budget for a small drainage basin, and the successful application of ^{137}Cs measurements in fingerprinting sediment sources and in estimating rates of overbank floodplain accretion has been demonstrated by a number of studies [52, 61, 62, 63, 64].

A further area to which effort could be profitably directed is exploitation of the potential for using other fallout radionuclides. Caesium-137 has attracted particular attention for application in soil erosion investigations by virtue of its high affinity for sediment particles, its relatively long half-life, its comparative ease of measurement and its well-defined temporal pattern of fallout input. As such it has effectively dominated most, if not nearly all, recent work and there have been very few attempts to use other fallout radionuclides that might offer similar or complementary opportunities. Thus, for example, the possibility of combining measurements of a natural (as distinct from man-made) fallout radionuclide characterised by an essentially constant fallout input with those of ^{137}Cs whose input was effectively restricted to a period in the late 1950s and the 1960s, could offer additional scope for interpreting the erosional history of a study site. In addition, such a tracer could prove invaluable in areas where Chernobyl fallout has seriously complicated the interpretation of radiocaesium inventories. Equally, the availability of a fallout radionuclide with a much shorter half-life could offer potential for investigating the short-term behaviour and dynamics of erosion processes. Any other fallout radionuclide used in this manner in soil-erosion investigations would clearly need to be rapidly and strongly fixed on reaching the soil and two that would appear to offer such potential are ^{210}Pb and ^{7}Be. Figure 6, based on the work of Walling and Woodward [52], presents a typical example of the distribution of ^{137}Cs, ^{210}Pb and ^{7}Be in soils from both cultivated and pasture areas near Exeter, UK, which emphasises the very similar behaviour of the three radionuclides in terms of their fixation by the surface horizons of the soils. Some variations in their depth distributions are, however, evident and these reflect the different half-lives and the different fallout histories of the individual radionuclides. Further consideration of the potential for using ^{210}Pb and ^{7}Be in soil erosion investigations can usefully focus on each of these radionuclides in turn.

5.1. The use of unsupported ^{210}Pb in soil erosion investigations

Lead-210 is a natural product of the ^{238}U decay series, with a half-life of 22.26 years. It is derived from the decay of gaseous ^{222}Rn, the daughter of ^{226}Ra. Radium-226 occurs naturally in soils and rocks and will generate ^{210}Pb that will be in equilibrium with its parent. Diffusion of a small quantity of the ^{222}Rn from the soil introduces ^{210}Pb into the atmosphere and its subsequent fallout provides an input of this radionuclide to the soil surface that is not in equilibrium with its parent ^{226}Ra. This fallout component is commonly referred to as 'unsupported' or 'excess' ^{210}Pb, since it cannot be accounted for (or supported) by decay of the in-situ parent. The amount of unsupported or

atmospherically derived ^{210}Pb in a sediment sample can be calculated by measuring both ^{210}Pb and ^{226}Ra and subtracting the supported or in situ component. Recent advances in the use of low-background, low-energy gamma spectrometry [49, 50] make such measurements relatively easy to undertake.

Although ^{210}Pb has been extensively used for dating sediment cores [65, 66], its potential for use in soil erosion investigations has been essentially ignored to date. As a fallout radionuclide that is rapidly and strongly adsorbed by the surface soil, unsupported ^{210}Pb will behave in a manner similar to ^{137}Cs, except that its fallout input has been essentially constant through time and the supply to the soil surface is continuously replenished. This accounts for the slight difference in the depth distributions of the two radionuclides apparent in Fig. 6. Because of the continuous surface replenishment, unsupported ^{210}Pb concentrations are greatest at the surface, whereas in the case of ^{137}Cs, the lack of significant replenishment over the past 20 years, coupled with biological activity within the soil and some downward diffusion, have caused the level of maximum concentration to be displaced a few centimetres below the surface.

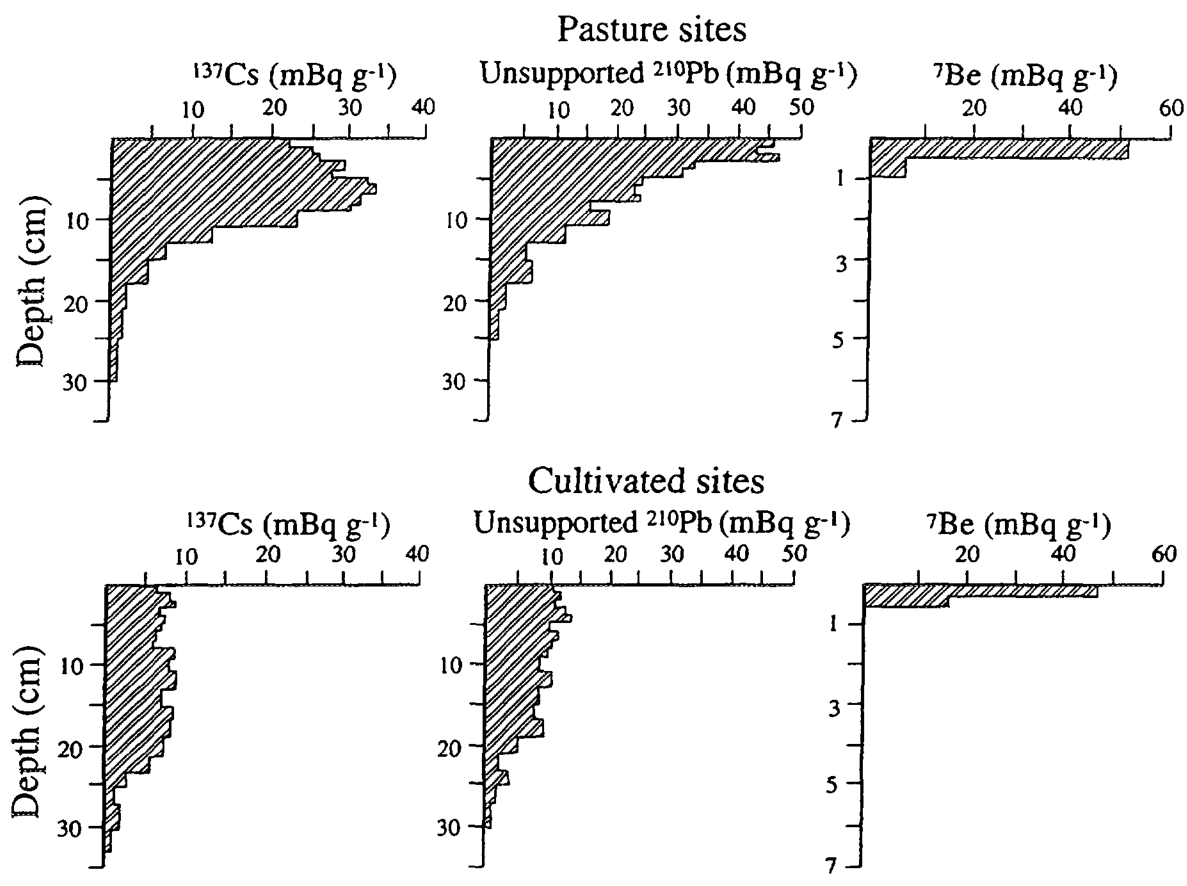

FIG. 6. Vertical distribution of ^{137}Cs, unsupported ^{210}Pb and ^{7}Be in soil profiles from representative pasture and cultivated sites near Exeter, Devon, UK.

Soil inventories associated with unsupported ^{210}Pb are generally somewhat greater than those of ^{137}Cs, and although little information exists as to the global pattern of unsupported ^{210}Pb fallout, there is some evidence that it is characterised by less variability than ^{137}Cs and that the existence of regions with very low inventories, where the approach may be difficult to apply, are likely to pose less of a problem.

Figure 7 emphasises the similar response of ^{137}Cs and unsupported ^{210}Pb to erosional redistribution within a small field at Butsford Barton near Colebrooke, Devon, UK, investigated by Walling et al. [67, 68]. The maps presented are based on data assembled for a 20m x 20m grid of >200 soil cores. In this location the reference inventories for ^{137}Cs and unsupported ^{210}Pb were estimated to be ca. 275 mBq/cm^2 and 600 mBq/cm^2 respectively. Considering the field as a whole, the loss of ^{137}Cs and unsupported ^{210}Pb relative to their respective reference inventories amounts to 12.7 and 16.7% respectively. The increased loss and slightly greater range of inventory values associated with the unsupported ^{210}Pb measurements reflect the continuous input of this radionuclide and thus the annual potential for erosion of newly accumulated ^{210}Pb from the soil surface prior to incorporation into the soil by tillage and the longer period available for removal of this radionuclide, the input of which was not restricted to the period post the mid 1950s. The unsupported ^{210}Pb inventory values depicted in Fig.7b have been converted to estimates of the long-term soil redistribution rate by using a theoretically derived calibration relationship similar to that employed by Walling and Quine [15] to convert measured ^{137}Cs inventories to estimates of erosion and deposition rates. The result is presented in Fig. 8, which shows clear evidence of soil accumulation in the central depression that traverses the field and against the lower field boundaries. In addition, the influence of tillage in displacing soil from the slope convexities is also evident. Further scope undoubtedly exists for interpreting the relative magnitude of the ^{137}Cs and unsupported ^{210}Pb inventories for individual sampling points to provide information on the erosional history of the site. Whereas the latter will have been influenced by soil redistribution over the past 100 years or more, the former will reflect only soil redistribution that has taken place since the mid 1950s. Wallbrink and Murray working in Australia (personal communication) have shown that measurements of the ratio of unsupported ^{210}Pb to ^{137}Cs can also be used to estimate rates of soil loss, since the value of this ratio will vary down the soil profile in uncultivated soils and its magnitude can therefore be used to provide an indication of the proportion of the soil profile removed by erosion.

5.2. Use of ^7Be in soil-erosion investigations

Beryllium-7 is a cosmogenic radionuclide produced in the upper atmosphere by cosmic ray spallation of nitrogen and oxygen. In this case the radionuclide is extremely short-lived (half-life of 53.3 days) relative to ^{137}Cs and ^{210}Pb and it offers potential for investigating soil erosion dynamics over much shorter timescales. Figure 6 indicates that ^7Be is typically concentrated in the upper 5mm of the soil profile and is therefore capable of providing good discrimination between sediment derived from the immediate soil surface and that derived from depths > 10mm where concentrations will be near zero. Burch et al. [69] and Wallbrink and Murray [70,71] working in Australia were, for example, able to use this radionuclide to distinguish sediment mobilised by sheet erosion and rill erosion in erosion plot experiments, to investigate the progressive incision of rills during the course

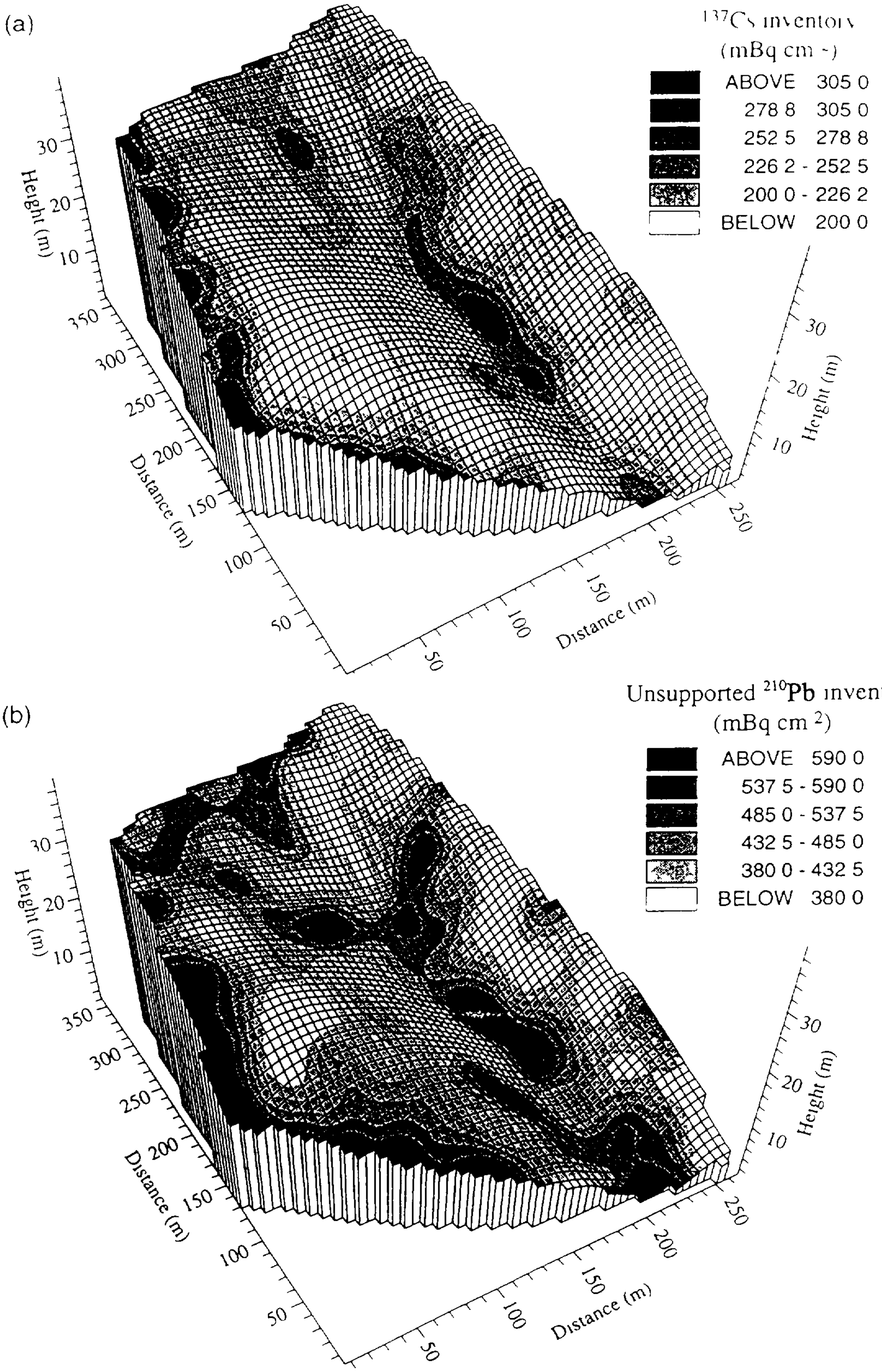

FIG. 7. Spatial patterns of (a) ^{137}Cs and (b) unsupported ^{210}Pb inventories in a field at Butsford Barton, near Colebrook, Devon

of a single simulated runoff event and to provide an effective tracer of surface soil. Scope clearly also exists to couple measurements of ^{7}Be activity with equivalent measurements of ^{137}Cs and unsupported Pb^{210} to provide increased capacity for sediment source discrimination [52]. Monitoring of the spatial distribution of ^{7}Be activity across small plots immediately after storm events could also provide a basis for investigating local erosion patterns in response to microtopographical control.

6 PERSPECTIVE

Fallout radionuclides, particularly ^{137}Cs and Pb^{210} have been extensively used for establishing the chronology of recent sediments, but their potential for use in soil erosion investigations has attracted much less attention. The growing need for information on the intensity of soil erosion in many areas of the world has, however, stimulated increasing interest in the use ^{137}Cs measurements to quantify rates and patterns of soil erosion and deposition The validity and potential of this approach has now been demonstrated by numerous studies undertaken in a range of environments in many parts of the world, but there is still a need for further development, refinement and standardisation of the procedures used and for exploring additional applications.

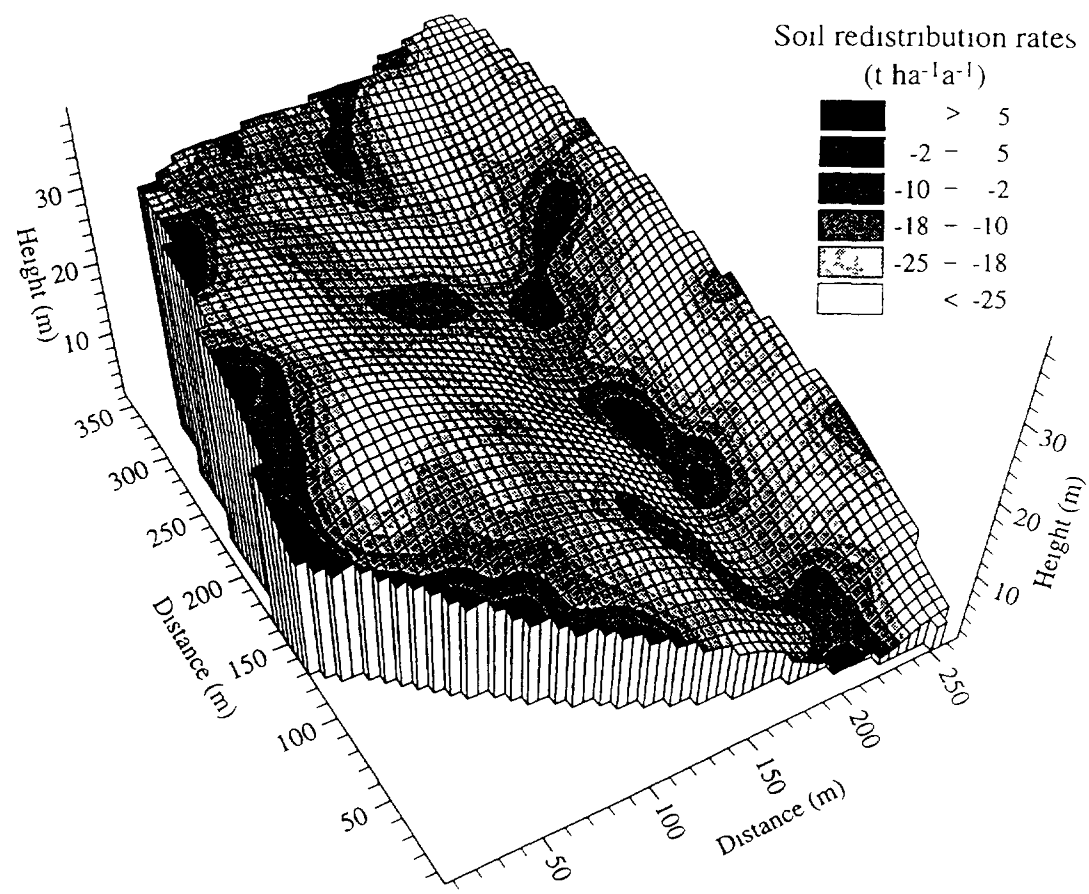

FIG. 8. Long-term soil redistribution rates within a field at Butsford Barton, near Colebrooke, Devon, UK, estimated from the unsupported ^{210}Pb inventory data presented in Fig. 7.

The use of other fallout radionuclides, including unsupported ^{210}Pb and ^{7}Be in soil-erosion investigations has attracted much less attention, but there is increasing evidence that they again offer considerable potential for use in soil-erosion investigations, both in their own right and as a complement to ^{137}Cs. Further work to explore and exploit this potential is clearly required

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REFERENCES

[1] BROWN, L R , "Conserving soils", State of the World, 1984 (BROWN, L R , Ed), Norton, New York (1984)

[2] ISRIC, World Map of the Status of Human-Induced Soil Degradation Global Assessment of Soil Degradation, ISRIC, Wageningen (1992)

[3] BURINGH, P , An Assessment of Losses and Degradation of Productive Agricultural Land in the World, Food and Agricultural Organization of the United Nations, Rome (1981)

[4] PIMENTEL, D , et al , "Soil erosion and agricultural productivity", World Soil Erosion and Conservation (PIMENTEL, D , Ed), Cambridge University Press (1993)

[5] BROWN, L R , YOUNG, J E , "Feeding the world in the nineties", State of the World, 1990 (BROWN, L R , et al Eds) , Norton, New York (1990)

[6] MAHMOOD, K , Reservoir Sedimentation Impact, Extent and Mitigation, The World Bank, Washington DC (1987)

[7] LOUGHRAN, R J , The measurement of soil erosion, Prog, Phys Geogr **13** (1990) 216-233

[8] EVANS, R , Some methods of directly assessing water erosion of cultivated land - a comparison of measurements made on plots and in fields, Prog Phys Geogr **19** (1995) 115-129

[9] RITCHIE, J C , et al , Estimating soil erosion from the redistribution of fallout ^{137}Cs, Soil Sci Soc Am Proc **38** (1974) 137-139

[10] WALLING, D E , QUINE, T A , The use of caesium-137 measurements to investigate soil erosion on arable fields in the UK potential applications and limitations, J Soil Sci **2** (1991) 147-165

[11] WALLING, D E , QUINE, T A , "The use of caesium-137 measurements in soil erosion surveys", Erosion and Sediment Transport Monitoring Programmes in River Basins (Proc Symp Oslo, 1992) International Association of Hydrological Sciences Publication No 210, IAHS Press, Wallingford, UK (1992) 143-152

[12] LOUGHRAN, R J et al , Estimation of soil erosion from caesium-137 measurements in a small cultivated catchment in Australia, J Appl Radiat Isot **39** (1988) 1153-1157

[13] SUTHERLAND, R A Caesium-137 estimates of erosion in agricultural areas, Hydrol Process **6** (1992) 215-225

[14] PENNOCK, D J et al , Caesium-137 measured erosion rates for five parent-material groups in southwestern Sakatchewan Canadian J Soil Sci **75** (1995) 205-210

[15] WALLING, D E , QUINE, T A , Calibration of caesium-137 measurements to provide quantitative erosion rate data, Land Degrad Rehabilitat **2** (1990) 161-175

[16] QUINE, T A "Estimation of erosion rates from caesium-137 data the calibration question", Sediment and Water Quality in River Catchments (FOSTER, I D L , GURNELL, A M , WEBB, B W Eds), Wiley, Chichester (1995) 307-329

[17] EVANS, R , COOK, S , Soil erosion in Britain, Seesoil **3** (1986) 28-59

[18] QUINE, T A , et al , "Investigation of soil erosion on terraced fields near Yanting, Sichuan Province, China, using caesium-137", Erosion, Debris Flows and Environment in Mountain Regions (Proc Symp Chengdu, 1992), International Association of Hydrological Sciences Publication No 209, IAHS Press, Wallingford, UK (1992) 155-168

[19] DE ROO, A P J , et al , Soil erosion modelling using 'ANSWERS and Geographical Information Systems Earth Surf Proc Landforms **14** (1989) 517-532

[20] ROGOWSKI, A S , TAMURA, T , Erosional behaviour of cesium-137, Health Phys **18** (1970) 467-477

[21] HASHOLT, B , WALLING, D E , "Use of caesium-137 to investigate sediment sources and sediment delivery in a small glacierized mountain drainage basin in eastern Greenland", Erosion, Debris Flows and Environment in Mountain Regions (Proc Symp Chengdu, 1992), International Association of Hydrological Sciences Publication No 209, IAHS Press, Wallingford, UK (1992) 87-100

[22] STROMQUIST, L , et al , Testing ^{137}Cs as an indicator of slope process activity in periglacial environments, Stud Geomorphol Carpatho-Balcanica **23** (1989) 93-104

[23] SUTHERLAND, R A , DE JONG, E , Estimation of sediment redistribution within agricultural fields using caesium-137, Crystal Springs, Saskatchewan, Canada, Appl Geogr **10** (1990) 205-221

[24] PENNOCK, D J et al , Cesium-137 measured erosion rates for five parent-material groups in southwestern Sakatchewan, Can J Soil Sci **75** (1995) 205-210

[25] KACHANOSKI, R G , Estimating soil loss from changes in soil cesium-137 Can J Soil Sci **73** (1993) 515-526

[26] OSTROVA, I V et al , Assessing the intensity of erosional accumulation processes by the content of caesium-137 in soils Geografiya **5** (1990) 79-85 (in Russian)

[27] NAVAS, A , WALLING, D E "Using caesium-137 to assess sediment movement on slopes in a semiarid upland environment in Spain", Erosion, Debris Flows and Environment in Mountain Regions (Proc Symp Chengdu, 1992), International Association of Hydrological Sciences Publication No 209, IAHS Press, Wallingford, UK (1992) 129-138

[28] KULANDER, L , STROMQUIST, L , Exploring the use of top-soil ^{137}Cs content as indicator of sediment transfer rates in a small Lesotho catchment, Z Geomorph N F **33** (1989) 455-456

[29] FORSYTH, T J , The use of caesium-137 measurements of soil erosion and farmers' perceptions to indicate land degradation amongst shifting cultivators in Northern Thailand, Mt Res Develop **14** (1994) 229-244

[30] WALLING, D E , QUINE, T A , Use of Caesium-137 as a Tracer of Erosion and Sedimentation Handbook for the Application of the Caesium-137 Technique, Report to the UK Overseas Development Administration (1993)

[31] RITCHIE, J C , RITCHIE, C A , "Bibliography of publications of ^{137}Cs studies related to erosion and sediment deposition", Use of Nuclear Techniques in Studying Soil Erosion and Siltation, International Atomic Energy Agency TECDOC-828, IAEA, Vienna, Austria (1995) 125-201

[32] LARSEN, R J , Worldwide Deposition of ^{90}Sr through 1983, United States Department of Energy, New York (1985) 160pp

[33] LOUGHRAN, R J et al , "A reconnaissance survey of soil erosion in Australia", Proc 7th ISCO Conf , Sydney, Sept 1992, Vol 1 (1992) 143-152

[34] QUINE, T A , et al , "An investigation of the influence of edaphic, topographic and land-use controls on soil erosion on agricultural land in the Borrowdale and Chinamora areas, Zimbabwe, based on caesium-137 measurements", Sediment Problems Strategies for Monitoring, Prediction and Control (Proc Symp Yokohama, 1993}, International Association of Hydrological Sciences Publication No 217, IAHS Press, Wallingford, UK (1993) 185-196

[35] HIGGITT, D L , et al , Catchment-scale deposition and redistribution of Chernobyl radiocaesium in upland Britain, Environ Internat **19** (1993) 155-166

[36] OWENS, P , WALLING, D E , Spatial variability of caesum-137 inventories at reference sites An example from two contrasting sites in England and Zimbabwe, Appl Radiat Isot (1996) (in press)

[37] WALLBRINK, P J , et al , "Measuring soil movement using ^{137}Cs implications of reference site variability", Variability in Stream Erosion and Transport (Proc Symp Canberra, 1994), International Association of Hydrological Sciences Publication No 224, IAHS Press, Wallingford, UK (1994) 95-102

[38] SUTHERLAND, R A , Spatial variability of ^{137}Cs and the influence of sampling on estimates of sediment redistribution, Catena **21** (1994) 57-71

[39] LIVENS, F R , LOVELAND, P J , The influence of soil properties on the environmental mobility of caesium in Cumbria, Soil Use Manage **4** (1988) 69-75

[40] LIVENS, F R , BAXTER, M S , Chemical associations of artificial radionuclides in Cumbrian soils J Environ Radioact **9** (1988) 75-86

[41] BACHHUBER, H , et al , The migration of ^{137}Cs ^{90}Sr in multilayered soils Results from batch, column and fallout investigations, Nucl Technol **59** (1982) 291-301

[42] FRISSEL, M J , PENNDERS, R "Models for the accumulation and migration of ^{90}Sr, ^{137}Cs, $^{923\ 240}$Pu and ^{241}Am in the upper layers of soils", Ecological Aspects of Radionuclide Release (COUGHTREY, P J , Ed), Blackwell Scientific, Oxford (1983) 63-72

[43] CAWSE, P A , HORRILL, A D , A Survey of Caesium-137 and Plutonium in British Soils in 1977, Rep R-10155, UKAEA Atomic Energy Research Establishment, Harwell (1977)

[44] FOSTER, G R et al , Sediment composition for nonpoint source pollution analyses, Trans Am Soc Ag Engrs **28** (1985) 133-139,146

[45] MENZEL, R G , "Enrichment ratios for water quality modelling", CREAMS-A field scale model for chemicals *runoff and erosion from agricultural management systems*, Vol III Supporting Information, US Dept Agric Conservation Research Report 26 (1980) 486- 492

[46] HE,Q , WALLING, D E , Interpreting particle size effects in the adsorption of ^{137}Cs and unsupported ^{210}Pb by mineral soils and sediments, J Environ Radioactivity **30** (1996) 117-137

[47] ELLIOTT, G L et al , Correlation of of erosion measurements and soil caesium-137 content Appl Radiat Isot **39** (1990) 1153-1157

[48] McINTYRE, S C et al , "Long-term Cs-137 and soil loss from field plots", Proc 5th Federal Interagency Sedimentation Conf , 1991 (1991) 5 33-5 39

[49] QUINE, T A , WALLING, D E , "Assessing recent rates of soil loss from areas of arable cultivation in the UK", Farm Land Erosion in Temperate Plains Environment and Hills (WICHEREK, S , Ed), Elsevier, Amsterdam (1993) 357-371

[50] DALGLEISH, H Y , FOSTER, I D L , 137Cs losses from a loamy surface water gleyed soil (Inceptisol), a laboratory simulation experiment Catena 26 (1996) 227-245

[51] OWENS, P N et al , The behaviour of bomb-derived caesium-137 fallout in catchment soils, J Environ, Radioactivity **32** (1996) 169-191

[52] WALLING, D E , WOODWARD, J C , "Use of radiometric fingerprints to derive information on suspended sediment sources", Erosion and Sediment Transport Monitoring Programmes in River Basins (Proc Symp Oslo, 1992), International Association of Hydrological Sciences Publication No 210, IAHS Press, Wallingford, UK (1992) 329-338

[53] MURRAY, A S et al , "Tracing the source of suspended sediment in the Murrumbidgee River, Australia", Tracers in Hydrology (Proc Symp Yokohama, 1993), International Association of Hydrological Sciences Publication No 215, IAHS Press, Wallingford, UK (1993) 293-302

[54] LUNDEN, B et al , "An evaluation of soil erosion intensity mapping from SPOT satellite imagery by studies of colour air-photos and top-soil content of 137-cesium", Monitoring Soil Loss at Different Observation Levels Case Studies of Soil Erosion in the Lesotho Lowlands (STROMQUIST, L Ed), UNGI Rep No 74, Naturgeografiska Institutionen, Uppsala Universitet (1991) 89pp

[55] QUINE, T A et al , " The role of tillage in soil redistribution within terraced fields on the loess plateau, China An investigation using caesium-137", Proc Int Symp on Runoff and Sediment Yield Modelling (BANASIK, K , ZBIKOWSKI, A , Eds), Warsaw Agricultural University Press, Warsaw (1993) 149-155

[56] QUINE, T A et al , "A comparison of the roles of tillage and water erosion in landform development on agricultural land near Leuven, Belgium", Variability in Stream Erosion and Sediment Transport (Proc Symp Canberra, 1994) International Association of Hydrological Sciences Publication No 224, IAHS Press, Wallingford, UK (1994) 77-86

[57] SUTHERLAND, R A et al , Cesium-137 estimates of sediment redistribution by wind, Soil Sci **151** (1991) 387-396

[58] DE ROO, A P J , Modelling Surface Runoff and Soil Erosion in Catchments Using Geographical Information Systems, Netherlands Geographical Studies No 157, University of Utrecht, Utrecht (1993) 295pp

[59] DE ROO, A P J , WALLING, D E , "Validating the ANSWERS soil erosion model using ^{137}Cs", Conserving Soil Resources, European Perspectives(RICKSON, R J Ed), CAB International, Wallingford (1995) 246-263

[60] WALLING, D E , BRADLEY, S B , "The use of caesium-137 measurements to investigate sediment delivery from cultivated areas in Devon, UK", Sediment Budgets (Proc Symp Porto Alegre, 1988), International Association of Hydrological Sciences Publication No 174, IAHS Press, Wallingford, UK (1988) 325-335

[61] WALLING, D E , WOODWARD, J C , Tracing sources of suspended sediment in river basins A case study of the River Culm, Devon, UK, Marine and Freshwater Res **46** (1995) 327- 336

[62] WALLING, D.E. et al., "A multi-parameter approach to fingerprinting suspended sediment sources". Tracers in Hydrology (Proc. Symp. Yokohama, 1993), International Association of Hydrolocial Sciences Publication No. 215, IAHS Press, Wallingford, UK (1993) 329-338.

[63] WALLING, D.E., HE, Q., "Use of cesium-137 as a tracer in the study of rates and patterns of floodplain sedimentation", Tracers in Hydrology (Proc. Symp. Yokohama, (1993), International Association of Hydrological Sciences Publication No. 215, IAHS Press, Wallingford, UK (1993) 319-328..

[64] WALLING, D.E., et al., "Rates and patterns of contemporary floodplain sedimentation", Lowland Floodplain Rivers:Geomorphological Perspectives (CARLING, P.A., PETTS, G.E. Eds), Wiley, Chichester (1992) 185-202.

[65] APPLEBY, P.G., et al., ^{210}Pb dating by low background gamma counting, Hydrobiologia 142 (1986) 21-27.

[66] JOSHI, S.R., Nondestructive determination of lead-210 and radium-226 in sediments by direct photon analysis, J. Radioanal. Nucl. Chem. **116** (1987) 169-182,

[67] WALLING, D.E., QUINE, T.A., "Use of fallout radionuclide measurements in soil erosion investigations", Nuclear Techniques in Soil-Plant Studies for Sustainable Agriculture and Environmental Preservation (Proc. Symp. Vienna, 1994), IAEA Publication STI/PUB/947 International Atomic Energy Agency, Vienna, {1995) 597-619.

[68] WALLING, D.E. et al., "Use of caesium-137 and lead-210 as tracers in soil erosioninvestigations", Tracer Technologies for Hydrological Systems (Proc. Symp.Boulder, (1995), International Association of Hydrological Sciences Publication No. 229, IAHS Press, Wallingford, UK (1995) 163-172.

[69] BURCH, G.J. et al., "Detection and prediction of sediment sources in catchments: Use of ^{7}Be and ^{137}Cs", Proc. Symp. on Hydrology and Water Resources, Canberra, ACT, Feb.1988, Australian National University, Canberra, ACT (1988) 146-151.

[70] WALLBRINK, P.J., MURRAY, A.S., "The use of fallout radionuclides as indicators of surface and subsoils", Paper presented at the Workshop on Environmental Radioactivity and Radionuclide Measurement, Adelaide, Australia, 1990.

[71] WALLBRINK, P.J., MURRAY, A.S., Distribution and variability of ^{7}Be in soils under different surface cover conditions and its potential for describing soil redistribution processes, Wat. Resour. Res. **32** (1996) 467-476.

BIBLIOGRAPHY[1] OF PUBLICATIONS OF ^{137}Cs STUDIES RELATED TO SOIL EROSION AND SEDIMENT DEPOSITION

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Abstract

BIBLIOGRAPHY OF PUBLICATIONS OF ^{137}Cs STUDIES RELATED TO SOIL EROSION AND SEDIMENT DEPOSITION.

This bibliography of some 1,600 citations presents significant publications as background for studies on soil erosion and sediment deposition. The ^{137}Cs technique, allows measurements of soil redistribution to be made quickly and efficiently, and we hope that this document will promote its use in planning strategies for landscape conservation.

1. INTRODUCTION

Soil erosion and its subsequent redeposition across the landscape is a major concern around the world. A quarter-century of research has shown that measurements of the spatial patterns of radioactive fallout caesium-137 can be used to measure soil erosion and sediment deposition on the landscape. By understanding the background for using the ^{137}Cs, scientists can obtain unique information to help in planning techniques to conserve the quality of the landscape. Research should continue on the development of the technique so that it can be used more extensively to understand the changing landscape.

On 16 July 1945 at 1230 Greenwich Civil Time, nuclear weapons tests were begun, releasing ^{137}Cs and other radioactive nuclides into the stratosphere. Over the 50 years since that first test, much research has been done to understand the movement and fate of ^{137}Cs in the global environment. Many of these studies are critical for understanding the application of ^{137}Cs to the study of soil erosion and the subsequent redeposition of the eroded particles on the land. This bibliography presents significant publications as background information for studies employing ^{137}Cs as a research tool, and includes citations on the application of ^{137}Cs technology to measure either soil erosion or sediment deposition.

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[1] Updated March 1, 1997

Although this collection is extensive, it is probable that some citations are missing. There has been a rapid increase in the number of publications on the use of ^{137}Cs in studies of erosion and sedimentation (Fig. 1), demonstrating the acceptance and widespread use the technique. We hope that this bibliography will further promote the technique, and assist those using or preparing to use ^{137}Cs in research on erosion and sediment deposition, for landscape preservation.

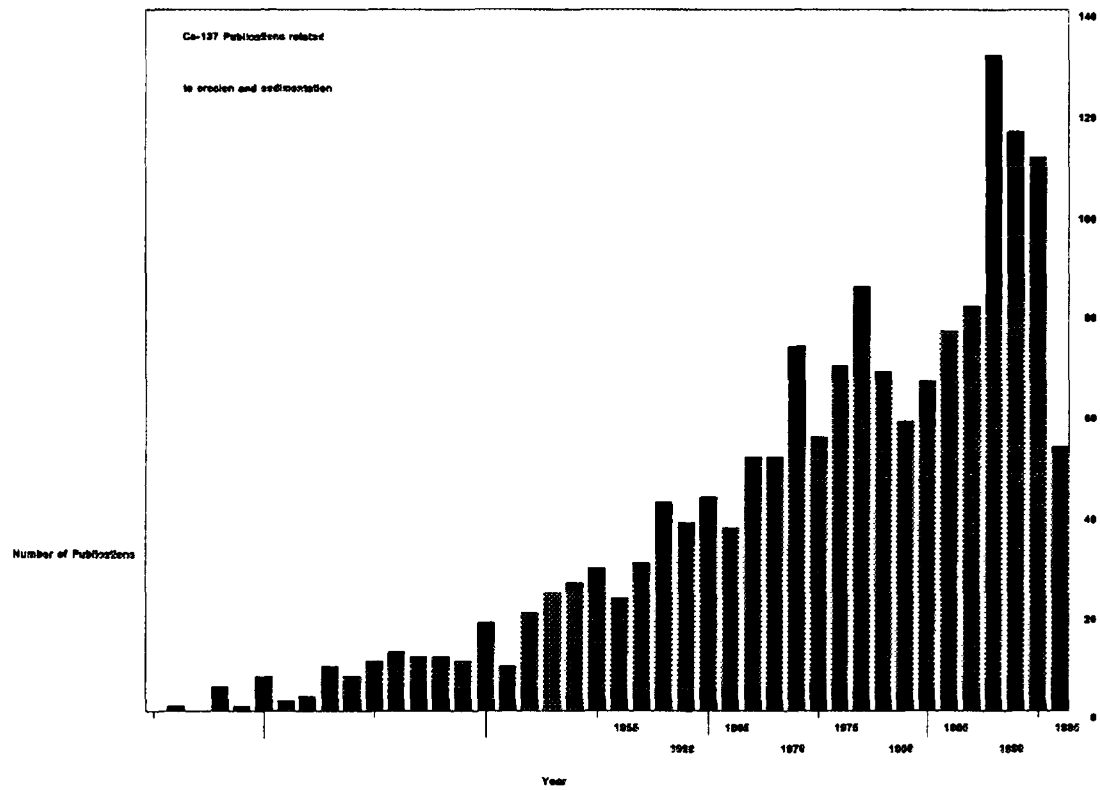

FIG. 1. Cumulative publications of ^{137}Cs related to soil erosion and sedimentation.

BIBLIOGRAPHY

Aarkog, A., G. Dal'gaardt, L. Hallstadius, H. Hansen, and E. Holm. 1983. Radiocesium from Sellafield effluents in Greenland water. Nat. 304:49-51.

Aarkog, A., G. Dal'gaardt, E.N. Karavaeva, N.V. Kulikov, K. Mittenar, I.V. Milchanov, S.P. Nil'sen, V.N. Pozolotina, and G.G. Polikarpov. 1992. Long-lived radionuclide concentration in the soil and trees in nuclear accident area in the southern Urals. Ekologiya 4:50-55. (Russian)

Absalom, J. P., N.M.J. Crout, and S.D. Young. 1996. Modeling radiocesium fixation in upland organic soils of northw est England. Environ. Sci. Technol. 30:2735-2741.

Absalom, J.P., S.D. Young and N.M.J. Crout. 1995. Radio-caesium fixation dynamics: Measurement in six Cumbrian soils. Eur. J. Soil Sci. 46:461-469.

Abril, J.M. and M. García-Leon. 1992. Modelos mathem<ticos en radiogeocronología. Anales de Física A 87:82-91. (Spanish)

Abril, J.M. and M. García-Leon. 1994. The integrated atmospheric flux effect in a radiogeochronological model. J. Environ. Radioact. 24:65-79.

Abril, J.M., M. García-Leon, R. García-Tenorio, C.I. Sánchez, and F. El-Daoushy. 1992. Dating of marine sediments by an incomplete mixing model. J. Environ. Radioact. 15:135-151.

Ackermann, F., H. Bergmann, and U. Schlieichert. 1983. Monitoring of heavy metals in coastal and estuarine sediments - A question of grain-size: <20 Fm versus <60 Fm. Environ. Tech. Lett. 4:317-328.

Adriano, D., G.D. Hoyt, and J.E. Pinder III. 1981. Fallout cesium-137 on a forest ecosystem in the vicinity of a nuclear reprocessing plant. Health Phys. 40:369-376.

Agapkina, G.I., F.A. Tikhomirov, A.I. Shcheglov, W. Kracke, and K. Bunzl. 1995. Association of Chernobyl-derived Pu-239+240, Am-241, Sr-90 and Cs-137 with organic matter in the soil solution. J. Environ. Radioact. 29:257-269.

Agre, A.L. and V.I. Korogodin. 1960. The distribution of radioactive contamination in a stagnant reservoir. Medical Radiology 5:161-175.

Aharoni, C., N.S. Pasricha, and D.L. Sparks. 1992. Adsorption and desorption kinetics of cesium in an organic matter-rich soil saturated with different cations. Soil Sci. 156:233-239.

Alberts, J.J., J.W. Bowling, and K.A. Orandini. 1987. The effect of seasonal anoxia on the distribution of ^{238}Pu, ^{239,240}Pu, ^{241}Am, ^{244}Cm, and ^{137}Cs in pond systems of the southeastern United States, pp. 371-390. *In:* J.E. Pinder, III, J.J. Alberts, K.W. McLeod and R.G. Schreckize (eds.), Environmental Research on Actinide Elements, US Department of Energy CONF-841142, Washington, DC.

Alberts, J.J. and R.N. Muller. 1979. The distribution of ^{239,240}Pu, ^{238}Pu, and ^{137}Cs in various particle size classes of Lake Michigan sediments. J. Environ. Qual. 8:20-22.

Alberts, J.J., L.J. Tilly, and T.J. Virgerstad. 1979. Seasonal cycling of cesium-137 in a reservoir. Science 203:649-651.

Alberts, J.J. and M.A. Wahlgren. 1984. Concentration of ^{239,240}Pu, ^{137}Cs, and ^{90}Sr in the waters of the Laurentian Great Lakes. Comparison of 1973 and 1976 values. Environ. Sci. Tech. 15:94-98.

Alberts, J.J., M.A. Wahlgren, K.A. Orlandini, and C.A. Durbahn. 1989. The distribution of ^{239,240}Pu, ^{238}Pu, ^{241}Am and ^{137}Cs among chemically-defined components of sediments, settling particles and net plankton of Lake Michigan. J. Environ. Radioact. 9:89-103.

Albrecht, A., P. Reichert, J. Beer, and A. Luck. 1995. Evaluation of the importance of reservoir sediments as sinks for reactor-derived radionuclides in riverine systems. J. Environ. Radioact. 28:239-269.

Aleksan'yan, O.M. 1978. A study of the vertical distribution of ^{90}Sr, and ^{137}Cs in bottom sediments of a sea of Azov, USSR. Ekologiya 5:95-97. (Russian)

Aleksan'yan, O.M. and Y.Y Katsnel'son. 1979. Radioactive pollution of bottom sediments and its prevention. Soviet J. Ecol. 10:243-245.

Alexander, C.R., R.G. Smith, F.D. Calder, S.J. Schropp, and H.L. Windom. 1993. The historical record of metal enrichment in two Florida estuaries. Estuar. 16:627-637.

Alhonen, P. 1979. The sedimentary record of the cultural eutrophication and pollution of lakes in Finland. Arch. Hydrobiologia 86:13-26.

Aliyev, D.A., M.A. Abdullayev, and A.T. Tagiyev. 1977. Distribution of Sr^{90} and Cs^{137} in plowed soils of the dry (subtropical) steppe zone of the lesser Caucasus in the Azerbaijan SSR. Pochvovedeniye 7:34-35.

Allan, R.L., G.T. Cook, H.J. Duncan, A.B. MacKenzie, and I.D. Pulford. 1995. Pollutant radionuclide geochemistry in salt marsh sediments. Contaminated soil '95: Volume 1: Proceedings of the Fifth International FZK/TNO Conference on Contaminated Soil, 30 October-3 November, 1995, Maastricht, The Netherlands, p.721-722.

Alldredge, A.W. and F.W. Whicker. 1972. A method for measuring soil erosion and deposition with beta particle attenuation. J. Range Manage. 25:393-398.

Allison, R.J. 1992. Slopes and slope processes: review. Prog. Phys. Geol. 15:423-427.

Anderson, E.C. 1958. Radioactivity of people and milk: 1957. Science 128:882-886.

Anderson, N.J. 1989. A whole-basin diatom accumulation rate for a small eutrophic lake in Northern Ireland and its palaeoecological implications. J. Ecol. 77:926-946.

Anderson, N.J. 1990. Variability of diatom concentrations and accumulation rates in sediment of a small lake basin. Limnol. Oceanogr. 35:497-508.

Anderson, N.J. and B.V. Odgaard. 1994. Recent paleoliminology of three shallow Danish Lakes. Hydrobiologia 275/276:411-422.

Anderson, R.F., S.L. Schiff, and R.H. Hesslein. 1987. Determining sediment accumulation and mixing rates using ^{210}Pb, ^{137}Cs and other tracers: problems due to postdepositional mobility or coring artifacts. Can. J. Fish. Aquat. Sci. 44:231-250.

Andersson, I. and H. Lonsjo. 1988. Transfer of Cs-137 in two farm ecosystems. Swedish J. Agric. Res. 18:195-206.

Andersson, K.G. and J. Roed. 1994. The behaviour of Chernobyl Cs-137, Cs-134 and Ru-106 in undisturbed soil - Implications for external radiation. J. Environ. Radioact. 22:183-196.

Anisimov, V.S., N.I. Sanzharova, and R.M. Aleksakhin. 1992. On the forms and vertical distribution of ^{137}Cs in soils near the accident at the Chernobyl nuclear power station. Eurasian Soil Sci. 24:1-10. (Translated from Pochvovedeniye 9:31-40, 1991)

Anonymous. 1988. Proceedings of the national workshop on the use of ^{137}Cs to measure erosion. Soil Conservation Service of New South Wales, Sydney, Australia, 24 pp.

Anonymous. 1995. Sediment dating. Bulletin of the Geological Survey of Japan, Vol. 46, No. 5, Japan, 58pp. (In Japanese)

Anonymous 1995. Sediment dating. Bulletin of the Geological Survey of Japan, Vol. 46, No. 6, Japan, 67pp. (In Japanese)

Anspaugh, L.R., R.J. Catlin, and M. Goldman. 1988. The global impact of the Chernobyl reactor accident. Science 242:1513-1519.

Antonopoulos-Domis, N, A. Clouvas, A. Hiladak, and S. Kadi. 1995. Radiocesium distribution in undisturbed soil: Measurements and diffusion-advection model. Health Phys. 69:949-953.

Aoyama, M. and K. Hirose. 1995. The temporal and spatial variation of ^{137}Cs concentration in the Western North Pacific and its marginal seas during the period from 1979 to 1988. J. Environ. Radioact. 29(1):57-74.

Appleby, P.G., J.A. Dearing, and F. Oldfield. 1985. Magnetic studies of erosion in a Scottish lake catchment. 1. Core chronology and correlation. Limnol. Oceanogr. 30:1144-1153.

Appleby, P.G., V.J. Jones, and J.C. Ellis-Evans. 1995. Radiometric dating of lake sediment from Signy Island (maritime Antarctic): evidence of recent climatic change. J. Paleolimnol. 13:179-191.

Appleby, P.G. and F. Oldfield. 1978. The calculation of lead-210 dates assuming a constant rate of supply of unsupported lead-210 to the sediment. Catena 5:1-8.

Appleby, P.G. and F. Oldfield. 1979. Correspondence. Environ. Sci. Tech. 13:478-490.

Appleby, P.G. and F. Oldfield. 1983. The assessment of ^{210}Pb data from sites with varying sediment accumulation rates. Hydrobiologia 103:29-35.

Appleby, P.G., F. Oldfield, R. Thompson, and P. Huttunen. 1978. ^{210}Pb dating of annually laminated lake sediments from Finland. Nature 280:53-55.

Appleby, P.G., N. Richardson, and P.J. Nolan. 1991. ^{241}Am dating of lake sediment. Hydrobiologia 214:35-42.

Appleby, P.G., N. Richardson, P.J. Nolan, and F. Oldfield. 1990. Radiometric dating of the United Kingdom SWAP sites. Phil. Trans. R. Soc. London B 327:233-238.

Appleby, P.G. and J.T. Smith 1993. The transport of radionuclides in lake-catchment systems, pp. 264-275. *In*: Hydrological considerations in relation to nuclear power plants, Proceedings of an International Workshop, UNESCO, Paris.

Arapis, G., E, Petrayev, E. Shagalova, O. Zhukova, G. Sokolik, and T. Ivanova. 1997. Effective migration velocity of ^{137}Cs and ^{90}Sr as a function of the type of soils in Belarus. J. Environ. Radioact. 34(2):171-185.

Armentano, T.V. and G.M. Woodwell. 1975. Sedimentation rates in a Long Island marsh determined by ^{210}Pb dating. Limnol. Oceanogr. 20:452-455.

Armstrong, N.E. and E.F. Gloya. 1969. Mathematical models for the dispersion of radionuclides in aquatic systems, pp. 329-335. *In*: D.J. Nelson and F.C. Evans (eds.), Symposium on radioecology, USAEC Doc. CONF-670503, US Atomic Energy Agency, Washington, DC.

Arnalds, O., N.H. Cutshall, and G.A. Nielsen. 1989. Cs-137 in Montana soils. Health Phys. 57:955-958.

Ashley, G.M. 1977. Sedimentology of a tidal river, Pitt River, B.C. Ph.D. Thesis, Univ. of British Columbia, Vancouver, BC.

Ashley, G.M. and L.E. Moritz. 1979. Determination of lacustrine sedimentation rates by radioactive fallout (^{137}Cs), Pitt Lake, British Columbia. Can. J. Earth Sci. 16:965-970.

Ashwood, T.L. and C.R. Olsen. 1988. Pearl Harbor bombing attack: a contamination legacy revealed in the sedimentary record. Marine Pollut. Bull. 19:68-71.

Askbrant, S., J. Melin, J. Sandalls, G. Rauret, R. Vallejo,T. Hinton, A. Cremers, C. Vandecastelle, N. Lewyckyj, Y.Y. Ivanov, S.K. Firsakova, N.P. Arkhipov, and R.M. Alexakhin. 1996. Mobility of radionuclides in undisturbed and cultivated soils in Ukraine, Belarus and Russia six years after the Chernobyl fallout. J. Environ. Radioact. 31:287-312.

Assinder, D.J., M. Kelly, and S.R. Aston. 1985. Tidal variations in dissolved and particulate phase radionuclide activities in the Esk estuary and their distribution coefficients and particulate activity fraction. J. Environ. Radioact. 2:1-22.

Assimakopoulos, P.A., K.G. Ioannides, D.T. Karamanis, A.A. Pakou, K.C. Stamoulis, A.S. Mantzios, and E. Nikolaou. 1993. Radiocaesium transfer to sheep's milk as a result of soil ingestion. Sci. Total Environ. 136:13-24.

Assimakopoulos, P.A., K.G. Ioannides, D.T. Karamanis, A.A. Pakou, K.C. Stamoulis, A. Vayonakis, and E. Veltsos. 1993. Time dependence of the transfer factor of Cs-137 from surface soil to plants. Sci. Total Environ. 138:309-315.

Aston, S.R. and E.K. Duursma. 1973. Concentration effects of ^{137}Cs, ^{65}Zn, ^{60}Co, and ^{106}Ru sorption by marine sediments with geochemical implications. Neth. J. Sea Res. 6:225-240.

Aston, S.R. and J.E. Rae. 1982. The deposition of Windscale radiocaesium in the Wyre Estuary and the measurement of sedimentation rates. Marine Environ. Res. 7:83-90.

Aston, S.R. and D.A. Stanners. 1979. The determination of estuarine sedimentation rates by ^{134}Cs/^{137}Cs and other artificial radionuclide profiles. Estuar. Coast. Marine Sci. 9:529-541.

Aston, S.R. and D.A. Stanners. 1982a. Gamma emitting fission products in surface sediments of the Ravenglass estuary. Mar. Pollut. Bull. 13:135-138.

Aston, S.R. and D.A. Stanners. 1982b. Local variability in the distribution of Windscale fission products in estuarine sediments. Estuar. Coast. Shelf Sci. 14:167-174.

Auerbach, S.I., J.S. Olson, and H.D. Waller. 1964. Landscape investigations using cesium-137. Nature 201:761-764.

Autenreith, R.L., J.S. Bonnet, and L. Schriebel. 1991. Aquatic sediment. Res. J. Water 63:709-725.

Authur, W.J. 1982. Radionuclide concentration in vegetation at a radioactive waste-disposal area in southern Idaho. J. Environ. Qual. 11:394-399.

Avnimelech, Y., J.R. McHenry, and J.D. Ross. 1984. Decomposition of organic matter in lake sediment. Environ. Sci. Tech. 18:5-11.

Axelman, J., C. Bandh, D. Broman, R. Carman, P. Jonsson, H. Larsson, H. Linder, C. Naf, and H. Pettersen. 1995. Time-trend analysis PAH and PCB sediment fluxes in the northern Baltics Proper using different dating methods. Mar. Freshwater Res. 46:137-144.

Bachhuber, H., K. Bunzl, and W. Schimmack. 1986. Spatial variability of distribution coefficients of ^{137}Cs, ^{65}Zn, ^{85}Sr, ^{57}Co, ^{109}Cd, ^{141}Ce, ^{103}Ru, ^{95m}Tc, and ^{131}I in cultivated soil. Nucl. Tech. 72:359-371.

Bachhuber, H., K. Bunzl, and W. Schimmack. 1987. Spatial variability of fallout ^{137}Cs in the soil of a cultivated field. Environ. Monit. Assessment 8:93-101.

Bachhuber, H., K. Bunzl, W. Schimmack, and I. Gans. 1982. The migration of ^{137}Cs and ^{90}Sr in multilayered soils: results from batch, column, and fallout investigations. Nucl. Tech. 59:291-301.

Baeza, A., M. Delrio, C. Miro, and J. Paniagua. 1993. Surface and depth fallout distribution of Cs-137 and Sr-90 in soils of Caceres (Spain) - Dose commitments due to external irradiation. J. Radiat. Nucl. Lett. 175:297-316.

Bakunov, N.A. and N.P. Arkhipov. 1995. Behavior of Sr-90 and Cs-137 of weapons and reactor origin in the soil-plant system. Eurasian Soil Sci. 27:40-52.

Balgoeva, R. and L. Zikovsky. 1995. Geographic and vertical distribution of Cs-137 in soils in Canada. J. Environ. Radioact. 27:269-274.

Baltakmens, T. and L.P. Gregory. 1977. Profile of ^{90}Sr and ^{137}Cs concentrations in selected New Zealand soils and their bearing on milk contamination levels. N.Z. J. Sci. 20:425-431.

Barber, D.A. 1964. Influence of soil organic matter on the entry of caesium-137 into plants. Nature 204:1326-1327.

Barbeau, C., R. Bougie, and J.E. CotJ. 1981. Variations spatiales et temporelles du cJsium-137 et du carbone dans des sJdiments du fjord du Saguenay. Can. J. Earth Sci. 18:1004-1011. (French)

Barnaby, F. 1986. Chernobyl: the consequences in Europe. Ambio 15:332-334.

Basher, L.R. and K.M. Matthews. 1993. Relationship between ^{137}Cs in some undisturbed New Zealand soils and rainfall. Aust. J. Soil Res. 31:655-663.

Basher, L.R., K.M. Matthews, and L. Zhi. 1995. Surface erosion assessment in the South Canterbury downlands, New Zealand using Cs-137 distribution. Aust. J. Soil Res. 33:787-803.

Baskaran, M., S. Asbill, P. Santschi, J. Brooks, M. Champ, D. Adkinson, M.R. Colmer, and V.P. Makeyev.1996. ^{137}Cs and excess ^{210}Pb in Russian Arctic sediments. Earth and Planetary Sci. Letters 140:243-257.

Baskaran, M., J.J. Kelley, A.S. Naidu, and D.F. Holleman. 1991. Environmental radiocesium in subarctic and arctic Alaska following Chernobyl. Arctic 44:346-350.

Battaglia, A., D. Capra, L. Guzzl, and W. Martinotti. 1996. ^{137}Cs and naturally occurring radionuclides as a tool for sedimentation study in river reservoirs. International Conference on Reservoir Sedimentation 1996 pp. 217-232.

Battarbee, R.W. 1978. Observations on the recent history of Lough Neagh and its drainage basin. Phil. Trans. R. Soc. London B 281:303-345.

Battarbee, R.W. 1984. Diatom analysis and acidification of lakes. Phil. Trans. R. Soc. London B 305:451-477.

Battarbee, R.W. 1986. The eutrophication of Lough Erne inferred from changes in diatom assemblages of ^{210}Pb- and ^{137}Cs-dated sediment cores. Proc. R. Irish Acad. 86B:141-168.

Battarbee, R.W. and G. Digerfeldt. 1976. Palaeoecological studies of recent developments of Lake Växjösjön. I. Introduction and chronology. Arch. Hydrobiologia. 77:330-326.

Battarbee, R.W., G. Digerfeldt, P. Appleby, and F. Oldfield. 1980. Palaeoecological studies of recent developments of Lake Växjösjön . III. Reassessment of recent chronology on the basis of modified ^{210}Pb dates. Arch. Hydrobiologia. 89:440-446.

Battiston, G.A., S. Degetto, R. Gerbasi, and G. Sbrignadello. 1989. Determination of sediment composition and chronology as a tool for environmental impact investigations. Marine Chem. 26:91-100.

Battiston, G.A., S. Degetto, R. Gerbasi, G. Sbrignadello, and L. Tositti. 1988. The use of ^{210}Pb and ^{137}Cs in the study of sediment pollution in a lagoon of Venice. Sci. Total Environ. 77:15-23.

Baxter, M.S., R.W. Crawford, D.S. Swan, and J.G. Farmer. 1981. ^{210}Pb dating of a Loch Lomond sediment core by conventional and particle track methods and some geochemical observations. Earth Planet. Sci. Lett. 53:434-444.

Baxter, M.S., J.G. Farmer, I.G. McKinley, D.S. Swan, and W. Jacks. 1981. Evidence of the unsuitability of gravity coring for collecting sediment in pollution and sedimentation rate studies. Environ. Sci. Tech. 15:843-846.

Baxter, M.S., I.G. McKinley, A.B. MacKenzie, and W. Jack. 1979. Windscale radiocaesium in the Clyde Sea area. Marine Pollut. Bull. 10:116-120.

Bazzoffi, P., P. Canuti, S. Morretti, G. Rodolfi, and C. Zanchi. 1096. Quantitative evaluation of some slope processes (Surface erosion, mass movement) in experimental areas with different agro-climatic conditions in central Italy. Z. Gemorphol. Suppl.-Bd. 60:131-148.

Bazzoffi, P. and M. Panicucci. 1983. Erosione sui versanti e congequente sedimentazione in piccoli serbatoi artificiali. Inst. Sperimentale Studio e Difesa Suolo, Firenze 14:127-178. (Italian)

Beasley, T.M., R. Carpenter, and C.D. Jennings. 1982. Plutonium, ^{241}Am and ^{137}Cs ratios, inventories, and vertical profiles in Washington and Oregon continental shelf sediments. Geochim. Cosmochim. Acta 46:1931-1946.

Beasley, T.M. and C.D. Jennings. 1984. Inventories of ^{239,240}Pu, ^{241}Am, ^{137}Cs, and ^{60}Co in Columbia River sediments from Hanford to the Columbia River Estuary. Environ. Sci. Tech. 18:207-212.

Beck, H.L. 1966. Environmental gamma radiation from deposited fission products 1960-1964. Health Phys. 12:313-322.

Begrgström, U. and S. Nordlinder. 1989. Comparison of predicted and measured Cs-137 in a lake ecosystem, pp. 283-288. *In*: W. Feldt (ed.) The radioecology of natural and artificial radionuclides, Proceedings of the 15th Regional Congress of the International Radiation Protection Association of Radioecology of Natural and Artificial Radionuclides, Visby, Sweden.

Bell, G.L. and B.J. Eadie. 1983. Variation in the distribution of suspended particles during an upwelling event in Lake Michigan in 1980. J. Great Lakes Res. 9:559-567.

Belli, M., M. Blasi, E. Capra, A. Drigo, S. Menegon, E. Piasentier, and U. Sansone. 1993. Ingested soil as a source of Cs-137 to ruminants. Sci. Total Environ. 136:243-249.

Belli, M. U. Sansone, and S. Menegon. 1994. Behaviour of radiocaesium in a forest in the eastern Italian Alps. Sci. Total Environ. 157:257-260.

Belli, M., U. Sansone, E. Piasentier, E. Capra, A. Drigo, and S. Menegon. 1993. Cs-137 transfer coefficients from fodder to cow milk. J. Environ. Radioact. 21:1-8.

Belousova, A.P., A.I. Shmakov, and O.V. Galaktionova. 1994. Ways of investigating radionuclide migration processes in the lithosphere and hydrosphere. Environ. Geol. 24:306-308.

Belperio, A.P., B.W. Smith, H.A. Polach, C.A. Nittrouer, D.J. DeMaster, J.R. Prescott, J.R. Hails, and V.A. Gostin. 1984. Chronological studies of the Quaternary marine sediments of northern Spencer Gulf, South Australia. Marine Geol. 61:265-296.

Beneš, P., M. Černik, and P. Lam Ramos. 1992b. Factors affecting interaction of radiocesium with freshwater solids. II. Contact time, concentration of solid and temperature. J. Radioanalyt. Nucl, Chem Articles 159:201-218.

Beneš, P., M. Černik, and O. Slávik. 1994. Modelling of migration of ^{137}Cs accidently released into a small river. J. Environ. Radioact. 22:279-293.

Bengtsson, L., T. Hellström, and I. Rakoczi. 1990. Redistribution of sediments in three Swedish lakes. Hydrobiologia 192:167-181.

Benninger, L.K., R.C. Aller, J.K. Cochran, and K.K. Turekian. 1979. Effects of biological sediment mixing on the ^{210}Po chronology and trace element distribution in a Long Island Sound sediment core. Earth Planet. Sci. Lett. 43:241-259.

Benninger, L.K. and M.M. Brinson. 1988. Chronometric radionuclides in sediments of Cedar Island Salt Marsh, North Carolina. EOS Trans. 69:379.

Benninger, L.K. and S. Krishnaswami. 1981. Sedimentary processes in the inner New York Bight: evidence from excess ^{210}Pb and ^{239,240}Pu. Earth Planet. Sci. Lett. 53:158-174.

Benninger, L.K. and J.T. Wells. 1993. Sources of sediment to the Neuse River estuary, North Carolina. Marine Chemistry 43:137-156.

Benson, D.W. 1960. Review of soil chemistry research at Hanford. HW-67201, Batelle Northwest Laboratory, Richland, WA.

Berg, A., M. Merlini, O. Ravera, and V. Tonolli. 1961. Accumulation of fission products from fall-out in Lake Biota (Lago Maggiore). Final Report, Contract No. 59, Rept. CNI-109, International Atomic Energy Agency, Vienna, Austria.

Berg, M.T. and L.J. Shuman. 1995a. A three-dimensional stochastic model of the behavior of radionuclides in forests I. Model structure. Ecol. Modelling 83:359-372.

Berg, M.T. and L.J. Shuman. 1995a. A three-dimensional stochastic model of the behavior of radionuclides in forests. II. Cs-137 behavior in forest soils. Ecol. Modelling 83:373-386.

Berg, M.T. and L.J. Shuman. 1995b. A three-dimensional stochastic model of the behavior of radionuclides in forests. III. Cs-137 uptake and release by vegetation. Ecol. Modelling 83:387-404.

Bergeijk van, K.E., H. Noordijk, J. Lembrechts, and M.J. Frissel. 1992. Influence of pH, soil type and soil organic matter on soil-to-plant transfer of radiocesium and radiostrontium an analyzed by a nonparametric method. J. Environ. Radioact. 15:265-276.

Berger, G.W., D. Eisma, and A.J. van Bennekom. 1987. ^{210}Pb derived sedimentation rate in the Vlieter, a recently filled-in tidal channel in the Wadden Sea. Neth. J. Sea Res. 21:287-294.

Bergersen, E.P. 1987. Aldrin, dieldrin, and mercury profiles in recent lake sediment at the Rocky Mountain Arsenal, Colorado. Arch. Environ. Contam. Toxicol. 16:61-67.

Bergman, R. 1994. The distribution of radioactive caesium in boreal forest, pp. 335-379. *In:* H. Dahlgaard (ed.), Studies in Environmental Science 62. Nordic Radioecology: The transfer of radionuclides through nordic ecosystems to man, Elsevier, New York.

Bergstrom, U., B. Sundblad, and S. Nordlinder. 1994. Models for predicting radiocaesium levels in lake water and fish, pp. 93-104. *In:* H. Dahlgaard (ed.), Studies in Environmental Science 62. Nordic Radioecology: The transfer of radionuclides through nordic ecosystems to man, Elsevier, New York.

Bernard, C. and M.R. Laverdière. 1990. Variabilité spatiale de l'activitie en césium-137 et ses repercussions sur l'estimation de l'érosion hydrique. Pedologie 40:299-310. (French)

Bernard, C. and M.R. Laverdière. 1992. Spatial redistribution of caesium-137 and soil erosion on Orleans Island, Quebec. Can. J. Soil Sci. 72:543-554.

Bernard, C., M.R. Laverdière, and A.R. Pesant. 1992. Variabilité de la relation entre les pertes de césium et de sol par Jrosion hydrique. Geoderma 52:265-277. (French)

Bertine, K.K. and M.F. Mendeck. 1978. Industrialization of New Haven, Conn., as recorded in reservoir sediments. Environ. Sci. Tech. 12:201-207.

Bettoli, M.G., L. Cantelli, M. Cecchini, L. Tositti, O. Tubertini, and S. Valcher. 1994. Vertical distribution of Cs-137 in the lacustrine areas and preliminary results of Be-7 activity in snow samples at Terra-Nova Bay (Antarctica). Internat. J. Environ. Analyt. Chem. 55:253-260.

Beurskens, J.E.M., G.A.J. Mol, H.L. Barreveld, B. Van Munster, and H.J. Winkels. 1993. Geochronology of priority pollutants in a sedimentation area of the Rhine river. Environ. Toxicol. Chem. 12:1549-1566.

Bickford, M.E. and W.R. Van Schmus. 1979. Geochronology and radiogenic isotope research. Rev. Geophys. Space Phys. 17:824-839.

Bilo, M., W. Steffens, F. Fuhr, and K.H. Pfeffer. 1993. Uptake of Cs-134/Cs-137 in soil by cereals as a function of several soil parameters of 3 soil types in upper Swabia and north Rhine-Westphalia (FRG). J. Environ. Radioact. 19:25-39.

Binford, M.W. 1984. Dating lake sediment cores with ^{210}Pb. In: Proceedings workshop on paleolimnological studies of the history and effects of acidic precipitation, May 23-24, 1984, Rockland, ME.

Birch, L., K.W. Hanselmann, and R. Bachofen. 1996. Heavy metal conservation in Lake Cadagno sediments: Historical records of anthropogenic emissions in a meromictic alpine lake. Water Research 30:676-687.

Bird, G.A. and W.G. Evenden. 1994. Effect of sediment type, temperature and colloids on the transfer of radionuclides from water to sediment. J. Environ. Radioact. 22:219-242.

Bird, G.A. and W.G. Evenden. 1996. Transfer of ^{60}Co, ^{65}Zn, ^{95}Tc, ^{134}Cs, and ^{238}U from water to organic sediment. Water Air Soil Pollut. 86:251-261.

Bishop, P., B. Campbell, and C. McFadden. 1991. Absence of caesium-137 from recent sediments in eastern Australia - Indications of catchment processes? Catena 18:61-69.

Bjørnstad, H.E., J.E. Brittain, R. Saxen, and B. Sundblad. 1994. The characterization of radiocaesium transport and retention in Nordic lakes, pp. 29-44. *In:* H. Dahlgaard (ed.), Studies in Environmental Science 62. Nordic Radioecology: The transfer of radionuclides through nordic ecosystems to man, Elsevier, New York.

Blagoeva, R. and L. Zikovbsky. 1995. Geographic and vertical distribution of Cs-137 in soils in Canada. J. Environ. Radioact. 27:269-274.

Blais, J.M., J. Kalff, R.J. Cornett, and R.D. Evans. 1995. Evaluation of ^{210}Pb dating in lake sediments using stable Pb, ambrosia pollen, and ^{137}Cs. J. Paleolimnol. 13:169-178.

Blakar, I.A., D. Hongve, and O. NjDstad. 1992. Chernobyl cesium in the sediments of Lake Hrysjren, Central Norway. J. Environ. Radioact. 17:49-58.

Bloemendal J., F. Oldfield, and R. Thompson. 1979. Magnetic measurements used to assess sediment influx at Llyn Goddionduon. Nature 280:50-53.

Bloesch, J. 1995. Mechanisms, measurement and importance of sediment resuspension in lakes. Marine and Freshwater Res. 46:295-304.

Bloesch, J. and R.D. Evans. 1982. ^{210}Pb dating of sediment compared with accumulation rates estimated by natural markers and measured with sediment traps. Hydrobilogia 92:579-586.

Bloesch, J. and M. Strum. 1986. Settling flux and sinking velocities of particle phosphorus (PP) and particulate organic carbon (POC) in Lake Zug, Switzerland, pp. 481-490. *In*: P.G. Sly (ed.), Sediment and water interactions, Springer-Verlag, New York.

Bodbacka, L. 1986. Sediment accumulation in Lake Lilla Ullfjärden and Stora Ullfjärden, Sweden. Hydrobiologia 143:337-342.

Bogen, J., H. Berg, and F. Sandersen. 1994. The contribution of gully erosion to the sediment budget of the River Leira. IAHS Publ: 224:307-315.

Bollhöfer, A., A. Mangini, A. Lenhard, M. Wessels, F. Giovanoli, and B. Swartz. 1994. High-resolution ^{210}Pb dating of Lake Constance sediments: Stable lead in Lake Constance. Environ. Geol. 24:267-274.

Bonazzola, G.C. and R. Ropolo. 1986. Environmental radioactivity measurements after the Chernobyl accident. Il Nuovo Saggiatore 3:135-143. (Italian)

Bonazzola, G.C., R. Ropolo, and A. Facchinelli. 1993. Profiles and downward migration of ^{134}Cs and ^{106}Ru deposited on Italian soils after the Chernobyl accident. Health Phys. 64:479-484.

Bondar' Yu I., G.S. Shmanay, and T.L. Yarmolovich. 1966. Investigation of radionuclides mobility in soils and their availability to plants by ion-exchange methods. Eurasian Soil Sci. 28:36-42.

Bonnett, P.J.P. 1989. A review of the erosional behavior of radionuclides in selected drainage basins. AERE-R-13631. United Kingdom Atomic Energy Authority Harwell, UK.

Bonnett, P.J.P. 1990. A review of the erosional behavior of radionuclides in selected drainage basins. J. Environ. Radioact. 11:251-266.

Bonnett, P.J.P. and M.A. Anderson. 1993. Radiocaesium dynamics in a coniferous forest canopy - A Mid-Wales case study source. Sci. Total Environ. 136:259-277.

Bonnett, P.J.P. and P.G. Appleby. 1991. Deposition and transport of radionuclides within an upland drainage basin in mid-Wales. Hydrobiologia 214:71-76.

Bonnett, P.J.P. and P.G. Appleby. 1994. Rates of removal of sediment associated radiocaesium from the Plynlimon Experimental Catchment, Powys, UK. Environ. Pollut. 83:327-334.

Bonnett, P.J.P., P.G. Appleby, and F. Oldfield. 1988. Radionuclides in coastal and estuarine sediments from Wirral and Lancashire. Sci. Total Environ. 70:215-236.

Bonnett, P.J.P. and R.S. Cambry. 1991. The record of deposition of radionuclides in the sediments of Ponsonby Tarn, Cumbria. Hydrobiologia 214:63-70.

Bonnett, P.J.P., G.J.L. Leeks, and R.S. Cambry. 1989. Transport processes for Chernobyl-labelled sediments: preliminary evidence from upland mid-Wales. Land Degradation and Rehabilitation 1:39-59.

Bonny, A.P. 1976. Recruitment of pollen to the seston and sediment of some Lake District lakes. J. Ecol. 64:859-887.

Bonny, A.P. 1978. The effect of pollen recruitment processes on pollen distribution over sediment surface of a small lake in Cumbria. J. Ecol. 66:385-416.

Bopp, R.F., M.F. Gross, H. Tong, H.J. Simpson, S.J. Monson, B.L. Deck, and F.C. Moser. 1991. A major incident of dioxin contamination: Sediments of New Jersy Estuaries. Environ. Sci. Technol. 25:951-956.

Bopp, R.F., H.J. Simpson, S.N. Chillrud, and D.W. Robinson. 1993. Sediment-derived chronologies of persistent contaminants in Jamaica Bay, New York. Estuar. 16:608-616.

Bopp, R.F., H.J. Simpson, C.R. Olsen, and N. Kostyk. 1981. Polychlorinated biphenyls in sediments of the tidal Hudson River, New York. Environ. Sci. Tech. 15:210-216.

Bopp, R.F., H.J. Simpson, C.R. Olsen, and N. Kostyk. 1982. Chlorinated hydrocarbons and radionuclide chronologies in sediments of the Husdon River and estuary, New York. Environ. Sci. Tech. 16:666-676.

Borzilov, V.A., A.V. Konoplev, and A.A. Bulgakov. 1993. Application of the Chernobyl experience in developing methodology for assessing and predicting the consequences of radioactive contamination of the hydrosphere, pp. 246-263. *In*: Hydrological considerations in relation to nuclear power plants, Proceeding of an International Workshop, UNESCO, Paris.

Borzilov, V.A., A.V. Konoplev, and A.A. Bulgakov. 1994. Application of the Chernobyl experience in developing methodology for assessing and predicting the consequences of radioactive contamination of the hydrosphere. IAHS Publ. 219:157-167.

Bourbonniere, R.A., S.L. Telford, and J.B. Kemper. 1996. Depositional history of sediments in Legend and Weekes lakes: Geochronology and bulk parameters. Northern River Basins Study project report no. no. 71, Northern River Basins Study (Canada), Edmonton (Alberta), Report No.: SSC-R71-49/3-71E; ISBN-0-662-24142-8c, 67p.

Bourbonniere, R.A., S.L. Telford, and J.B. Kemper. 1996. Depositional history of sediments in Lake Athabasca: Geochronology, bulk parameters, contaminants and biogeochemical markers. Northern River Basins Study project report no. no. 72,Northern River Basins Study (Canada), Edmonton (Alberta), Report No.: SSC-R71-49/3-72E; ISBN-0-662-24143-6c, 149p.

Boudreau, B.P. 1986a. Mathematics of tracer mixing in sediments: I. spatially-dependent, diffusive mixing. Am. J. Sci. 286:161-198.

Boudreau, B.P. 1986b. Mathematics of tracer mixing in sediments: II. nonlocal mixing and biological conveyor-belt phenomena. Am. J. Sci. 286:199-238.

Bowen, V.T., V.E. Noshkin, and H.L. Volchok. 1970. Can land run-off be a major vector of fallout to the ocean. HASL-217, pp. I-119 to I-125. Health and Safety Laboratory, New York.

Brakensiek, D.L., H.B. Osborn, and W.J. Rawls. 1979. Field manual for research in agricultural hydrology. USDA Agriculture Handbook No. 224, US Department of Agriculture, Washington, DC.

Bray D.I. and H.X. Xie. 1993. A regression method for estimating suspended sediment yield from ungauged watershed in Atlantic Canada. Can. J. Civ. Engr. 20:82-87.

Bremer, E., E. De Jong, and H.H. Janzen. 1995. Difficulties in using ^{137}Cs to measure erosion in stubble-mulched soil. Can. J. Soil Sci. 75:357-359.

Brenner, M., T.J. Whitmore, and C.L. Schelske. 1996. Paleolimnological evaluation of historical trophic state conditions in hypereutrophic Lake Thonotosassa, Florida, USA. Hydrobiologia 331(1-3):143-152.

Brewster, G.R. and V. Pillay. 1991. Using Cs-137 to assess soil erosion in the Cobequid Bay area of Nova Scotia. Can. J. Soil Sci. 71:261-262.

Bricker-Urso, S., S.W. Nixon, J.K. Cochran, D.J. Hirschberg, and C. Hunt. 1989. Accretion rates and sediment accumulation in Rhode Island salt marshes. Estuaries 12:300-317.

Brisbin, I.L. Jr., R.J. Beyers, R.W. Dapson, R.A. Geiger, J.B. Gentry, J.W. Gibbons, M.H. Smith, and S.K. Woods. 1974. Patterns of radiocesium in the sediments of a stream channel contaminated by production reactor effluent. Health Phys. 27:19-27.

Brøberg, A. 1994. The distribution and characterization of ^{137}Cs in lake sediment, pp. 45-62. *In:* H. Dahlgaard (ed.), Studies in Environmental Science 62. Nordic Radioecology: The transfer of radionuclides through nordic ecosystems to man, Elsevier, New York.

Brøberg, A. and E. Andersson. 1991. Distribution and circulation of Cs-137 in lake ecosystems, pp. 151-175. *In*: L. Moberg (ed.), The Chernobyl fallout in Sweden, Swedish Radiation Protection Institute, Stockholm, Sweden.

Brøberg, A., L. Malmgren, and M. Jansson. 1995. Relations between resuspension and content of ^{137}Cs in freshwater fish in some Swedish lakes. J. Aquatic Ecosystem Health 4:285-294.

Broom, M.J., P.D. Grimwood, and E.G. Bellinger. 1973. Caesium-137: its accumulation in littoral community. Marine Pollut. Bull. 6:24-26.

Brouwer, E., B. Aaeyens, A. Maes, and A. Cremers. 1983. Cesium and rubidium ion equilibria in illite clay. J. Phys. Chem. 87:1213-1219.

Brown, L. 1987a. ^{10}Be: recent applications in earth science. Phil. Trans. R. Soc. London A 323:75-86.

Brown, L. 1987b. ^{10}Be as a tracer of erosion and sediment transport. Chem. Geol. 65:189-196.

Brown, L., M.J. Pavich, R.E. Hickman, J. Klein, and R. Middleton. 1988. Erosion of the eastern United States observed with ^{10}Be. Earth Surf. Process. Landforms 13:441-457.

Brown, L.R. and E.C. Wolf. 1984. Soil erosion: quiet crisis in the world economy, Worldwatch Paper 60, 51 pp, World Watch, Washington, DC.

Brown, R.B. 1980. Agricultural erosion and sediment in the Western Willamette Valley as indicated by the redistribution of cesium-137. Ph.D. Thesis, Oregon State Univ., Corvallis, OR. (DAI no. 41:1191-b)

Brown, R.B., N.H. Cutshall, and G.F. Kling. 1981. Agricultural erosion indicated by ^{137}Cs redistribution: I. levels and distribution of ^{137}Cs activity in soils. Soil Sci. Soc. Am. J. 45:1184-1190.

Brown, R.B. and G.F. Kling. 1980. Erosion and sediment as indicated by redistribution of cesium-137, Chapter 7. Spec. Report Oregon Agricultural Experiment Station, Nov. 1980 (602) pp. 90-108.

Brown, R.B., G.F. Kling, and N.H. Cutshall. 1981. Agricultural erosion indicated by ^{137}Cs redistribution: II. estimates of erosion rates. Soil Sci. Soc. Am. J. 45:1191-1197.

Brückmann, A. and V. Wolters. 1994. Microbial immobilization and recycling of ^{137}Cs in the organic layers of forest ecosystems - Relationship to environmental conditions, humification and invertebrate activity. Sci. Total Environ. 151:249-256.

Brugam, R.D. 1978. Pollen indicators of land-use change in Southern Connecticut. Quat. Res. 9:349-362.

Brunn, H., S. Georgii, and U. Eskens. 1993. Cesium-137 and cesium-134 in roe deer from North and Middle Hesse (Germany) subsequent to the reactor accident in Chernobyl. Bull. Environ. Contam. Toxicology 51:633-639.

Brunskill, G.J., S.D. Ludlam, and T.H. Peng. 1984. Fayetteville Green Lake, New York, U.S.A. VIII. Mass balance of ^{137}Cs in water, varved and non-varved sediments. Chem. Geol. 44:101-117.

Brunskill, G.J., D. Povoledo, B.W. Graham, and M.P. Stainton. 1971. Annual supply of ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, ^{210}Pb, ^{210}Po and ^{232}Th to lake 239 (Experimental Lakes Area, northwestern Ontario) from terrestrial and atmospheric sources. Can. J. Fish. Aquat. Sci. 44:215-230.

Brush, G.S. 1984. Patterns of recent sediment accumulation in Chesapeake Bay (Virginia-Maryland, U.S.A.) tributaries. Chem. Geol. 44:227-242.

Brush, G.S., E.A. Martin, R.S. DeFries, and C.A. Rice. 1982. Comparison of ^{210}Pb and pollen methods for determining rates of estuarine sediment accumulation. Quat. Res. 18:196-217.

Bryant, C.L., J.G. Framer, A.B. MacKenzie, A.E. Bailey-Watts, and A. Krika. 1993. Distribution and behaviour of radiocaesium in Scottish freshwater loch sediments. Environ. Geochem. Health 15:153-161.

Brydsten, L. and M. Jasson. 1989. Studies of estuarine sediment dynamics using ^{137}Cs from the Tjernobyl accident as a tracer. Estuar. Coast. Shelf Sci. 28:249-259.

Bubenzer, G.D. 1986. Quantifying erosion losses using cesium-137. Paper of the 1986 Summer Meetings of the Am. Soc. Agric. Engr. (ASAE Microfiche 86-2042).

Buesseler, K.O. and C.R. Benitez. 1994. Determination of mass accumulation rates and sediment radionuclide inventories in the deep Black Sea Deep - Sea Research Part I. Oceanographic Research Papers 41:1605-1615.

Buesseler, K.O., H.D. Livingston, S. Honjo, B.J. Hay, S.J. Manganini, E. Degens, V. Ittekkol, E. Izdar, and T. Konuk. 1987. Chernobyl radionuclides in a Black Sea sediment trap. Nat. 329:825-828.

Buesseler, K.O. and E.R. Sholkovitz. 1987. The geochemistry of fallout plutonium in the North Atlantic: I. a pore water study in shelf, slope and deep-sea sediments. Geochim. Cosmochim. Acta 51:2605-2622.

Bulygin, S.Y., G.A. Mozheiko, and D.O. Timchenko. 1992. Rate of chernozem erosion in the Donetsk steppe. Prochvovedeiye 8:121-128. (Russian)

Bulygin, S.Y., G.A. Mozheiko, and D.O. Timchenko. 1993. Rate of erosion of the chernozems of the Donets steppe. Eurasion Soil Sci. 25:117-126.

Bulygin, S.Y., G.A. Mozheiko, and D.O. Timchenko. 1995. Erosion resistance parameters of forest-steppe zone soils in the Ukraine. Pochvovedenie 6:768-774. (Russian)

Bunzl, K., H. Förster, W. Kracke, and W. Schimmack. 1994. Residence times of fallout Pu-239+240, Pu-238, Am-241 and Cs-137 in the upper horizons of an undisturbed grassland soil. J. Environ. Radioact. 22:11-27.

Bunzl, K., H. Kofuji, W. Schimmack, A. Tsumura, K. Ueno, and M. Yamamoto. 1995. Residence times of global weapons testing fallout ^{237}Np in a grassland soil compares to $^{239+240}$Pu, ^{241}Am and ^{137}Cs. Health Physics 68:89-93.

Bunzl, K. and W. Kracke. 1984. Distribution of ^{210}Pb, ^{210}Po, stable lead and ^{137}Cs in soil, plants and moorland sheep of a heath. Sci. Total Environ. 39:143-159.

Bunzl, K. and W. Kracke. 1988. Cumulative deposition of ^{137}Cs, ^{238}Pu, $^{239+240}$Pu and ^{241}Am from global fallout in soils from forest, grassland and arable land in Bavaria (FRG). J. Environ. Radioact. 8:1-14.

Bunzl, K., W. Kracke, and W. Schimmack. 1992. Vertical migration of $^{239+240}$Pu, ^{241}Am and ^{137}Cs fallout in forest soil under spruce. Analyst 117:469-474.

Bunzl, K., W. Kracke, W. Schimmack, and K. Auerswald. 1995. Migration of fallout $^{239+240}$Pu, ^{241}Am and ^{137}Cs in the various horizons of a forest soil under pine. J. Environ. Radioact. 28:17-34.

Bunzl, K. and W. Schimmack. 1989. Associations between the fluctuations of the distribution coefficients of Cs, Zn, Sr, Co, Cd, Ce, Ru, Tc, and I in the upper two horizons of a podzol forest soil. Chemosphere 18:2109-2120.

Bunzl, K. and W. Schimmack. 1991. Kinetics of sorption of ^{137}Cs, ^{85}Sr, ^{57}Co, $_{65}$Zn and ^{109}Cd by the organic horizons of a forest soil. Radiochim Acta 54:97-102.

Bunzl, K., W. Schimmack, K. Kreutzer, and R. Schierl. 1989a. The migration of fallout ^{134}Cs, ^{137}Cs and ^{106}Ru from Chernobyl and ^{137}Cs from weapons testing in a forest soil. Z. Pflanzenernahr. Bodenk 152:39-44.

Bunzl, K., W. Schimmack, K. Kreutzer, and R. Schierl. 1989b. Interception and retention of Chernobyl-derived ^{134}Cs, ^{137}Cs and ^{106}Ru in a spruce stand. Sci. Total Environ. 78:77-87.

Bunzl, K. and W. Schultz. 1985. Distribution coefficients of ^{137}Cs and ^{85}Sr by mixtures of clay and humic material. J. Radioanal. Nucl. Chem. Art. 90:23-37.

Buravlev, Y.P., M.N. Lebedinskiy, S.K. Drich, and V.K. Chumak. 1992. Migration of Cs-137 and Ce-144 in soils of the evacuated zone around the Chernobyl Nuclear Power Plant. Soviet Soil Sci. 23:121-125.

Burch, G.J., C.J. Barnes, I.D. Moore, R.D. Barling, D.H. Mackensie, and J.M. Olley. 1988. Detection and prediction of sediment sources in catchments: use of Be-7 and Cs-137, pp. 146-151. *In*: Proceedings, hydrology and water resources symposium, Australian Inst. Eng., Canberra, Australia.

Burrough, P.A., M. Gillespie, B. Howard, and B. Prister. 1996. Redistribution of Chernobyl ^{137}Cs in Ukraine wetlands by flooding and runoff. IAHS Publ. No. 235:269-277.

Busacca, A.J., C.A. Cook, and D.J. Mulla. 1993. Comparing landscape-scale estimation of soil erosion in the Palouse using Cs-137 and RUSLE. J. Soil Water Conserv. 48:361-367.

Bush, B., L.A. Shane, M. Wahlen, and M.P. Brown. 1987. Sedimentation of 74 PCB congeners in the upper Hudson River. Chemosphere 16:733-744.

Buzdalkin, K.N. 1985. Cs-137 redistribution by horizonal migration in soil. Doklady Akademii Nauk Belarusi 38:104-107.

Cahill, R.A. and J.D. Steele. 1986. ^{137}Cs as a tracer of recent sedimentary processes in Lake Michigan. Hydrobiologia 143:29-35.

Cahill, R.A. and M.T. Unger. 1993. Evaluation of the extent of contaminated sediments in the West Branch of the Grand Calumet River, Indiana-Illinois, USA. Water Sci. Tech. 28:53-58.

Caitcheon, G. 1990. Sedimentation in Lake Albert - the history of sediment sources and catchment sediment yields. Aust. J. Soil Water Conserv. 3:42-46.

Caitcheon, G.G. 1993a. Applying environmental magnetism to sediment tracing. IAHS Publ. No.215:285-292.

Caitcheon, G.G. 1993b. Sediment source tracing using environmental magnetism: a new approach with examples from Australia. Hydrol. Process. 7:349-358.

Calcagno, T.H. and G.M. Ashley. 1984. Sediment processes in an impoundment, Union Lake, New Jersey. Environ. Geol. Water Sci. 6:237-246.

Callaway, J.C., R.D. De Laune, and W.H. Patrick Jr. 1996a. Chernobyl ^{137}Cs used to determine sediment accretion rates at selected northern European coastal wetlands. Limnol. Oceanography 41:444-450.

Callaway, J.C., R.D. De Laune, and W.H. Patrick Jr. 1996b. Sediment accretion rates from four coastal wetlands along the Gulf of Mexico. J. Coastal Res. (In. Press)

Callaway, J.C., J.A. Nyman, and R.D. De Laune. 1996c. Sediment accretion rates in coastal wetlands: A review and a simulation model of processes. Curr. Top. Wetland Biogeochem. (In Press).

Callender, E. and J.A. Robbins. 1993. Transport and accumulation of radionuclides and stable elements in a Missouri River reservoir. Water Resour. Res. 29:1787-1804.

Cambray, R.S., P.A. Cawse, J.A. Garland, J.A.B. Gibson, P. Johnson, G.N.J. Lewis, D. Newton, L. Salmon, and B.O. Wade. 1987. Observations on radioactivity from the Chernobyl accident. Nucl. Energy 26:77-101.

Cambray, R.S. and J.D. Eakins. 1980. Studies of environmental radioactivity in Cumbria, Part 1. Concentrations of plutonium and ^{137}Cs in environmental samples from West Cumbria and a possible maritime effect. AERE-R-9807. U.K. Atomic Energy Authority Report, Harwell, UK.

Cambray, R.S. and J.D. Eakins. 1982. Pu, ^{241}Am and ^{137}Cs in soil in West Cumbria and a maritime effect. Nature 300:46-48.

Cambray, R.S., K. Playford, and G.N.J. Lewis. 1983. Radioactive fallout in air and rain: results to the end of 1982. AERE-R-10859. U.K. Atomic Energy Authority Report, Harwell, UK.

Cambray, R.S., K. Playford, and G.N.J. Lewis. 1985. Radioactive fallout in air and rain: results to the end of 1984. AERE-R-11915. U.K. Atomic Energy Authority Report, Harwell, UK.

Cambray, R.S., K. Playford, G.N.J. Lewis, and R.C. Carpenter. 1989. Radioactive fallout in air and rain: results to the end of 1988. AERE-R-13575. U.K. Atomic Energy Authority Report, Harwell, UK.

Cambray et al. 1987. Observation of radioactivity from the Chernobyl accident. Nucl. Energy 26:77-101.

Campbell, B.L. 1982. Application of environmental caesium-137 for the determination of sedimentation rates in reservoirs and lakes and related catchment studies in developing countries. AAEC Research Establishment, Lucas Heights Research Lab., PMB Sutherland 3322, N.S.W., Australia.

Campbell, B.L. 1983. Application of environmental caesium-137 for the determination of sedimentation rates in reservoirs and lakes and related catchment studies in developing countries. Radioisotopes in Sediment Studies, Tech. Doc. 298:7-30, International Atomic Energy Agency, Vienna, Austria.

Campbell, B.L., P.L. Airey, and G.E. Calf. 1987. Use of isotopic techniques in hydrological and erosion-sedimentation studies in tropical and temperate zones of the Asian-Pacific region, pp. 751-766. *In*: V. Gardiner (ed.), International geomorphology, Part 1. Wiley, London.

Campbell, B.L., G.L. Elliott, and R.J. Loughran. 1980a. Nuclear fallout aids the hydrologist. Environ. Newsletter 5:2-3.

Campbell, B.L., G.L. Elliott, and R.J. Loughran. 1980b. Sediment dynamics in a small Hunter Valley catchment, Vol. 6, pp. 1-17. *In*: Hunter environment, Univ. Newcastle, N.S.W., Australia.

Campbell, B.L., G.L. Elliott, and R.J. Loughran. 1985. Nuclear fallout as an aid to measuring soil erosion. J. Soil Conserv. New South Wales 42:86-89.

Campbell, B.L., G.L. Elliott, and R.J. Loughran. 1986. Measurement of soil erosion from fallout ^{137}Cs. Search 17:148-149.

Campbell, B.L., R.J. Loughran, and G.L. Elliott. 1982. Caesium-137 as an indicator of geomorphic processes in a drainage system. Aust. Geographical Studies 20:49-64.

Campbell, B.L., R.J. Loughran, and G.L. Elliott. 1988. A method for determining sediment budgets using caesium-137. IAHS Publ. No. 174:171-179.

Campbell, B.L., R.J. Loughran, G.L. Elliott, and D.J. Shelly. 1986. Mapping drainage basin sediment sources using caesium-137. IAHS Publ. No. 159:437-446.

Campbell, B.L. and M. Ross. 1980. Determination of sedimentation rate in Stephens Creek reservoir using environmental caesium-137. Papers of the Newcastle (16th) Conf., Inst. Aust. Geographers, pp. 43-51.

Cao, Y.Z., D.R. Coote, N.C. Nolin, and C. Wang. 1993. Using ^{137}Cs to investigate net soil erosion at two soil benchmark sites in Quebec. Can. J. Soil Sci. 73:515-526.

Cao, Y.Z., D.R. Coote, H.W. Rees, C. Wang, and T.L. Chow. 1994. Effects of intensive potato production on soil quality and yield at a benchmark site in New Brunswick. Soil Tillage Res. 29:23-34.

Capra, D., U. Facchini, V. Gianelle, G. Ravasini, O. Ravena, A. Pizzala, and P. Bacci. 1987. The Chernobyl accident: the radioactive contamination in the area of Lake Como and in other Northern Italy sites. Nuovo Cimento 10:285-313.

Carlsen, L., P. Bo, and G. Larsen. 1984. Radionuclide-humic acid interactions studied by dialysis, pp. 167-178. *In*: G.G. Barney, J.D. Navratil, and W.W. Schultz (eds.), Geochemical behavior of disposed radioactive waste, American Chemical Soc., Seattle, Wa.

Carlsson, S. 1976. Cesium-137 in a dysoligotrophic lake, a radioecological field study. LUNDO-MERI-NFRA 76-1005, 180 pp. Radiation Physic Department, Univ. Lund, Lund, Sweden.

Carlsson, S. 1978. A model for the movement and loss of ^{137}Cs in a small watershed. Health Phys. 34:33-37.

Carpenter, R., T.M. Beasley, D. Zahnle, and B.L.K. Somayajulu. 1987. Cycling of fallout (Pu, ^{241}Am, ^{137}Cs) and natural (U, Th, ^{210}Pb) radionuclides in Washington continental slope sediments. Geochim. Cosmochim. Acta 51:1897-1921.

Carr, A.P. and M.W.L. Blackley. 1986. Implications of sedimentological and hydrological processes on the distribution of radionuclides: an example of a salt marsh near Ravenglass, Cumbria. Estuar. Coast. Shelf Sci. 22:529-543.

Carrard, G. (Comp.) 1980. Nuclear method can give early warning of erosion. AAEC Nucl. News 7:1-2.

Carringan, P.A. Jr. and R.J. Pickering. 1967. Radioactive materials in bottom sediments of the Clinch River. ORNL-3721, Part A and B, Oak Ridge National Laboratory, Oak Ridge, TN.

Carter, M.W. and A.A. Moghissi. 1977. Three decades of nuclear testing. Health Phys. 33:55-71.

Cawse, P. 1983. The accumulation of ^{137}Cs and $^{239+240}$Pu in soils of Great Britain, and transfer to vegetation, pp. 47-61. *In*: P.J. Coughtrey (ed.), Ecological aspects of radionuclide release. Blackwell, Oxford.

Cawse, P.A. and A.D. Horrill. 1986. A survey of caesium-137 and plutonium in British soils in 1977. AERE R-10155. United Kingdom Atomic Energy Authority Report, Harwell, UK.

Cerling, T.E., S.J. Morrison, and R.W. Sobocinski. 1990. Sediment-water interaction in a small stream: adsorption of ^{137}Cs by bed load sediments. Water Resour. Res. 26:1165-1176.

Cerling, T.E. and R.R. Turner. 1982. Formation of freshwater Fe-Mn coatings on gravel and behavior of ^{60}Co, ^{90}Sr, and ^{137}Cs in a small watershed. Geochim. Cosmochim. Acta 46:1333-1343.

Cerrai, E., B. Schreiber, and C. Triulzi. 1967. Vertical distribution of Sr^{90}, Ce^{144}, Pm^{147}, and Eu^{155} in coastal marine sediments. Energia Nucleare 14:586-592.

Cerrai, E., B. and C. Triulzi. 1969. Vertical distribution of Cs^{137}, Sb^{125}, and Co^{60} in coastal marine sediments. Energia Nucleare 16:36-40.

Chakrapani, G.J. and V. Subramanian. 1993. Rates of erosion and sedimentation in the Mahanadi River Basin. India J. Hydrol. 149:39-48.

Chamard, P., R.H. Velasco, M. Belli, G. Disilvestro, G. Ingrao, and U Sansone. 1993 Caesium-137 and strontium-90 distribution in a soil profile. Sci. Total Environ. 136:251-258.

Chamberlain, A.C. 1970. Interception and retention of radioactive aerosols by vegetation. Atmos. Environ. 4:57-78.

Chant, L.A. and R.J. Cornett. 1991. Smearing of gravity core profiles in soft sediment: note. Limnol. Oceanogr. 36:1492-1498.

Chanton, J.P., C.S. Martens, and G.W. Kipphut. 1983. Lead-210 sediment geochronology in a changing coastal environment. Geochim. Cosmochim. Acta 47:1791-1804.

Chappell, A., M. Oliver, and A. Warren. 1996.Net soil flux derived from multivariate soil property classification in Southwest Niger: A quantified approach based on ^{137}Cs, PP. 69-85. *In*: B. Buerkert, B.E. Allison, and M. Von Oppen (eds.), Wind erosion in West Africa: the problem and its control. Proceedings, Margraf Verlag Weikersheim, Germany.

Charles, D.F., D.R. Whitehead, D.R. Engstrom, B.D. Fry, R.A. Hites, S.A. Norton, J.S. Owen, L.A. Roll, S.C. Schindler, J.P. Smol, A.J. Uutala, J.R. White, and R.J. Wise. 1987. Paleolimnological evidence for recent acidification of Big Moose Lake, Adirondack Mountain N.Y. (USA). Biogeochemistry 3:267-296.

Charles, M.J. and R.A. Hites. 1987. Sediment as archives of environmental pollution trends. Adv. in Chem. Series 216:365-389.

Chebotina, M.Y. and V.F. Bochenin. 1981. ^{90}Sr and ^{137}Cs in bottom sediments of a fresh water lake. Gidrobiol. ZH 17:82-82. (Russian)

Chershire, M.V. and C. Strand. 1991. Translocation and plant availability of radiocaesium in an organic soil. Plant and Soil 134:287-296.

Chelmicki, W. and J. Swiechwicz. 1992. Application of Cs-137 and soil trapping methods for studying slope processes in the Carpathian foothills. Pirineos 139:3-14.

Chenhall, B.E., I. Yassini, A.M. Depers, G. Caitcheon, B.G. Jones, G.E. Bailey, and G.S. Ohmsen. 1995. Anthropogenic marker evidence for accelerated sedimentation in Lake Illawarra, New South Wales, Australia. Environ. Geol. 26:124-135.

Chenouard, L. and C. Lalou. 1969. Gamma-ray spectrometry as a tool for a rapid investigation of detritic cores. J. Sedimentary Petrology 39:1477-1483.

Cheshire, M.V. and C. Shand. 1991. Translocation and plant availability of radiocaesium in an organic soil. Plant and Soil 134:287-296.

Chibowski, S. and A. Mitura. 1995. Studies of the rate of migration of radiocesium in some types of soils of Eastern Poland. Sci. Total Environ. 170:193-198.

Chibowski, S., J. Solecki, J. Szczypa, and R. Suprynowicz. 1994. Study of radioactive contamination of Eastern Poland. Sci. Total Environ. 158:71-77.

Chittenden D.M. II 1983. Factors affecting the soluble-suspended distribution of strontium-90 and cesium-137 in Dardanelle Reservoir, Arkansas. Environ. Sci. Tech. 17:26-31.

Chmura, G.L. and E.C. Kosters. 1994. Storm deposition and Cs-137 accumulation in fine-grained marsh sediments of the Mississippi Delta Plain. Estuar. Coastal Shelf Sci. 39:33-44.

Choppin, G.R. 1988. Humics and radionuclide migration. Radiochimica Acta 44/45:23-28.

Christensen, E.R. 1982. A model for radionuclides in sediment influenced by mixing and compaction. J. Geophys. Res. 87:566-572.

Christensen, E.R. and P.K. Bhunia. 1986. Modelling radiotracers in sediments: comparison with observations in Lake Michigan and Huron. J. Geophys. Res. 91:8559-8571.

Christensen, E.R. and N. Chien. 1981. Fluxes of arsenic, lead, zinc, and cadmium to Green Bay and Lake Michigan sediments. Environ. Sci. Tech. 15:553-558.

Christensen, E.R. and R.H. Goetz. 1987. Historical fluxes of particle-bound pollutants from deconvolved sedimentary records. Environ. Sci. Technol. 21:1088-1096.

Christensen, E.R. and J.F. Karl. 1996. Unmixing of lead, ^{137}Cs, and PAH records in Lake sediments using curve fitting with first- and second-order corrections. Water Research 30:2543-2558.

Christensen, E.R. and R.J. Klein. 1991. Unmixing of ^{137}Cs, Pb, Zn, and Cd records in lake sediment. Environ. Sci. Tech. 25:1627-1637.

Christensen, E.R. and C.K. Lo. 1986. Polychlorinated biphenyls in dated sediments of Milwaukee Harbour, Wisconsin, USA. Environ. Pollut. (Series B) 12:217-232.

Christensen, E.R. and X. Zhang. 1993. Sources of polycyclic aromatic hydrocarbons to Lake Michigan determined from sedimentary records. Environ. Sci. Technol. 27:139-146.

Church, M. 1980. Records of recent geomorphological events, pp. 13-29. *In*: R.A. Cullingford, D.A. Davidson, and J. Lewin (eds.), Timescales in geomorphology, Wiley, London.

Churchill, J.H., C.T. Hess, and C.W. Smith. 1979. Measurement and computer modelling of radionuclide uptake by marine sediments near a nuclear power reactor. Health Phys. 38:327-340.

Clague, J.J. and P.T. Bobrowsky. 1994. Evidence for a large earthquake and tsunami 100-400 years ago on western Vancouver Island, British Columbia. Quat. Res. 14:176-184.

Clague, J.J., P.T. Bobrowsky, and T.S. Hamilton. 1994. A sand sheet deposited by the 1964 Alaska Tsunami at Port-Alberni, British-Columbia. Estuar. Coastal Shelf Sci. 38:413-421.

Clark, E.H. II 1985. The off-site cost of soil erosion. J. Soil Water Conserv. 40:19-22.

Clark, M.J. and F.B. Smith. 1988. Wet and dry deposition of Chernobyl releases. Nature 332:245-249.

Clemens, G. and K. Stahr. 1994. Present and past soil erosion rates in catchments of the Kraichgau Area (SW-Germany). Catena 22:153-168.

Clifton, R.J. and E.I. Hamilton. 1982. The application of radioisotopes in the study of estuarine sedimentary processes. Estuar. Coast. Shelf Sci. 14:433-466.

Clifton, R.J., P.G. Watson, J.T. Davey, and P.E. Frickers. 1995. A study of processes affecting the uptake of contaminants by intertidal sediments, using the radioactive tracers: Be-7, Cs-137 and unsupported Pb-210. Estuar. Coastal Shelf Sci. 41:459-474.

Cline, J.F. and W.H. Richards. 1972. Radioactive strontium and cesium in cultivated and abandoned plots. Health Phys. 23:317-324.

Clint, G.M. and J. Dighton. 1992. Uptake and accumulation of radiocaesium by mycorrhizal and non-mycorrhizal heather plants. New Phytol. 121:555-561.

Clymo, R.S. 1983. Peats, pp. 159-224. *In*: A.J. Core (ed.), Mires: swamps, bogs, fen and moor. Ecosystems of the world, 4A. Elsevier, New York.

Clymo, R.S., F. Oldfield, P.G. Appleby, G.W. Pearson, P. Ratnessar, and N. Richardson. 1990. A record of atmospheric deposition on a rain-dependent peatland. Phil. Trans. Royal Soc. London B 303:331.338.

Coard, M.A., S.M. Cousen, A.H. Cuttler, H.J. Dean, J.A. Dearing, T.I. Eglinton, A.M. Greaves, K.P. Lacey, P.E. O'Sullivan, D.A. Pickering, M.M. Rhead, J.K. Rodwell, and H. Simola. 1983. Paleolimnological studies of annually-laminated sediments in Loe Pool, Cornwall, U.K. Hydrobiologia 103:185-191.

Cockran, J.K. 1985. Particle mixing rates in sediments of the eastern equatorial Pacific: evidence from ^{210}Pu, $^{239+240}$Pu and ^{137}Cs distribution at MANOP sites. Geochim. Cosmochim. Acta 49:1195-1210.

Cockran, J.K. and J.K. Osmond. 1974. Gamma spectrometry of deep-sea cores and sediment accumulation rates. Deep Sea Res. 21:721-737.

Colacicco, D., T. Osborn, and K. Alt. 1989. Economic damage from soil erosion. J. Soil Water Conserv. 44:35-39.

Coleman, N.T., D. Craig, and R.J. Lewis. 1963. Ion exchange reactions of cesium. Soil Sci. Soc. Am. Proc. 27:287-289.

Coleman, N.T., R.J. Lewis, and D. Craig. 1963. Sorption of cesium by soil and its displacement by salt solutions. Soil Sci. Soc. Am. Proc. 27:290-294.

Colgan, P.A., P. McCann, E.J. McGee, and I.R. McAulay. 1993. Short and long-term losses of cesium-137 from peatland soils. Irish J. Agric. Food Res. 32:37-46.

Comans, R.N.J., M. Haller, and P. De Preter. 1991. Sorption of cesium on illite: non-equilibrium behavior and reversibility. Geochim. Cosmochim. Acta 55:433-440.

Comans, R.N.J. and D. Hockley. 1992. Kinetics of cesium sorption on illite. Geochim. Cosmochim. Acta 56:1157-1164.

Comans, R.N.J., J.J. Middleburg, J. Zonderhuis, R.J.W. Woittiez, G.J. DeLange, A.K. Das, and C.H. Van der Weijden. 1989. Mobilization of radio caesium in pore water of lake sediments. Nat. 367-369.

Cook, C. 1990. The evaluation of soil movement rates in a closed watershed using Cs-137 as a tracer. Unpublished MS Thesis, Washington State Univ., Pullman, Washington, USA.

Cooper, C.M. and J.R. McHenry. 1987. Sediment deposition and its effects on a Mississippi River oxbow lake. Environ. *Geol. Water Sci. 13:33-37.*

Cooper, C.M., F.R. Schiebe, and J.C. Ritchie. 1991. An inexpensive sampler for obtaining bulk sediment cores. Environ. Geol. Water Sci. 18:115-117.

Cooper, J.R., J.W. Gilliam, R.B. Daniels, and W.P. Robarge. 1987. Riparian areas as filters for agricultural sediment. Soil Sci. Soc. Am. J. 51:416-420.

Cooper, J.R., J.W. Gilliam, and T.C. Jacobs. 1986. Riparian areas as a control of nonpoint pollution, pp. 166-190. *In*: D.L. Correll (ed.), Watershed research perspectives, Smithsonian Institution Press, Washington, DC.

Cooper, L.W., J.M. Grebmeier, I.L. Larsen, C. Solis, and C.R. Olsen. 1995. Evidence for re-distribution of ^{137}Cs on Alaskan tundra, lakes, and marine sediments. Sci. Total Environ. 160/161:295-306.

Cooper, L.W., C.R. Olsen, D.K. Solomon, I.L. Larsen, R.B. Cook, and J.M. Grebmeir. 1991. Stable isotopes of oxygen and natural and fallout radionuclides used for tracing runoff during snowmelt in an Arctic watershed. Water Resour. Res. 27:2171-2179.

Coppinger, K.D., W.A. Reiners, I.C. Burke, and R.K. Olson. 1991. Net erosion on a sagebrush steppe landscape as determined by cesium-137 distribution. Soil Sci. Soc. Am. J. 55:254-258.

Cornett, R.J. and L. Chant. 1984. ^{239,240}Pu residence times in freshwaters and accumulation in shield lake sediments. Can. J. Fish. Aquat. Sci. 45:407-415.

Cornett, R.J., L. Chant, and D. Link. 1984. Sedimentation of ^{210}Pb in laurentian shield lake sediment. Water Pollut. Res. J. Can. 19:97-109.

Cornett, R.J., L.A. Chant, B.A. Risto, and E. Bonvin. 1994. Identifying resuspended particles using isotope ratios. Hydrobiologia 284:69-77.

Coughtrey, P.J., J.A. Kirton, and N.G. Mitchell. 1989. Transfer of radioactive caesium from soil to vegetation and comparison with potassium in upland grasslands. Environ. Pollut. 62:281-315.

Coughtrey, P.J. and M.C. Thorne. 1983. Radionuclide distribution and transport in terrestrial and aquatic ecosystems: a critical review. A.A. Balkema, Rotterdam.

Cox, M.E. and B.L. Frankhauser. 1984. Distribution of fallout ^{137}cesium in Hawaii. Health Phys. 46:65-71.

Craft, C.B. and J. Richardson. 1993. Peat accretion and N, P, and organic C accumulation in nutrient-enriched and unenriched peatland. Ecol. Applications 3:446-458.

Craft, C.B., E.D. Seneca, and S.W. Broome. 1993. Vertical accretion in microtidal regularly and irregularly flooded estuarine marshes. Estuar. Coast. Shelf Sci. 37:371-386.

Cranwell, P.A. 1973. Branched-chain and cyclopropanoid acids in a recent sediment. Chem. Geol. 11:307-313.

Cranwell, P.A. 1976. Decomposition of aquatic biota and sediment formation: lipid components of two blue-green algal species and detritus resulting from microbial attack. Freshwater Biol. 6:481-488.

Cranwell, P.A. 1977. Organic chemistry of Cam Loch (Sutherland) sediments. Chem. Geol. 20:205-221.

Cremers, A., A. Elsen, P. De Preter, and A. Maes. 1988. Quantitative analysis of radiocaesium retention in soils. Nat. 335:247-249.

Cremers, A., A. Elsen, E. Valcke, J. Wauters, F.J. Sandalls, and S.L. Gaudern. 1990. The sensitivity of upland soils to radiocesium contamination, pp. 238-248. *In*: G. Desment, P. Nassimbeni, and M. Belli (eds.), Transfer of radionuclides in natural and semi-natural environments, Proceedings of a CEC workshop, Udine, Italy.

Crete, M., M.A. Lefebvre, L. Zikovsky, and P. Walsh. 1992. Cadmium, lead, mercury and cesium-137 in fruticose lichens of Northern Quebec. Sci. Total Environ. 121:217-230.

Crickmore, M.J., G.S. Tazioli, P.G. Appleby, and F. Oldfield. 1990. The use of nuclear techniques in sediment transport and sedimentation problems. IHP-III Project 5.2 SC-90/WS-49, 170 pp. UNESCO, Paris, France.

Cromroy, H.L., W.A. Goldsmith, C.R. Phillips, and W.P. Bonner. 1967. Uptake of cesium-137 from contaminated soil by selected grass crops. Radiat. Health Data Report 8:421-424.

Crozier, C.R., I. Devai, and R.D. Delaune. 1995. Methane and reduced sulfur gas production by fresh and dried wetland soils. Soil Sci. Soc. Am. J. 59:277-284.

Crusius, J and R F Anderson 1990 ^{137}Cs mobility inferred from ^{210}Pb and ^{239,240}Pu analyses of laminated lake sediments EOS Trans 71 72

Crusius, J and R F Anderson 1991 Core compression and surficial sediment loss of lake sediments of high porosity caused by gravity coring Limnol Oceanogr 36 1021-1031

Crusius, J and R F Anderson 1995a Evaluating the mobility of ^{137}Cs, $^{239+240}$Pu and ^{210}Pb from their distributions in laminated lake sediments J Paleolimnol 13 119-141

Crusius, J and R F Anderson 1995b Sediment focusing in six small lakes inferred from radionuclide profiles J Paleolimnol 13 143-155

Cundy, A B and I W Croundace 1995 Sedimentary and geochemical variations in a salt marsh-mud flat environment from the mesotidal Hamble esturay, southern England Marine Chem 51 115-132

Cundy, A B and I W Croudace 1996 Sediment accretion and recent sea-level rise in the solent, southern England - inferences from radiometric and geochemical studies Estuar Coastal Shelf Sci 43 449-467

Cunha, I I L and E L Fabra 1995 Cs-137 radioactivity data in Brazil Fresenius Environ Bull 4 19-24

Cunha, I I L , C S Munita, R P Paiva, and A Teixeira 1993 Levels of cesium-137 in seawater and fish from the Brazilian Coast Sci Total Environ 140 431-435

Cushing, C E and D G Watson 1974 Aquatic studies of Gable Mountain pond BNWL-1884, 24 pp Battelle Pacific Northwest Laboratories, Richland, WA

Cutshall, N H , I L Larsen, and M M Nichols 1981 Man-made radionuclides confirm rapid burial of kepone in James River sediments Science 213 440-442

Czuczwa, J M and R A Hites 1984 Environmental fate of combustion-generated polychlorinated dioxins and furans Environ Sci Tech 18 444-450

Dahlgaard, H 1994a Nordic radioecology the transfer of radionuclides through Nordic ecosystems to man, Elsevier, New York, 483pp

Dahlgaard, H 1994b Sources of Cs-137, Sr-90 and Tc-99 in the East Greenland current J Environ Radioact 25 37-55

Dahlman, R C and S I Auerbach 1968 Preliminary estimation of erosion and radiocesium redistribution in a fescue meadow ORNL-TM-2343, Oak Ridge National Laboratory, Oak Ridge, Tennessee

Dahlman, R C , C W Francis, and T Tamura 1975 Radiocesium cycling in vegetation and soil, pp 462-481 *In* F G Howell, J B Gentry, and M H Smith (eds), Mineral cycling in southeastern ecosystems, USAEC Symposium Series, CONF-740513, US Atomic Energy Commission, Washington, DC

Dalgleish, H Y and I D L Foster 1996 ^{137}Cs losses from a loamy surface water gleyed soil (Inceptisol) A laboratory simulation experiment Catena 26 227-245

Davidson, C I , J R Harrington, M J Stephenson, M C Monaghan, J Pudykiewicz, and W R Schell 1987 Radioactive cesium from the Chernobyl accident in the Greenland ice sheet Science 237 633-634

Davies, K S and G Shaw 1993 Fixation of Cs-137 by soil and sediment in the Esk estuary, Cumbria, UK Sci Total Environ 132 71-92

Davis, F W 1985 Historical changes in submerged macrophyte communities of upper Chesapeake Bay Ecol 66 981-983

Davis, J J 1963 Cesium and its relationship to potassium in ecology, pp 539-556 *In* V Schultz and A W Klement Jr (eds), Radioecology, Reinhold, New York

Davis, J J and R F Foster 1958 Bioaccumulation of radioisotopes through aquatic food chains Ecol 39 137-535

Davis, M B and M S Ford 1982 Sediment focusing in Mirror Lake, New Hampshire Limnol Oceanogr 27 137-150

Davis, R B , C T Hess, S A Norton, D W Hanson, K D Hoagland, and D S Anderson 1984 ^{137}Cs and ^{210}Pb dating of sediment from soft-water lakes in New England (U S A) and Scandinavia, a failure of ^{137}Cs dating Chem Geol 44 151-185

Davis, R B and S A Norton 1978 Paleolimnology of six New England lakes, pp 217-308 *In* R W Hardy (ed), The impact of urbanization on New England lakes, selected technical papers, Vol III, New England Council Water Center Dir , Boston, MA

Davis, R B , S A Norton, D F Brakke, F Berge, and C T Hess 1980 Atmospheric deposition in Norway during the past 300 years as recorded in SNSF lake sediments, Part IV Synthesis and comparison with New England, pp 274-275 *In* D Drablos and A Tollan (eds), Proceedings international conference on ecological impact of acid precipitation, Sandefjord, Norway

Davis, R B , S A Norton, C T Hess, and D F Brakke 1983 Paleolimnological reconstruction of the effect of atmospheric deposition of acid and heavy metals on the chemistry and biology of lakes in New England and Norway Hydrobiologia 103 113-123

Davison, W , J Hilton, J Hamilton-Taylor, M Kelly, F Livens, E Rigg, T R Carrick, and D L Singleton 1993 The transport of Chernobyl derived caesium through two freshwater lakes in Cumbria, U K J Environ Radioact 19 125-153

Davison, W , P Spezzano, and J Hilton 1993 Remobilization of caesium from freshwater sediments J Environ Radioact 19 109-124

Dawson, R and E K Duursma 1974 Distribution of radioisotopes between phytoplankton, sediment and sea water in a dialysis compartment system Neth J Sea Res 8 339-353

Day, D G and B L Campbell 1986 Environmental caesium-137 as an indicator of accelerated erosion and sedimentation in Birchams Creek, NSW Centre for Resource and Environmental Studies, ANU, Canberra Working Paper 1986/42

Day, L R and H H Zumpe 1986 Radioactivity in silt from the River Lea, England Environ Pollut (Series B) 12 75-84

Dearing, J.A. 1983. Changing patterns of sediment accumulation in a small lake in Scania, Southern Sweden. Hydrobiologia 103:59-64.

Dearing, J.A. 1991. Lake sediment records of erosional processes. Hydrobiologia 214:99-106.

Dearing, J.A. 1992. Sediment yields and sources in a Welsh upland catchment during the past 800 years. Earth Surf. Proc. Landforms 17:1-22.

Dearing, J.A., J.K. Elner, and C.M. Happey-Wood. 1981. Recent sediment flux and erosional processes in a Welsh upland lake-catchment based on magnetic susceptibility measurements. Quat. Res. 16:356-372.

Dearing, J.A., H. Hakansson, B. Lieberg-Jonsson, A. Persson, S. Skansjo, D. Widholm, and F. El-Daoushy. 1987. Lake sediments used to quantify the erosional response to land use change in southern Sweden. Oikos 50:60-78.

Deevey, E.S. Jr. 1988. Estimation of downward leakage from Florida lakes. Limnol. Oceanogr. 33:1308-1320.

de Brouwer, S., Y. Thiry and C. Myttenaere. 1994. Availability and fixation of radiocaesium in a forest brown acid soil. Sci. Total Environ. 143:183-191.

de Jong, E., C.B.M. Begg, and R.G. Kachanoski. 1983. Estimates of soil erosion and deposition from some Saskatchewan soils. Can. J. Soil Sci. 63:607-617.

de Jong, E. and R.G. Kachanoski. 1988. The importance of erosion in the carbon balance of prairie soils. Can. J. Soil Sci. 68:111-119.

de Jong, E. and T.E. Kowalchuk.1995. The effect of shelterbelts on erosion and soil properties. Soil Sci. 159:337-345.

de Jong, E., H. Villar, and J.R. Bettany. 1982. Preliminary investigations on the use of ^{137}Cs to estimate erosion in Saskatchewan. Can. J. Soil Sci. 62:673-683.

de Jong, E., C. Wang, and H.W. Rees. 1986. Soil distribution on three cultivated New Brunswick hillslopes calculated from ^{137}Cs measurement, solum data and the USLE. Can. J. Soil Sci. 66:721-730.

DeLaune, R.D. 1986. The use of $\delta^{13}C$ signature of C-3 and C-4 plants in determining past depositional environments in rapidly accreting marshes of the Mississippi River deltaic plain, Louisiana, U.S.A. Chem. Geol. 59:315-320.

DeLaune, R.D., R.H. Baumann, and J.G. Gosselink. 1983. Relationship among vertical accretion, coastal submergence, and erosion in Louisiana Gulf Coast marsh. J. Sedimentary Petrology 53:147-157.

DeLaune, R.D. and R.P. Gambrell. 1996. Role of sedimentation in isolating metal contaminants in wetland environments. J. Environ. Sci.Health Part A Environ. Sci. Engr. & Toxic and Hazardous Substance Control 31(9):2349-2362.

DeLaune, R.D., G.L. Jones, and C.J. Smith. 1986. Radionuclide concentrations in Louisiana soils and sediments. Health Phys. 51:239-244.

DeLaune, R.D., C.W. Lindau, R.S. Knox, and C.J. Smith. 1990. Fate of nitrogen and phosphorus entering a Gulf Coast fresh water lake: a case study. Water Resour. Bull. 26:621-631.

DeLaune, R.D., J.A. Nyman, and W.H. Patrick Jr. 1994. Peat collapse, ponding and wetland loss in a rapidly submerging coastal marsh. J. Coastal Res. 10:1021-1030.

DeLaune, R.D. and W.H. Patrick Jr. 1990. Nitrogen cycling in Louisiana Gulf Coast brackish marshes. Hydrobiologia 199:73-79.

DeLaune, R.D., W.H. Patrick Jr., and R.J. Buresh. 1978. Sedimentation rates determined by ^{137}Cs dating in a rapidly accreting salt marsh. Nature 275:532-533.

DeLaune, R.D., W.H. Patrick Jr., and S.R. Pezeshki. 1987. Foreseeable flooding and death of coastal wetland forest. Environ. Conserv. 14:129-133.

DeLaune, R.D, W.H. Patrick, and C.J. Smith. 1992. Marsh aggradation and sediment distribution along rapidly submerging Louisiana Gulf Coast. Environ. Geol. Water Sci. 20:57-64.

DeLaune, R.D., C.N. Reddy, and W.H. Patrick Jr. 1981. Accumulation of plant nutrients and heavy metals through sedimentation processes and accretion in a Louisiana salt marsh. Estuar. 4:328-334.

DeLaune, R.D., C.J. Smith, and W.H. Patrick Jr. 1986. Sedimentation patterns in a Gulf Coastal backbarrier marsh: response to increasing submergence. Earth Surf. Proc. Landforms 11:485-490.

DeLaune, R.D., C.J. Smith, W.H. Patrick Jr., and H.H. Roberts. 1987. Rejuvenated marsh and bay-bottom accretion on rapidly subsiding Coastal Plain of the U.S. Gulf coast: a second-order effect of the emerging Atchafalaya delta. Estuar. Coast. Shelf Sci. 25:381-389.

DeLaune, R.D., C.J. Smith, and M.N. Sarafyan. 1986. Nitrogen cycling in a freshwater marsh of *Panicum hemitomon* on the deltaic plain of the Mississippi River. J. Ecol. 74:249-256.

Delle Site, A., O. Ferretti, V. Marchionni, and C. Papucci. 1984. Measurement of ^{137}Cs, $^{239,240}Pu$ and ^{238}Pu in some coastal sediment of Tyrrhenian sea. Comm. Eur. Communities, (Rep) EUR(CECED9), pp. 233-243.

DeMaster, D.J., B.A. McKee, C.A. Nittrouer, D.C. Brewster, and P.E. Biscaye. 1985. Rates of sediment reworking at the Hebble Site based on measurements of Th-234, Cs-137 and Pb-210. Marine Geol. 66:133-148.

De Preter, P.M. 1990. Radiocesium retention in the aquatic, terrestrial and urban environment: a quantitative and unifying analysis. Doctoraatsproefschrift Nr. 1990. Katholieke Universiteit te Leuven, Leuven, Belgium.

De Roo, A.P.J. 1991. The use of ^{137}Cs as a tracer in an erosion study in South Limburg (The Netherlands) and the influence of Chernobyl fallout. Hydrol. Process. 5:215-227.

De Roo, A.P.J. and D.E. Walling. 1994. Validating the ANSWERS soil erosion model using ^{137}Cs, pp 246-263. *In*: R.J. Rickson (ed.) Conserving Soil Resources: European Prespective, Wallingford, UK.

Derose, R.C., N.A. Trustrum, and P.M. Blaschke. 1993. Post-deforestation soil loss from steepland hillslopes in Taronki, New Zealand. Earth Surf. Proc. Landforms 18:131-144.

Desloges, J.R. 1987. Paleohydrology of the Bella Coola river basin: an assessment of environmental reconstruction. Ph.D. Thesis. Univ. British Columbia, Canada.

Desmet, G.M., L.R. Van Loon, and B.J. Howard. 1991. Chemical speciation and bioavailability of elements in the environment and their relevance to radioecology. Sci. Total Environ. 100:124.

Dickman, M.D. and H.G. Thode. 1985. The rate of lake acidification in four lakes north of Lake Superior and its relationship to downcore sulphur isotope ratios. Water Air Soil Pollut. 26:233-253.

Dickman, M., H.G. Thode, S. Rao, and R. Anderson. 1988. Downcore sulphur isotope ratio and diatom inferred pH in an artificially acidified Canadian Shield lake. Environ. Pollut. 49:265-288.

Dickson, J.H., D.A. Stewart, R. Thompson, G. Turner, M.S. Baxter, N.D. Drndarsky, and J. Rose. 1978. Palynology, paleomagnetism, and radiometric dating of Flandrian marine and freshwater sediments of Loch Lomond. Nature 274:548-553.

Digerfeldt, G., R. Battarbee, and L. Bengtsson. 1975. Report of annually laminated sediments in Lake Järlasjön, Nacka, Stockholm. Geologiska Foreningens i Stockholm Forhand Lingar 97:29-40.

Dighton, J., G.M. Clint, and J. Poskitt. 1991. Uptake and accumulation of ^{137}Cs by upland grassland soil fungi: A potential pool of Cs immobilization. Mycol. Res. 95:1052-1056.

Duliu, O.G., L.C. Dinescu, M.C. Dinescu, R.D. Dorcioman, N.G. Mihailescu, and I.S. Vanghelie. 1996 Some considerations concerning 137Cs vertical profile in the Danube Delta: Matita Lake core. Sci. Total Environ. 188: 9-14.

Dodd, J.D. and G.L. Van Amburg. 1970. Transfer to and distribution of ^{134}cesium in the soil of two grassland habitats. Can. J. Sci. 50:121-129.

Domanov, M.M. and A.E. Gorbunov. 1992. The prognosis of the field of cesium-137 in the upper layers of the Black Sea. Okeanologiya 32:253-256.

Domanov, M.M., E.A. Kontarö, R.D. Kosöyan, Yu.A. Sapozhnikov, and K.N. Shimkus. 1996. Anthropogenic radionuclides in the north-west Black Sea. Okeanologiya 36:550-555. (Russian)

Dominik, J. 1989. Application des radio-isotopes naturels at anthropogènes pour l'étude des processes sédimentaires dans le Léman. Cashier Fac. Sci. Université de Genève 19:83-95. (French)

Dominik, J., D. Burrus, and J.P. Vernet. 1987. Transport of the environmental radionuclides in an alpine watershed. Earth Planet. Sci. Lett. 84:165-180.

Dominik, J., U. Förstner, A. Mangini, and H. Reineck. 1978. ^{210}Pb and ^{137}Cs chronology of heavy metal pollution in a sediment core from the German Bight (North Sea) Senckenbergiana Marit 10:213-227.

Dominik, J., J.L. Loizeau, and D. Span. 1992. Radioisotopic evidence of perturbations of recten sedimentary records in lakes: a word of caution from climate studies. Clim. Dynamics 6:145-152.

Dominik, J., A. Mangini, and G. Müller. 1981. Determination of recent deposition rates in Lake Constance with radioisotopic methods. Sedimentology 28:653-677.

Dominik, J., A. Mangini, and F. Prosi. 1984. Sedimentation rate variations and anthropogenic metal fluxes into Lake Constance sediments. Environ. Geol. 5:151-157.

Dominik, J. and D. Span. 1992. The fate of Chernobyl cesium-137 in Lake Lugano. Aquat. Sci. 54:238-254.

Donoghue, J.F., O.P. Bricker and C.R. Olsen. 1989. Particle-borne radionuclides as tracers for sediment in the Susquehanna River and Chesapeake Bay. Estuar. Coast. Shelf Sci. 29:341-360.

Dörr, H. 1995. Application of ^{210}Pb in soils. J. Paleolimnol. 13:157-168.

Dörr, H. and K.O. Münnich. 1987. Spatial distribution of soil ^{137}Cs and ^{134}Cs in West Germany after Chernobyl. Naturwissenschaften 74:249-251.

Dörr, H. and K.O. Münnich. 1989. Downward movement of soil organic matter and its influence on trace element transport (Pb-210, Cs-137) in soil. Radiocarbon 31:655-663.

Dörr, H. and K.O. Münnich. 1991. Lead and cesium transport in European forest soils. Water Air Soil Pollut. 57:809-818.

Dregne, H.E. 1990. Erosion and soil productivity in Africa. J. Soil Water Conserv. 45:431-436.

Dregne, H.E. 1992. Erosion and soil productivity in Asia. J. Soil Water Conserv. 47:8-13.

Drndarski, N and M. Krizman. 1994. Radioisotopes in periphyton and sediments from the Kolubara River and it tributaries. Water Res. 28:1471-1474.

Drndarski, N.D. and N. Lavi. 1996. Radioactivity in sediments from the Grliska impoundment. Water Res. 30:1539-1542.

Dunn, D.L., W.G. Win, and P.J. Bresnahan. 1996. Coping measurements of radionuclides in L Lake with an underwater HPGe detector. Report No.: WSRC-TR-95-0397 36p, Westinghouse Savannah River Co., Aiken, SC.

Durham, R.W. and S.R. Joshi. 1980a. Recent sedimentation rates, ^{210}Pb fluxes, and particle settling velocities in Lake Huron, Laurentian Great Lakes. Chem. Geol. 31:53-66.

Durham, R.W. and S.R. Joshi. 1980b. The ^{210}Pb and ^{137}Cs profiles in sediment cores from Lake Matagami and Quevillon, northwest Quebec, Canada. Can. J. Earth Sci. 17:1746-1750.

Durham, R.W. and S.R. Joshi. 1980c. Radioactive dating of sediment cores from four contiguous lakes in Saskatchewan, Canada. Sci. Total Environ. 15:65-71.

Durham, R.W. and S.R. Joshi. 1981. Sedimentation rates in western Nipigon Bay, Lake Superior using the ^{210}Pb method. Sci. Total Environ. 22:51-59.

Durham, R.W. and S.R. Joshi. 1984a. Dose equivalent commitments from fallout radionuclides in the open waters of the Great Lakes. 1973-1981. Environ. Monit. Assessment 4:405-417.

Durham, R.W. and S.R. Joshi. 1984b. Lead-210 dating of sediments from some northern Ontario lakes, pp. 75-85. *In*: W.C. Mahaney (ed.), Quaternary dating methods, Elsevier, Amsterdam.

Durham, R.W., S.R. Joshi, and R.J. Allan. 1980. Radioactive dating of sediment cores from four contiguous lakes in Saskatchewan, Canada. Sci. Total Environ. 15:65-71.

Durham, R.W. and B.G. Oliver. 1983. History of Lake Ontario contamination from the Niagara River sediment radiodating and chlorinated hydrocarbons analysis. J. Great Lakes Res. 9:160-168.

Duursma, E.K. and C.J. Bosch. 1970. Theoretical, experimental and field studies concerning diffusion of radioisotopes in sediments and suspended particles of the sea. Part B: methods and experiments. Neth. J. Sea Res. 4:395-469.

Duursma, E.K. and D. Eisma. 1973. Theoretical experimental and field studies concerning the molecular diffusion of radioisotopes in sediments and suspended solid particles in the sea. Part C: Applications to field studies. Neth J. Sea Res. 6:265-284.

Duursma, E.K. and C. Hoede. 1967. Theoretical experimental and field studies concerning the molecular diffusion of radioisotopes in sediments and suspended solid particles in the sea. Part A: theories and mathematical calculations. Neth. J. Sea Res. 3:423-457.

Eadie, B.J. and J.A. Robbins. 1987. The role of particulate matter in the movement of contaminants in the Great Lakes, pp. 319-364. *In*: R.A. Hites and S.J. Eisenreich (eds.), Sources and fates of aquatic pollutants, American Chemical Society, Washington, DC.

Eakins, J.D. and R.S. Cambray. 1985. Studies of environmental radioactivity in Cumbria, Part 6: the chronology of discharge of caesium-137, plutonium, and americium-241 from BNFL Sellafield, as recorded in lake sediments. AERE-R-11182. United Kingdom Atomic Energy Authority Report, Harwell, UK.

Eakins, J.D., R.S. Cambray, K.C. Chambers, and A.E. Lally. 1984. The transfer of natural and artificial radionuclides to Brotherswater from its catchment, pp. 125-144. *In*: E.Y. Haworth and J.W.G. Lund (eds.), Lake sediment and environmental history, Univ. Minnesota Press, Minneapolis, MN.

Eakins, J.D. and R.T. Morrison. 1978. A new procedure for the determination of lead-210 in lake and marine sediments. J. Appl. Radiat. Isot. 29:531-536.

Eberl, D.D. 1980. Alkali cation selectivity and fixation by clay minerals. Clays Clay Minerol. 28:161-172.

Eckblad, J.W., N.L. Peterson, K. Ostlie, and A. Temte. 1977. The morphometry, benthos and sedimentation rates of a floodplain in Pool 9 of the upper Mississippi River. Am. Midland Naturalist 97:433-443.

Edberg, N. 1980. Determination of recent sedimentation rates in lakes by ^{137}Cs. Vatten 36:35-44.

Edgington, D.N. and D.M. Nelson. 1986. The persistence of pollutants in large lakes: the lessons from study of radioactivity, pp. 250-266. *In*: T.H. Sibley and C. Myttenaere (eds.), Application of distribution coefficients to radioecological assessment models, Elsevier, London.

Edgington, D.N., J.C. Ritchie, and J.A. Robbins. 1975. Comments on the paper: "Use of rivers to predict accumulation in sediments of radionuclides discharged from nuclear power plants" by P. Plato. Health Phys. 29:429-431.

Edgington, D.N. and J.A. Robbins. 1974a. Determination of recent sedimentation rates in Lake Michigan using Pb-210 and Cs-137, pp. 39-62. *In*: Radiological and environmental research division annual report, ecology, January-December 1973, Argonne National Laboratory, Argonne, IL.

Edgington, D.N. and J.A. Robbins. 1974b. The application of natural and fallout radionuclides to the studies of Lake Michigan, pp. 443-458. *In*: Proceeding conference on nuclear methods in environmental research, US ERDA Conference 740701, US Energy Research and Development Authority, Washington, DC.

Edgington, D.N. and J.A. Robbins. 1976a. The behavior of plutonium and other long-lived radionuclides in Lake Michigan II. Patterns of deposition in sediments, pp. 245-260. *In*: Impacts of nuclear releases into the aquatic environment, International Atomic Energy Agency, Vienna, Austria.

Edgington, D.N. and J.A. Robbins. 1976b. Patterns of deposition of natural and fallout radionuclides in Lake Michigan and their relation to limnological processes, pp. 705-729. *In*: J.O. Nriagu (ed.), Environmental biochemistry, volume 2: metal transfer and ecological mass balances, Ann Arbor Science Publishers, Ann Arbor, MI.

Edgington, D.N. and J.A. Robbins. 1976c. Records of lead deposition in Lake Michigan sediments since 1800. Environ. Sci. Tech. 10:266-274.

Edgington, D.N. and J.A. Robbins. 1976d. Patterns of deposition of radionuclides in sediments, pp. 1-12. *In*: Symposium on nonbiological transport and transformation of pollutants on land and water: processes and critical data required for predictive description, Gaithersburg, MD.

Edgington, D.N. and J.A. Robbins. 1976e. Patterns of natural and fallout radionuclides in sediment of Lake Michigan, pp. 705-729. *In*: J.O. Nriagu (ed.), Environmental biogeochemistry, Vol. 2, Ann Arbor Science Publ. Inc., Ann Arbor, MI, USA.

Edgington, D.N. and J.A. Robbins. 1977. Radionuclide geochronology and pollution history in lake sediment. Trans. Am. Nucl. Sci. 27:117.

Edgington, D.N. and J.A. Robbins. 1979. Reply to Appleby and Oldfield (1979). Environ. Sci. Tech. 13:480-482.

Edgington, D.N. and J.A. Robbins. 1988. Time scales of sediment focussing in Lake Michigan as revealed by measurement of fallout Cs-137. *In*: D. Imboden (ed.), Functional and structural properties of large lakes, Societas Internationalis Limnologiue Symposium, Konstunz, Germany.

Edgington, D.N. and J.A. Robbins. 1990. Time scales of sediment focussing in Lake Michigan as revealed by measurements of fallout Cs-137, pp. 210-223. *In*: M. Tilzer and C. Serruya (eds.), Large Lakes: ecological structure and function. Science Technology, Madison, WI.

Edgington, D.N., J.A. Robbins, and J.O. Karttunen. 1974. The distribution of Pb-210 and stable lead in Lake Michigan sediments, pp. 63-76. *In*: Radiological and environmental research division annual report, Ecology, January-December 1973, Argonne National Laboratory, Argonne, IL.

Edgington, D.N., J. Val Klump, J.A. Robbins, Y.S. Kusner, V.D. Pampura, and I.V. Sandimmirov 1991. Sedimentation rates, residence time, and radionuclide inventories in Lake Baikal from ^{137}Cs and ^{210}Pb in sediment cores. Nature 350:601-604.

Edwards, K. 1980. Runoff and soil loss in the wheat belt of New South Wales, pp. 94-98. *In*: IAHS proceedings of the agricultural engineering conference.

Effler, S.W. 1987. The impact of a chlor-alkali plant on Onondaga Lake and adjoining systems. Water Air Soil Pollut. 33:85-115.

Effler S.W. and C.F. Carter. 1987. Spatial variability in selected physical characteristics and processes in Cross Lake, New York. Water Resour. Bull. 23:243-249.

Effler, S.W., M.C. Rand, and T.A. Tamayo. 1979. The effect of heavy metals and other pollutants on the sediments of Onondago Lake. Water Air Soil Pollut. 12:117-134.

Ehlers, J., K. Nagorny, P. Schmidt, B. Stieve, and K. Zietlow. 1993. Storm surge deposits in North Sea salt marshes dated by Cs-134 and Cs-137 determination. J. Coast. Res. 9:698-701.

Elejalde, C., M. Herranz, F. Romero, and F. Legarda. 1996. Correlations between soil parameters and radionuclide contents in samples from Biscay (Spain). Water, Air, Soil Pollut. 89:23-31.

Elliott, G.L., B.L. Campbell, and R.J. Loughran. 1984. Correlation of erosion and erodibility assessments using Caesium-137. J. Soil Conserv. (New South Wales) 40:24-29.

Elliott, G.L., B.L. Campbell, and R.J. Loughran. 1990. Correlation of erosion measurement and soil caesium-137 content. J. Appl. Radiat. Isot. 41:713-717.

Elliott, G.L. and B.E. Cole-Clark. 1993. Estimates of erosion on potato lands on Krasnozems at Dorrigo, N.S.W. using the caesium-137 technique. Aust. J. Soil Res. 31:209-223.

Elliott, G.L., R.D. Lang, and B.L. Campbell. 1983. The association of tree species, landform, soils and erosion on Narrabeen sandstone west of Putty, New South Wales. Aust. J. Ecol. 8:321-331.

Ellis, J. and S. Kanamori. 1977. Water pollution studies on Lake Illawarra III. Distribution of heavy metals in sediments. Aust. J. Marine Freshwater Res. 28:485-496.

Ely, L.L., R.H. Webb, and Y. Enzel. 1992. Accuracy of post-bomb ^{137}Cs and ^{14}C in dating fluvial deposits. Quat. Res. 38:196-204.

Engstrom, D.R., E.B. Swain, and J.C. Kingston. 1985. A palaeolimnological record of human disturbance from Harvey's Lake, Vermont: geochemistry, pigment and diatoms. Freshwater Biol. 15:261-288.

Entry, J.A., P.T. Rygiewicz, and W.H. Emmingham. 1993. Accumulation of cesium-137 and strontium-90 in Ponderosa pine and Monterey pine seedlings. J. Environ. Qual. 22:742-746.

Eremeev, V.N., L.M. Ivanov, A.D. Kirwan, and T.M. Margolina. 1995a. Analysis of caesium pollution in the Black Sea by regularization methods. Marine Pollut. Bull. 30:460-462.

Eremeev, V.N., L.M. Ivanov, A.D. Kirwan, and T.M. Margolina. 1995b. Amount of Cs-137 and Cs-134 radionuclides in the Black Sea produced by the Chernobyl accident. J. Environ. Radioact. 27:49-63.

Erten, H.N., H.R. von Gunten, E. R`ssler, and M. Strum. 1985. Dating the sediments of Lake Zurich (Switzerland) with ^{210}Pb and ^{137}Cs. Schweiz. Z. Hydrol. 47:5-11.

Erten, N.N., S. Aksoyoglu, and H. Gokturk. 1988. Sorption/desorption of caesium on clay and soil fraction from various regions of Turkey. Sci. Total Environ. 69:269-296.

Erten, N.N., S. Aksoyoglu, S. Hahpoglu, and H. Gokturk. 1988. Sorption of caesium and strontium on montmorillonite and kaolinite. Radiochimica Acta 44/45:147-151.

Essington, E.H. and E.M. Romney. 1985. Mobilization of ^{137}Cs during rainfall simulation studies at the Nevada Test Site, pp. 35-38. *In*: L.J. Lane (ed.) Proceedings of the rainfall simulator workshop, Society for Range Management, Denver, CO.

Evans, D.W., J.J. Alberts, and R.A. Clark III. 1983. Reversible ion-exchange fixation of cesium-137 leading to mobilization from reservoir sediments. Geochim. Cosmochim. Acta 47:1041-1049.

Evans, E.J. and A.I. Dekker. 1966a. Plant uptake of Cs-137 from nine Canadian soils. Can. J. Soil Sci. 46:167-176.

Evans, E.J. and A.I. Dekker. 1966b. Fixation and release of Cs-137 in soils and soil separates. Can. J. Soil Sci. 46:217-222.

Evans, H.E., D.C. Lasenby, and P.J. Dillon. 1986. The effect of core compression on the measurement of zinc concentration and anthropogenic burdens in lake sediments. Hydrobiologia 132:185-192.

Evans, M.S. 1996. Depositional history of sediment in Great Slave Lake: Spatial and temporal patterns in geochronology, bulk parameters, PAHs and chlorinated contaminants. Canadian Northern River Basins Study project Report No.: SSC-R71-49/3-99E; ISBN-0-662-24644-6, 198p.

Evans, R.D. and F.H. Rigler. 1983. A test of lead-210 dating for the measurement of whole lake soft sediment accumulation. Can. J. Fish. Aquat. Sci. 40:506-515.

Eyman, L.D. and N.R. Kevern. 1975. Cesium-137 and stable cesium in a hypereutrophic lake. Health Phys. 28:549-555.

Facher, E. And R.A. Schmidt. 1996. A siliceous chrysophycean cyst-based pH transfer function for Central European lakes. J. Paleolimnol. 16:275-321.

Fahaad, A.A., A.W. Ali, and R.M. Shihab. 1989. Mobilization and fractionation of ^{137}Cs in calcareous soils. J. Radiat. Nucl. Chem. 130:192-201.

Farmer, J.G. 1977. The determination of sedimentation rates in Lake Ontario using ^{210}Pb dating methods. Can. J. Earth Sci. 15:431-437.

Farmer, J.G. 1978. Lead concentration profiles in lead-210 dated Lake Ontario sediment cores. Sci. Total Environ. 10:117-127.

Farmer, J.G. 1983. Metal pollution in marine sediment cores from the west coast of Scotland. Marine Environ. Res. 8:1-28.

Farmer, J.G., D.S. Swan, and M.S. Baxter. 1980. Records and sources of metal pollutants in a dated Loch Lomond sediment core. Sci. Total Environ. 16:131-147.

Faulkner, D and S McIntyre 1996 Persisting sediment yields and sediment delivery changes Water Resour Bull 32 817-829

Favarger, P and J Vernet 1979 L'isotope ^{137}Cs utilisé comme dateur de la pollution des sédiments lacustres Arch Sci 32 25-41 (French)

Fawaris, B H and K J Johanson 1995a Fractionation of caesium (^{137}Cs) in coniferous forest soil in central Sweden Sci Total Environ 170 221-228

Fawaris, B H and K J Johanson 1995b Sorption of ^{137}Cs from undisturbed forest soil in a zeolite trap Sci Total Environ 172 251-256

Feely, H W , H L Volchok, E P Hardy, Jr , and L E Toonkel 1978 Worldwide deposition of ^{90}Sr through 1976 Am Chem Soc J 12 808-809

Feijtel, T C , R D DeLaune, and W H Patrick Jr 1985 Carbon flow in coastal Louisiana Marine Ecol Progress Series 24 255-260

Feijtel, T C , R D DeLaune, and W H Patrick Jr 1988a Biogeochemical control on metal distribution and accumulation in Louisiana sediments J Environ Qual 17 88-94

Feijtel, T C , R D DeLaune, and W H Patrick Jr 1988b Seasonal pore water dynamics in marshes of Barataria Basin, Louisiana Soil Sci Soc Am J 52 59-67

Fesenko, S V , S I Spiridonov, N I Sanzharova, and R M Alexakhin 1996 Modelling of ^{137}Cs availability in soils subjected to contamination after the accident at the Chernobyl NPP Radiatsionnaya Biologiya Radioekologiya 36(4) 479-487 (Russian)

Fesenko, S V , S I Spiridonov, N I Sanzharova, and R M Alexakhin 1997 Dynamics of ^{137}Cs bioavailability in a soil-plant system in areas of the Chernobyl Nuclear Power Plant accident zone with a different physico-chemical composition of radioactive fallout J Environ Radioact 34 287-313

Filipovic-Vincekovic, N D Barisic, N, Masic, and S Liluic 1991 Distribution of fallout radionuclides through the soil surface layer J Radioanal Nucl Chem Art 148 53-62

Fisher, J B , W J Lick, P L McCall, and J A Robbins 1980 Vertical mixing of lake sediments by tubificid Oligochaetes J Geophys Res 85 3998-4006

Fleishman, D G , V A Nikiforov, A A Saulus, and V T Komov 1994 Cs-137 in fish of some lakes and rivers of the Bryansk Region and North-West Russia in 1990-1992 J Environ Radioact 24 145-158

Flowers, R J , R W Battarbee, J Natkanski, B Rippey, and P G Appleby 1988 The recent acidification of large Scottish Loch located partly within a national nature reserve and site of special scientific interest J Appl Ecol 25 715 724

Flowers, R J , A C Stevenson, J A Dearing, I D L Foster, A Airey, B Rippey, J P F Wilson, and P G Appleby 1989 Catchment disturbance inferred from paleolimnological studies of three contrasted sub-humid environments in Morocco J Paleolimnology 1 293-322

Flynn, W W 1970 A rapid solvent extraction method of the determination of caesium-137 in environmental materials Analytica Chimica Acta 50 365-373

Forster, H And Schimmack 1992 Influence of stemflow on the depth distribution of radiocesium in soil under beech stand Naturwissenschaften 79 23-24

Förstner, U 1987 Sediment-associated contaminants - an overview of scientific bases for developing remedial options Hydrobiologia 149 221-246

Forsyth, T J 1994 The use of cesium-137 measurements of soil erosion and farmers perceptions to indicate land degradation amongst shifting cultivators in northern Thailand Mountain Research and Development 14 229-244

Foster, G R 1991 Advances in wind and water erosion prediction J Soil Water Conserv 46 27-29

Foster, G R and T E Hakonson 1984 Predicted erosion and sediment delivery of fallout plutonium J Environ Qual 13 595-602

Foster, I D L 1995 Lake and reservoir bottom sediments as a source of soil erosion and sediment transport data in the U K , pp 265-283 *In* I D L Foster, A M Gurnell, and B W Webb (eds), Sediment and water quality in River Catchments, Wiley, Chichester, U K

Foster, I D L , H Dalgeish, J A Dearing, and E D Jones 1994 Quantifying soil erosion and sediment transport in drainage basins Some observations on the use of ^{137}Cs IAHS Publ No 224 55-64

Foster, I D L , J A Dearing, and P G Appleby 1986 Historical trends in catchment sediment yields a case study in reconstruction from lake-sediment records in Warwickshire, UK Hydrological Sci J 31 427-443

Foster, I D L , J A Dearing, A Simpson, A D Carter, and P G Appleby 1985 Lake catchment based studies of erosion and denudation in the Merevale Catchment, Warwickshire, U K Earth Surf Process Landforms 10 45-68

Foster, I D L , R Grew, and J Dearing 1990 Magnitude and frequency of sediment transport in agricultural catchments a paired lake-catchment study in Midland England, pp 153-171 *In* J Boardman, I D L Foster, and J A Dearing (eds), Soil erosion of agricultural land, Wiley, London

Foster, I D L , P N Owens, and D E Walling 1996 Sediment yields and sediment delivery in the catcments of slapton Lower Ley, South Devon, UK Field Studies 8 629-661

Foster, I D L and D E Walling 1994 Using reservoir deposits to reconstruct changing sediment yields and sources in the catchment of the Old Mill Reservoir, South Devon, UK, over the past 50 years Hydrol Sci J 39 347-368

Foster, I D L , D E Walling, and P Owens 1993 Sediment yields and budgets in the Start Valley, pp 25-30 *In* T P Burt (ed), A field guide to geomorphology of the Slapton Region, British Geomorphological Research Group, Occassional Publications of the Field Studies Council 27, Shrewsbury, UK

Fraley, L., G. Chavez, and O.D. Markham. 1993. Seasonal variations in deposition and retention of cerium-141 and cesium-134 in cool desert vegetation. J. Environ. Radioact. 21:203-212.

France, R.L., J. Svoboda, and H.W. Taylor. 1993. Latitudinal distribution of cesium-137 fallout in 1990 on Saxifraga-Oppositifolia from Elles Mere Island Canada. Can. J. Bot. 71:708-711.

Francis, C.W. and F.S. Brinkley. 1976. Preferential adsorption of ^{137}Cs to micaceous minerals in contaminated freshwater sediments. Nature 260:511-513.

Fraley, L., G. Chavez, and O.D. Markham. 1993. Seasonal variations in deposition and retention of cerium-141 and cesium-134 in cool desert vegetation. J. Environ. Radioact. 21:203-212.

Franklin, R.E., P.L. Gersper, and N. Holowaychuk. 1967. Analysis of gamma-ray spectra from soils and plants: II. effects of trees on the distribution of fallout. Soil Sci. Soc. Am. Proc. 31:43-45.

Fredericks, D.J., V. Norris, and S.J. Perrens. 1988. Estimating erosion using caesium-137: I. measuring caesium-137 activity in soil. IAHS Publ. No. 174:225-231.

Fredericks, D.J. and S.J. Perrens. 1988. Estimating erosion using caesium-137: II. Estimating rates of soil loss. IAHS Publ. No. 174:233-240.

Fredriksson, L., B. Eriksson, B.G. Rasmuson, K. Eduarson, B. Gahne, and K. Low. 1958. Studies of soil-plant-animal interrelationships with respect to fission products, peaceful uses of atomic energy, pp. 449-470. *In*: Proceedings 2nd international conference, United Nations, Geneva, Switzerland.

Frere, M.H. and H.J. Roberts Jr. 1963. The loss of strontium^{90} from small cultivated watersheds. Soil Sci. Soc. Am. Proc. 27:82-83.

Frid, A.S. and V.S. Grakovskiy. 1988. Diffusion of ^{137}Cs in soils. Pochvovedeniye 2:78-86.

Frissel, M.J. and R. Pennders. 1983. Models for the accumulation and migration of ^{90}Sr, ^{137}Cs, $^{239+240}$Pu and ^{241}Am in the upper layer of soils, pp. 63-72. *In*: P.J. Coughtrey, J.N.B. Bell, and T.M. Roberts (eds.), Ecological aspects of radionuclide release. Blackwell, Oxford.

Frissel, M.J., J.F. Soutjesdijk, A.C. Hoolwijk, and H.W. Koster. 1987. The Cs-137 contamination of soils in the Netherlands and its consequences for the contamination of crop products. Neth. J. Agr. Sci. 35:339-346.

Fröhlich, K., T. Franke, R. Gellermann, and D. Herbert. 1987. Silicon-32 in different aquifer types and implications for ground water dating. Proc. Isotope Techniques in Water Resources Development, pp. 149-163. International Atomic Energy Agency, Vienna, Austria.

Fröhlich, W. 1995. Sediment dynamics in the Polish Flysch Carpathians, pp. 453-461. *In:* I.D.L. Foster, A.M. Gurnell, and B.W. Webb (eds.), Sediment and water quality in river catchments, Wiley, Chichester, UK.

Frölich, W., D.L. Higgitt, and D.E. Walling. 1993. The use of cesium-137 to investigate soil erosion and sediment delivery from cultivated slopes in the Polish Carpathians, pp 271-283. *In*: S. Wicherek (ed.), Farmland erosion, Elsevier, Amsterdam.

Frölich, W. and D.E. Walling. 1992. The use of radionuclides in investigations of erosion and sediment delivery in the Polish Flysh Carpathians. IAHS Publ. No. 209:61-76.

Frölich, W. and D.E. Walling. 1994. Use of Chernobyl-derived radiocaesium to investigate contemporary overbank sedimentation of the flood plains of Carpathain rivers. IAHS Publ. No. 224:161-169.

Fujikawa, Y., M. Fukui, D.J. Drew, and T.T Vandergraaf. 1993. Large analysis of the migration of instantaneously injected cesium in artificial fractures of Lac du Bonnet Granite, Manitoba, Canada. J. Contam. Hydrol. 14:207-232.

Fukui, M. 1990. Desorption kinetics and mobility of some radionuclides in sediments. Health Phys. 59:879-889.

Fukumori, E., E.R. Christensen, and R.J. Klein. 1992. A model of ^{137}Cs and other tracers in lake sediment considering particle size and the inverse solution. Earth Planet. Sci. Lett. 114:85-99.

Gaggino, G.F., G. Parise, G. Premazzi, and A. Provini. 1984. Trends in evolution of nutrient and trace elements in sediments from 13 Italian subalpine lakes over the last 30 years. Proceedings third international symposium on the interaction between sediments and water, Geneva, Switzerland, pp. 135-138.

Galloway, J.N. and G.E. Likens. 1979. Atmospheric enhancement and metal deposition in Adirondack lake sediment. Limnol. Oceanogr. 24:427-433.

Garcia-Oliva, F., L. Martinez, and J.M. Maass. 1995a. Soil ^{137}Cs activity in a tropical deciduous ecosystem under pasture conversion in Mexico. J. Environ. Radioact. 26:37-49.

Garcia-Oliva, F., L. Martinez, and J.M. Maass. 1995b. Long-term net soil erosion as deretmined by ^{137}Cs redistribution in an undisturbed and perturbed tropical deciduous forest ecosystem. Geoderma 68:135-147.

García-Olivares, A. and A. Aghero. 1993. A model for the behavior of ^{137}Cs in watershed scenarios. J. Contam. Hydrol. 13:183-211.

García-Tenorio, R, C.I. Sanches-Angulo, M. García-León, J.M. Abril, and F. El-Daoushy. 1992. The use of ^{137}Cs in marine and lacustrine sediment dating. Nuclear Geophy. 6:395-403.

Garland, J.A., W.A. McKay, P.J. Burton, and R.S. Cambray. 1990. Studies of environmental radioactivity on the coast of Northern Ireland. Nucl. Energy 29:205-233.

Garland, J.A., W.A. McKay, R.S. Cambray, and P.J. Burton. 1989. Man-made radionuclides in the environment of Dumfries and Galloway. Nucl. Energy 28:369-392.

Garnham, G.W., G.A. Codd, and G.M. Gadd. 1993. Uptake of cobalt and cesium by microalgal-clay and cyanobacterial-clay mixtures. Microbiol. Ecol. 25:71-82.

Garrett, A.R. Jr, S.L. Cummings, and J.E. Regnier. 1971. Accumulation of ^{137}Cs and ^{90}Sr by Florida forages in a uniform environment. Health Phys. 21:67-70.

Garten, C.T. Jr, J.B. Gentry, J.E. Pinder III, R.R. Scharitz, and M.H. Smith. 1975. Radiocaesium dynamics in a contaminated floodplain ecosystem in the southeastern United States, pp. 331-347. *In*: Impact of nuclear releases into aquatic environments, International Atomic Energy Agency, Vienna,

Geng, G.Q. and D.R. Coote. 1991. The residual effects of soil loss on the chemical and physical quality of three soils. Geoderma 48:415-429.

Gerdol, R., S. Degetto, D. Mazzotta, and G. Vecchiata. 1994. The vertical distribution of Cs-137 derived from Chernobyl fall-out in the uppermost *Sphagnum* layer of two peatlands in the southern Alps. Water, Air, Soil Pollut. 75:93-106.

Gerino, M., G. Stora, and J.P. Durbec. 1994. Quantitative estimation of biodiffusive and bioadvective sediment mixing: In situ experimental approach. Oceanologica Acta 17:547-554.

Gerritse, R., F. Hermandez, A.S. Murray, P.J. Wallbrink, and G. Brunskill. 1995. Distribution of organochlorines, polycyclic aromatic hydrocarbons, phosphorus and Cs-137 in sediment profiles from Ellen Brook in western Australia. Mar. Freshwater Res. 46:843-851.

Gersper, P.L. 1970. Effect of American beech trees on the gamma radioactivity of soils. Soil Sci. Soc. Am. Proc. 34:318-323.

Gerzabek, M.H. and S.M. Ullah. 1988. Uber die Verteilung van ^{137}Cs in den Korngr` Benfraktionen zweier kontaminierter B`den. Bodenkultur 39:293-297. (German)

Gerzabek, M.H., K. Muck, F. Steger, and S.M. Algader. 1996. Leaching of ^{60}Co, ^{137}Cs and ^{226}Ra in lysimeter experiments. Bodenkultur 47:71-80.

Ghuman, G.S., B.G. Motes, S.J. Fernandez, K.W. Guardipee, G.W. Mcmanus, C.M. Wilcox, and F.J. Weesner. 1993. Distribution of antimony-125, cesium-137, and iodine-129 in the soil plant system around a nuclear fuel reprocessing plant. J. Environ. Radioact. 21:161-176.

Giani, L., H. Gebhardt, W. Gusy, and H. Helmers. 1987. Verhalten einiger radioaktiver nuklide (freigesetzt durch den reaktorunfall in Tschernobyl) in typischen B`den Norddeutschlands. Z. Pflanzenernahr. Bodenk. 30:103-107. (German)

Gibley, J., S. Bradley, and D.E. Walling. 1987. The deposition of caesium 137 on grassland at a site in SW England following the Chernobyl accident. Grass Forage Sci. 42:439-442.

Gilbert, R. and J.R. Desloges. 1987. Sediments of ice-dammed, self-draining Ape Lake, British Columbia. Can. J. Earth Sci. 14:

Gill, A.C., J.R. McHenry, and J.C. Ritchie. 1976. Efficiency of nitrogen, carbon, and phosphorus retention by small agricultural reservoirs. J. Environ. Qual. 5:310-315.

Gillieson, D., A. Cochrane, and A. Murray, and. 1994. Surface hydrology and soil erosion in an arid karst: Nullarbor Plain, Australia. Environ. Geol. 23:141-147.

Gillieson., D., P. Wallbrink, and A. Cochrane. 1996. A vegetation change, erosion risk and land management on the Nullarbor Plain, Australia. Environ. Geol. 28:145-153.

Gillieson, D., P. Wallrink, A. Murray, and A. Cochrane. 1996. Estimation of wind erosion using radioactive caesium-137 on the Nallarbor Plain karst, Australia. Z. Geomorphol. Suppl. 105:73-90.

Godoy, J.M., J.R.D. Guimaraes, and Z.L. Carvalho. 1993. Cs-137 pre-concentration from water samples using a Prussian Blue impregnated ion-exchanger. J. Environ. Radioact. 20:213-219.

Goldberg, E.D. 1963. Geochronology with lead-210 radioactive dating. STI/PUB/68, pp. 121-131, International Atomic Energy Agency, Vienna, Austria.

Goldberg, E.D. and M. Koide. 1962. Geochronological studies of deep sea sediments by the ionium/thorium method. Geochem. Cosmochim. Acta 26:417-450.

Golosov, V.N. 1996. Some approaches for studying the intensity of small river aggradation. Inter. J. Sediment Res. 11:38-46.

Golosov, V.N., L.F. Litvin, and A.N. Silant'yev. 1990. Use of radioisotope methods to estimate the intensity of soil erosion, pp. 190-201. *In*: Study of dangerous natural phenomena: methods and results. A collection of scientific papers. MGU, Moscow.

Golosov, V.N., I.V. Ostrova, A.N. Silant'yev and I.G. Shkuratova. 1992. Radiosotope method of assessment of basin accumulation. Geomorphologika 1:30-36. (In Russian).

Gonzales, G.J., M.T. Saladen, and T.E. Hakonson. 1995. Effects of pocket gopher burrowing on cesium-133 distribution on engineering plots. J. Environ. Qual. 24:1056-1062.

Goreau, T.J. 1977. Qualitative effects of sediment mixing on stratigraphy and biochemistry: a signal theory approach. Nat. 265:525-526.

Gorham, E. and J.E. Sanger. 1976. Fossilized pigments as stratigraphic indicators of cultural eutrophication in Shagawa Lake northeastern, Minnesota. Geol. Soc. Am. Bull. 87:1638-1642.

Gottgens, J.F. and T.L. Crisman. 1993. Quantitative impacts of lake-level stabilization on material transfer between water and sediment in Newmans Lake, Florida. Can. J. Fish. Aquat. Sci. 50:1610-1616.

Govers, G., T.A. Quine, P.J.J. Desmet, and D.E. Walling. 1996. The relative contribution of soil tillage and overland flow erosion to soil redistribution on agricultural land. Earth Surface Processes and Landforms 21:929-946.

Govers, G., T.A. Quine, and D.E. Walling. 1993. The effect of water erosion and tillage movement on hillslope profile development: a comparison of observations and model results, pp. 285-300. *In*: S. Wicherek (ed.), Farm land erosion in temperate plains environments and hills, Elsevier, Amsterdam.

Graham, E.R. 1963. Factors affecting Sr-85 and I-131 removal by runoff water. Water and Sewage Works 110:407-410.

Graham, E R and D D Kılhon 1962 Soıl colloıds as a factor ın the uptake of cobalt, caesıum and strontıum ın plants Soıl Scı Soc Am Proc 26 545-547

Graham, J C and S L Sımon 1996 A study of ^{137}Cs ın soıl profiles from the Marshall Islands Scı Total Envıron 183 255-268

Graustein, W C and K K Turekıan 1986 ^{210}Pb and ^{137}Cs ın aır and soıl measure the rates and vertıcal profile of aerosol scavengıng J Geophys Res 91 14355-14366

Grebmeıer, J M and J P Barry 1991 The ınfluence of oceanographıc processes on plegalıc-benthıc couplıng ın polar regıons a benthıc perspectıve J Marıne Syst 2 495-518

Grebmeıer, J M , L W Cooper, I L Larson, C Solıs, and C R Olsen 1993 Cesıum-137 ınventorıes ın Alaskan tundra, lake and marıne sedıment An ındıcator of recent organıc matter transport Report No, IAEA-SM-329/21/0 (Conf - 930412-1), 22pp

Green, N , B T Wılkıns, and D J Hammond 1994 The transfer of Cs-137 and Sr-90 along the soıl-pasture-cows mılk pathway ın an area of land reclaımed from the sea J Envıron Radıoact 23 151-170

Gregorıch, E G and D W Anderson 1985 Effects of cultıvatıon and erosıon on four toposequences ın the Canadıan praırıes Geoderma 36 343-354

Grıffith, M 1978 Specıfic blue-green algal carotenoıds ın sedıments of Esthwaıte Water Lımnol Oceanogr 23 777-784

Grımes, J A and S R Rushforth 1983 Dıatoms of surface sedıments of Utah Lake, Utah, U S A Hydrobıologıa 99 161-174

Grıtchenko, Z G , L M Ivanova, Y A Panteleev, N A Tıshkova, T K Ikaheımonen, E Ilus, and R Saxen 1996 Joıntt Russıan-Fınnısh study of radıoactıve contamınatıon ın the NW part of Lake Ladoga Hydrobıologıa 322 (1/3) 125-128

Grovers, G , T A Quıne, P J J Desmet, and D E Wallıng 1996 The relatıve contrıbutıon of soıl tıllage and overland flow erosıon to soıl redıstrıbutıonon agrıcultural land Earth Surf Processes Landforms 21 (ın press)

Grovers, G , T A Quıne, and D E Wallıng 1993 The effect of water erosıon on hıllslope profile development a comparıson of field observatıons and model results, pp 285-300 *In* S Wıcherek (ed), Framland erosıon ın temperate plaıns envıronment and hılls, Elsever, London

Grzybowska, D and G J Soszka 1978 ^{90}Sr and ^{137}Cs contamınatıon level ın Zarnowıec lake Bulletın de L Academıe Polonaıse des Scıences Serıe des Scıences Bıologıques Cl II 26 751 757

Gschwend, P M and R A Hıtes 1981 Fluxes of polycyclıc aromatıc hydrocarbons to marıne and lacustrıne sedıments ın the northeastern Unıted States Geochım Cosmochım Acta 45 2359-2367

Guınasso, N L Jr and D R Schınk 1975 Quantıtatıve estımates of bıologıcal mıxıng rates ın abyssal sedıments J Geophys Res 80 3032-3043

Gulın, S B , G G Polıkarpov, V N Egorov, V N Zherko, and N A Stokozov 1995 Reconstructıon of chronology of the ^{137}Cs and chloroorganıc pollutant ınput to the western Black Sea deep sedıments (from 1940s to 1990s) Dopovıvı Natısonal'noyı Akademıyı Nauk Ukrayıny 1 93-96 (Russıan)

Gulınck, H , I Vanden Berghe, and E Abts 1988 Dynamıcs, ınteractıons and connectıvıty of lınear elements ın rural landscapes of central Belgıum Plannıng opportunıtıes, pp 89-91 *In* K F Schreıber (ed), Connectıvıty ın landscape ecology, Proceedıngs of the 2nd Internatıonal Semınar of the Internatıonal Assocıatıon for Landscape Ecology, Munster, Germany

Gutıerrez, M and H R Fuentes 1991 Competıtıve adsorptıon of cesıum, cobalt and strontıum ın condıtıoned clayey soıl suspensıons J Envıron Radıoact 13 271-282

Haghırı, F 1970 Fate of strontıum-90 ın soıl, plants, and water Ohıo Report 55 74-77

Haırr, L 1974 An ınvestıgatıon of factors ınfluencıng radıocesıum cyclıng ın estuarıne sedıments ın the Hudson Rıver Ph D Thesıs, New York Unıv , New York

Håkanson, L 1980 An ecologıcal rısk ındex for aquatıc pollutıon control A sedımentologıcal approach Water Res 14 975-1001

Håkanson, L 1994 A revıew on effect-dose-sensıtıvıty models for aquatıc ecosystems Internatıonale Revue der Gesamten Hydrobıologıe 79 621-667

Håkanson, L and T Andersson 1992 Remedıal measures agaınst radıoactıve caesıum ın Swedısh lake fish after Chernobyl Aquat Scı 54 141-164

Håkanson, L , J E Brıttaın, L Monte R Helıng, U Bergstrom, and V Suolanen 1996 Modellıng of radıocesıum ın Lakes The VAMP model J Envıron Radıoact 33 255-308

Håkanson, L and A Källström 1978 An equatıon of state for bıologıcally actıve lake sedıment and ıts ımplıcatıons for ınterpretatıons of sedıment data Sedımentology 25 205-226

Hakenson, T E and F W Wıcker 1975 Cesıum kınetıcs ın a montane lake ecosystem Health Phys 28 699-706

Häkkınen, U and E Lakanen 1968 Strontıum 90 and caesıum 137 ın some Fınnısh soıl profiles Ann Agrıc Fenn 7 123-126

Halldın, S , A Rodhe, and B Bjurman 1990 Urban storm water transport and wash-off of caesıum-137 after the Chernobyl accıdent Water Aır Soıl Pollut 49 139-158

Hamılton, E I and K R Clarke 1984 The recent sedımentatıon hıstory of the Esk estuary Cumbrıa, U K the applıcatıon of radıochronology Scı Total Envıron 35 325-386

Hansen, H J M and A Aarkrog 1990 A dıfferent surface geology ın Denmark, the Faroe ıslands and Greenland ınfluences the radıologıcal contamınatıon of drınkıng water Water Res 24 1137-1141

Harbor, J and J Warburto 1993 Relatıve rates of glacıal and nonglacıal erosıon ın Alpıne envıronments Arctıc A R 25 1-7

Hardy, E P 1975 Regional uniformity of cumulative radionuclides fallout HASL-288 Health and Safety Laboratory, New York

Hardy, E P , H D Livingston, J C Burke, and H L Volchok 1978 Time pattern of off-site plutonium contamination from *Rocky Flats Plant by lake sediment analyses* EML-342, pp J-123 to J-146 Environmental Monitoring Laboratory, New York

Hardy, E P , M W Meyer, J S Allen, and L T Alexander 1968 Strontium-90 on the earth's surface Nature 219 584-587

Hargrove, W W , F M Hoffman, and D A Levine 1995 Interpolation of bottom bathymetry and potential erosion in a large Tennessee reservoir system usin GRASS Department of Energy Conference CONF-9503121-3, 6p

Harper, R J and R J Gilkes 1994 Evaluation of the Cs-137 techniques for estimating wind erosion losses for some sandy Western Australian soils Aust J Soil Res 32 1369-1387

Haselwandter, V K 1977 Radioaktives Cäsium (Cs 137) in fruchtkörpern verschiedener Basidiomycetes Zeitschr F Pilzkunde 43 323-326 (German)

Haselwandter, V K 1978 Accumulation of radioactive nuclide ^{137}Cs in fruitbodies of Basidimycetes Health Phys 34 713-715

Hasholt, B and D E Walling 1992 Use of caesium-137 to investigate sediment sources and sediment delivery in a small glacierized mountain drainage basin in Eastern Greenland IAHS Publ No 209 87-100

Hatton, R S , R D DeLaune, and W H Patrick Jr 1983 Sedimentation, accretion, and subsidence in marshes of Barataria Basin, Louisiana Limnol Oceanogr 28 494-502

Hawks, P H , J C Ritchie, and J R McHenry 1974 Measuring recent valley sedimentation rates using fallout cesium-137 Geol Soc Am Abstracts with Program 6 363

Haworth, E Y 1976 The changes in the composition of diatoms assemblages found in the surface sediments of Blelham Tarn in the English Lake District during 1973 Ann Bot 40 1195-1205

Haworth, E Y 1980 Comparison of continuous phytoplankton records with the diatom stratigraphy in recent sediments of Blelham Tarn Limnol Oceanogr 25 1093-1103

Haworth, E Y 1984 *Stratigraphic changes in algal remains (diatoms and chrysophytes) in recent sediments* of Blelham Tarn, English Lake District, pp 165-190 *In* E Y Haworth and J W G Lund (eds), Lake sediment and environmental history, Univ Minnesota Press, Minneapolis, MN

He, Q and P Owens 1995 Determination of suspended sediment provenance using caesium-137, unsupported lead-210 and radium-226 A numerical mixing model approach, pp 207-227 *In* I D L Foster, A M Gurnell, and B W Webb (eds), Sediment and water quality in river catchments, John Wiley and Sons, London

He, Q and D E Walling 1996a Interpreting particle size effects in the absorption of ^{137}Cs and unsupported ^{210}Pb by mineral soils and sediments J Environ Radioact 30 117-137

He, Q and D E Walling 1996b Use of fallout Pb-210 to investigate longer-term rates and patterns of overbank sediments deposition on the flood plains of lowland rivers Earth Surf Proc Landforms 21 141-154

He, Q and D E Walling 1997 The distribution of fallout ^{137}Cs and ^{210}Pb in undisturbed and cultivated soils Applied Radiat Isoto (In press)

He, Q , D E Walling, and P N Owens 1996 Interpreting the ^{137}Cs profiles observed in several small lakes and reservoirs in southern England Chem Geol 129 115-131

Health and Safety Laboratory Fallout Program 1972 HASL-258, A-40-41, A-93-94, Health and Safety Laboratory, New York

Heathwaite, A L 1993 Catchment control on the recent sediment history of Slapton Ley, South-west England, pp 241-259 *In* D S G Thomas and R J Allison (eds), Landscape sensitivity, John Wiley and Sons, Chichester, UK

Heathwaite, A L and T P Burt 1993 The evidence for past and present erosion in the slapton catchment Southwest Devon *In* J Boardman, I D L Foster, and J A Dearing (eds), Soil erosion on agricultural land, John Wiley, Chichester, UK

Hebel, S J and D C Wilkin 1982 Agricultural land management strategies for sediment reduction Landscape Architecture *1982 91-95*

Heijnis, H , G W Berger, and D Eisma 1987 Accumulation rates of estuarine sediments in the Dollard Area comparison of ^{210}Pb and pollen influx methods Neth J Sea Res 21 295-301

Heit, M and K Miller 1987 Cesium-137 sediment depth profiles and inventories in Adirondack lake sediments Biogeochemistry 3 243-265

Heit, M , K M Miller, P Krey, D Bogen, and H Freely 1984 Other radionuclides plutonium with some comments about ^{137}Cs chronologies in freshwater sediments Workshop on paleolimnological studies of the history and effects of acidic precipitation, Rockland, ME pp 34-77

Heit, M , Y L Tan, C S Klusek, and J C Burke 1981 Anthropogenic trace elements and polycyclic aromatic hydrocarbons in sediment cores from two lakes in the Adirondack acid lake region Water Air Soil Pollut 15 441-464

Heit, M , Y L Tan, C S Klusek, H L Volchok, and J C Burke 1980 The origin and deposition history of trace elements and polynuclear aromatic hydrocarbons in two remote lakes in the Adirondack acid rain region EML-381, pp I-75 to I-127 Environmental Measurements Laboratory, New York

Heit, M , Y L Tan, K M Miller, J Quanci, C Marinetti, and S Silvestri 1986 The sediment chronology and polycyclic aromatic hydrocarbon concentrations and fluxes in Cayuga Lake, N Y , EML-451 Environmental Measurement Laboratory, New York, 53pp

Helton, J.C., A.B. Muller, and A. Bayer. 1985. Contamination of surface-water bodies after reactor accidents by the erosion of atmospherically deposited radionuclides. Health Phys. 48:757-771.

Hermanson, M.H. 1990. ^{210}Pb and ^{137}Cs chronology of sediments from small, shallow Arctic lakes. Geochim. Cosmochim. Acta 54:1443-1451.

Hermanson, M.H. 1991. Chronology and sources of anthropogenic trace-metals in sediment cores from small shallow Arctic lakes. Environ. Sci. Tech. 25:2059-2064.

Hermanson, M.H. 1993. Historical accumulation of atmospherically derived pollutant trace metals in the Arctic as measured in dated sediment cores. Wat. Sci. Tech. 28:33-41.

Hermanson, M.H. and E.R. Christensen. 1991. Recent sedimentation in Lake Michigan. J. Great Lakes Res. 17:33-50.

Hermanson, M.H., E.R. Christensen, D.J. Buser, and L.M. Chen. 1991. Polychlornated biphenyl in dated sediments cores from Green Bay and Lake Michigan. J. Great Lakes Res. 17:94-108.

Hesslein, R.H. 1987. Whole-lake metal radiotracer movement in fertilized lake basins. Can. J. Fish. Aquat. Sci. 44:74-82.

Hesslein, R.H., W.S. Broecker, and D.W. Schindler. 1980. Fates of metal radiotracers added to a whole lake: sediment-water interactions. Can. J. Fish. Aquat. Sci. 37:378-386.

Hetherington, J.A. and D.F. Jefferies. 1974. The distribution of some fission product radionuclides in sea and estuarine sediments. Neth. J. Sea Res. 8:319-338.

Hewitt, A.E. 1996. Estimating surface erosion using ^{137}Cs at a semi-arid site in Central Otago, New Zealand. J. Royal Soc. New Zealand 26:107-118.

Hien, P.Z., N.T. Binh, T.Y. VT Bac, and N.T. Ngo. 1994. Variations of caesium isotope concentrations in air and fallout at Dalat, South Vietnam, 1986-91. J. Environ. Radioact. 22:55-62.

Higgitt, D.L. 1991. Soil erosion and soil problems. Prog. Phys. Geol. 15:91-100.

Higgitt, D.L. 1995. Quantifying erosion rates from caesium-137 measurements: A comment. Aust. J. Soil Res. 33:709-714.

Higgitt, D.L., W. Froehlich, and D.E. Walling. 1992. Applications and limitations of Chernobyl radiocaesium measurements in a Carpathian erosion investigation, Poland. Land Degradation and Rehabilitation 3:15-26.

Higgitt, D.L., J.S. Rowan, and D.E. Walling. 1993. Catchment-scale deposition and redistribution of Chernobyl radiocaesium in upland Britain. Environ. Internat. 19:155-166.

Higgitt, D.L. and D.E. Walling. 1993. The value of caesium-137 measurements for estimating soil erosion and sediment delivery in an agricultural catchment, Avon, UK, pp. 301-315. *In:* S.Wicherek (ed) Farm land erosion: In temperate plains environment and hills, Elsevier, Amsterdam.

Higgitt, D.L., D.E. Walling, and M.J. Haigh. 1994. Estimating rates of ground retreat on mining spoils using caesium-137. Appl. Geogr. 14:294-307.

Hillmann, U., W. Schimmack, P. Jacob, and K. Bunzl. 19996. In situ gamma-spectrometry several years after deposition of radiocesium: Part I. Approximation of depth distributions by the Lorentz function. Radiat. Environ. Biophysics 35:297-303.

Hilton, J. 1985. A conceptional framework for predicting the occurrence of sediment focusing and sediment redistribution in small lakes. Limnol. Oceanogr. 30:1131-1143.

Hilton, J., R.S. Cambray, and N. Green. 1992. Chemical fractionation of radioactive caesium in airborne particles containing bomb fallout, Chernobyl fallout and atmospheric materials from the Stellafield site. J. Environ. Radioact. 15:103-111.

Hilton, J., L. Davison, J. Hamilton-Taylor, M. Kelly, F.R. Livens, E. Rigg, and D.L. Singleton. 1994. Similarities in the behaviour of Chernobyl derived Ru-103, Ru-106 and Cs-137 in two freshwater lakes. Aquat. Sci. 56:133-144.

Hilton, J., J.P. Lishman, and P.V. Allen. 1986. The dominant processes of sediment distribution and focusing in a small, eutrophic, monomictic lake. Limnol. Oceanogr. 31:125-133.

Hilton, J., F.R. Livens, P. Spezzano, and D.R.P. Leonard. 1993. Retention of radioactive caesium by different soils in the catchment of a small lake. Sci. Total Environ. 129:253-266.

Hilton, J., E. Rigg, W. Davison, J. Hamilton-Taylor, M. Kelly, F.R. Livens, and D.L. Singleton. 1995. Modeling and interpreting element ratios in water and sediments: A sensitivity analysis of post-Chernobyl Ru:Cs ratios. Limnol. Oceanogr. 40:1302-1309

Hilton, J. and P. Spezzano. 1994. An investigation of possible processes of radiocaesium release from organic upland soils to water bodies. Water Res. 28:975-983.

Hird, A.B., D.L. Rimer, and F.R. Livens. 1995. Total caesium-fixing potential of acid organic soils. J. Environ. Radioact. 26:103-118.

Hird, A.B., D.L. Rimmer, and F.R. Livens. 1996. Factors affecting the sorption and fixation of caesium in acid organic soil. European J. Soil Sci. 47:97-104.

Hirschberg, D.J. and J.R. Schubel. 1979. Recent geochemical history of flood deposits in the northern Chesapeake Bay. Estuar. Coast. Marine Sci. 9:771-784.

Hodge, V., C. Smith, and J. Whiting. 1996. Radiocesium and plutonium: Still together in "background" soils after more than thirty years. Chemosphere 32:2067-2075.

Hohenemser, C., M. Deicher, A. Ernst, H. Hofs@ss, G. Linder, and E. Recknagel. 1986. Chernobyl: an early report. Environ. 28:6-43.

Hongve, D., I.A. Blakar, and J.E. Brittain. 1995. Radiocesium in the sediments of qvre Heimdalsvatn, a Norweigan subalpine lake. J. Environ. Radioact.27:1-11.

Horowitz, A.J., K.A. Elrick, and R.B. Cook. 1993. Effect of mining and related activities on sediment trace element geochemistry of Lake Coeur D'Alene, USA Part I: Surface sediments. Hydrol. Process. 7:403-423.

Horowitz, A J, K A Elrick, J A Robbins, and R B Cook 1995 Effect of mining and related activities on sediment trace element geochemistry of Lake Coeur D'Alene, USA Part II Subsurface sediments Hydrol Process 9 35-54

Hornill, A D and G Clint 1994 Caesium cycling in heather moorlands ecosystems, pp 395-416 *In* S M Ross (ed), Toxics in Plant-Soil Systems, John Wiley, Chichester, UK

Hornill, A D and M Howard 1991 Chernobyl fallout in three areas of upland pasture in west Cumbria J Radiol Prot 11 249-257

Hotzl, H, G Rosner, and R Winkler 1992 Sources of present Chernobyl-derived caesium concentrations in surface air and deposition samples Sci Total Environ *119 231-242*

Howard, B J, N A Beresford, and F R Livens 1990 An overview of caesium in the semi-natural ecosystem of an upland sheep farm, *In* G Desmet, P Nossimbeni, and M Belli (eds), Transfer of radionuclides in natural and seminatural ecosystems, Elsevier, Amsterdam

Howard, B J, F R Livens, and C B Walters 1996 A review of radionuclides in tide-washed pastures on the Irish sea coast in England and Wales and their transfer to food products Environ Pollut 93 63-74

Hubbard, J E and W D Striffler 1973 Cesium 137 in a mountain channel Water Resour Res 9 1440-1442

Hunt, G J and P J Kershaw 1990 Remobilization of artificial radionuclides from the sediment of the Irish Sea J Radiol Prot 10 147-151

Huntley, S L, R J Wenning, S H Su, N L Bonnevie, and D J Paustenbach 1995 Geochronology and sedimentology of the lower Passaic River, New Jersey Estuar 18 351-361

Hutchinson, S M 1994 Distribution of ^{137}Cs in saltmarsh sediment in the Dee Estuary, NW England Marine Pollut Bull 28 262-265

Hutchinson, S M and D Prandle 1994 Siltation in salt marsh of the Dee Estuary derived from ^{137}Cs analysis of shallow cores Estuar Coast Shelf Sci 38 471-478

Hutchinson-Benson, E, J Svoboda, and H W Taylor 1985 The latitudinal inventory of ^{137}Cs in vegetation and topsoil in Northern Canada, 1980 Can J Bot 63 784-791

Inbar, M 1982 Measurement of fluvial sediment transport compared with lacustrine sedimentation rates the flow of the River Jordan into Lake Kinneret Hydrological Sci J 4 439-449

Inbar, M 1992 Rates of fluvial erosion in basins with a Mediterranean climate Catena 19 393-409

Irlweck, K 1985 Depth distribution of ^{137}cesium, ^{90}strontium and ^{210}lead in sediments of Lake Mondsee, Austria J Radiat Nucl Chem Lett 93 115-124

Irlweck, K and D L Danielopol 1985 Caesium-137 and lead-210 dating of recent sediment from Mondsee (Austria) Hydrobiologia 128 175-185

Irlweck, K, B Khademi, E Henrich, and R Kronraff 1993 Pu-239(240), Pu-238, Sr-90, Ru-103 and Cs-137 concentrations in surface air in Austria due to dispersion of Chernobyl releases over Europe J Environ Radioact 20 133-148

Isaksson, M and B Erlandsson 1995 Experimental determination of the vertical and horizonal distribution of ^{137}Cs in the ground J Environ Radioact 27 141-160

Ivanov, Y A, N Lewyckyj, S E Levchuk, B S Prister, S K Firsakova, N P Arkhipov, A N Arkhipov, S V Kruglov, R M Alexakhin, J Sandalls, and S Askbrant 1997 Migration of ^{137}Cs and ^{90}Sr from Chernobyl fallout in Ukrainian, Belarussian and Russian soils J Environ Radioact 35 1-21

Jaakkola, T, K Tolonen, P Huttunen, and S Leskinen 1983 The use of ^{137}Cs and ^{239,240}Pu for dating lake sediments Hydrobiologia 103 15-19

Jasinski, T and J A Robbins 1988 Radiotracers in Polish lake sediments EOS Trans 69 1119

Jaworowski, Z 1966 Temporal and geographical distribution of radium D (lead 210) Nature 212 886-889

Jefferies, D F and A K Steele 1989 Observed and predicted concentrations of caesium-137 in the seawater of the Irish Sea J Environ Radioact 10 173-189

Jefferies, D F, A K Steele, and A Preston 1973 Distribution of caesium-137 in British coastal water Mar Pollut Bull 4 118-122

Jefferies, D F, A K *Steele, and A Preston 1982 Further studies on the distribution of* ^{137}*Cs in British coastal water I* Irish Sea Deep-Sea Res 29 713-738

Jenkins, C E, N A Wogman, and H G Rieck 1972 Radionuclide distribution in Olympic National Park, Washington Water, Air, Soil Pollut 1 181-204

Jenne, E A and J S Wahlberg 1968 Role of certain stream-sediment components in radioion sorption U S Geological Survey, Paper 433-F, 16 pp, Washington, DC

Johanson, K J, R Bergstrom, O Eriksson, and A Erixon 1994 Activity concentrations of Cs-137 in moose and their forage plants in Mid-Sweden J Environ Radioact 22 251-267

Johnson, T C 1984 Sedimentation in large lakes Ann Rev Earth Planet Sci 12 179-204

Johnston, C A 1992 Sediment and nutrient retention by freshwater wetland - effects of surface water quality Cr R Environ Con 21 491-565

Johnston, C A, G D Bubenzer, G B Lee, F W Madison, and J R McHenry *1984 Nutrient trapping by sediment* deposited in a seasonally flooded lakeside wetland J Environ Qual 13 283-290

Johnston, S E 1981 A comparison of dating methods in laminated lake sediments in Maine M S Thesis, Univ Maine, Orno, ME

Johnston, S E, S A Norton, C T Hess, R B Davis, and R S Anderson 1982 Chronology of atmospheric deposition of acid and metals in New England based on the record in lake sediment, pp 177-187 In L H Keith (ed), Energy and environmental chemistry Vol 2 Acid rain, Ann Arbor Science Publishers, Ann Arbor, MI

Jones, D G , J M Miller, and P D Roberts 1984 The distribution of ^{137}Cs in surface intertidal sediments from the Solway Firth Marine Pollut Bull 15 187-194

Jones, F and R G Castle 1987 Radioactivity monitoring of the water cycle following the Chernobyl accident J Inst Water Environ Manage 1 205-217

Joshi, S R 1985 Recent sedimentation rates and ^{210}Pb fluxes in Georgian Bay and Lake Huron Sci Total Environ Art 41 219-233

Joshi, S R 1987a Nondestructive determination of lead-210 and radium 226 in sediments by direct photon analysis J Radioanal Nucl Chem Art 116 169-182

Joshi, S R 1987b Early Canadian results on the long-range transport of Chernobyl radioactivity Sci Total Environ 63 125-137

Joshi, S R 1988 West valley-derived radionuclides in the Niagara River area of Lake Ontario Water Air Soil Pollut 37 111-120

Joshi, S R 1989 Common analytical errors in the radiodating of recent sediments Environ Geol Water Sci 14 203-207

Joshi, S R 1991 Radioactivity in Lake Michigan - Review Sci Total Environ 100 61-104

Joshi, S R and R W Durham 1976 Determination of ^{210}Pb, ^{226}Ra and ^{137}Cs in sediments Chem Geol 18 155-160

Joshi, S R and M E Fox 1985 The ^{210}Pb and ^{137}Cs profiles in sediment cores from Bay of Quinte, Lake Ontario J Radioanal Nucl Chem Art 90 207-215

Joshi, S R and A Mudock 1988 Direct determination of geochronologically useful radionuclides in sediments by low-energy photon analysis Nucl Instruments and Methods in Phys Res A263 529-536

Joshi, S R and B S Shukla 1991 The role of water/soil distribution coefficient in the watershed transport of environmental radionuclides Earth Planet Sci Lett 105 314-318

Joshi, S R , B S Shukla, and R McNeely 1988 The calculation od lead-210 dates from Mckay lake sediments J Radioanal Nucl Chem Art 125 341-349

Juang, T C 1988 Tracing soil erosion sources of Teh-chi reservoir watershed by radiochemical and geochemical methods Soil and Fertilizer in Taiwan 1988 17-24

Juzdan, Z 1988 Worldwide deposition of ^{90}Sr through 1985 USDOE Report, EML-515, Environmental Monitoring Laboratory, New York

Kachanoski, R G 1987 Comparison of measured soil 137-cesium losses and erosion rates Can J Soil Sci 67 199-203

Kachanoski, R G 1993 Estimating soil loss from changes in soil cesium-137 Can J Soil Sci 73 515-526

Kachanoski, R G and E de Jong 1984 Predicting the temporal relationship between cesium-137 and erosion rate J Environ Qual 13 301-304

Kacieszczenko, J and Z Banasik 1981 An effect of bioturbation on the results of the ^{137}Cs dating technique used for lacustrine sediments Ekologia Polska 29 615-623

Kada, J and M Heit 1992 The inventories of anthropogenic lead, zinc, arsenic, cadmium and radionuclides cesium-137 and excess lead-210 in lake sediment of the Adirondack region, USA Hydrobiologia 246 231-241

Kada, J , M Heit, and K M Miller 1994 Chronology of anthropogenic trace element input to four Utah lakes reconstructed using sediment cores Water Air Soil Pollut 75 353-369

Kadlec, R H and J A Robbins 1984 Sedimentation and sediment accretion in Michigan coastal wetlands (U S A) Chem Geol 44 119-150

Kagan, L M and V D Kadatsky 1996 Depth migration of Chernobyl originated ^{137}Cs and ^{90}Sr in soils of Belarus J Environ Radioact 33 27-39

Kaminski, S 1991 Radionuklide aus dem Tschernobyl-Fallout im Bodensee GWF-Wasser Abwasser 132 671-674

Kamiyama, K , S Okuda, and M Koyama 1982 Vertical distribution of ^{137}Cs and its accumulation rate in lake sediment Jap J Limnol 43 35-38

Kansanen, P H 1985 Assessment of pollution history from recent sediment in Lake Vavajavesi, southern Finland II Changes in the Chironomidae, Chaoboridae and Ceratopogonidae (Diptera) fauna Ann Zool Fennici 22 57-90

Kansanen, P H and T Jaakkola 1985 Assessment of pollution history from recent sediment in Lake Vavajavesi, southern Finland I Selection of representative profiles, their dating and chemostratigraphy Ann Zool Fennici 22 13-55

Kansanen, P H , T Jaakkola, S Kulmala, and R Suutarinen 1991 Sedimentation and distribution of gamma-emitting radionuclides in bottom sediments of southern Lake P@ij@nne, Finland after the Chernobyl accident Hydrobiologia 222 121-140

Kansanen, P H and J Seppala 1992 Interpretation of mixed sediment profiles by means of a sediment-mixing model and radioactive fallout Hydrobiologia 243 371-379

Karavaeva, Y N , N V Kulikov, I V Molchanova, V N Pozolotina, and P I Yushkov 1994 Accumulation and distribution of long-living radionuclides in the forest ecosystems of the Kyshtym accident zone Sci Total Environ 157 147-151

Kasimovsky, A A 1993 Analytical solution for the model of soil radionuclide migration with fixation-leaching reaction Ecol Modell 66 217-229

Katajisto, T 1996 Copepod egg survive a decade in the sediments of the Baltic Sea Hydrobiologica 320 153-159

Kawabata, T 1967 Studies on the sorption and release of radionuclides by river sediments J Radiat Res 8 20-30

Kearney, M S , J C Stevenson, and L G Ward 1994 Spatial and temporal changes in marsh vertical accretion rates at Monie Bay Implications for sea-level rise J Coastal Res 10 1010-1020

Kedhi, K 1989 Radiotracer study of deposition caused by suspended sediments of river Seman J Radioanal Nucl Chem Lett 135 395-402

Keilty, T.J., D.S. White, and P.F. Landrum. 1988. Sublethal responses to endrin in sediment by *Stylodrilus heringianus* (Lumbriculidae) as measured by a ^{137}cesium marker layer technique. Aquat. Toxicology 13:251-270.

Kemp, A.L.W., T.W. Anderson, R.L. Thomas, and A. Mudrochova. 1974. Sedimentation rates and recent sediment history of Lakes Ontario, Erie and Huron. J. Sedimentary Petrology 44:207-218.

Kemp, A.L.W., R.L. Thomas, C.I. Deli, and J.M. Jaquel. 1976. Cultural impact on geochemistry of sediment in Lake Erie. J. Fish. Res. 33:440-462.

Kershaw, P.J., D.S. Woodhead, S.J. Malcolm, D.J. Allington, and M.B. Lovett. 1990. A sediment history of Sellafield discharge. J. Environ. Radioact. 12:201-241.

Kim, K-H. 1995. Use of Cs-137 redistribution in estimating deposition at the Sansu reservoir. Agric. Chem. Biotechnol. 38:157-162. (Chinese)

Kirihara, S., R. Nakamura, M. Nakahara, M. Notoya, and Y. Aruga. 1993. Translocation of Sr-85, Cs-137, Co-57, and Zn-65 through *Stoloniferous haptera* between the thalli of Ecklonia stolonifera Okamura (Laminariales, Phaeophyta) Nippon Suisan Gakkaishi. Bull. Japanese Soc. Scientific Fisheries 59:589-592.

Kirk, G.J.D. and S. Staunton. 1989. On predicting the fate of radioactive caesium in soil beneath grassland. J. Soil Sci. 40:71-84.

Kiss, J.J., E. de Jong, and L.W. Martz. 1988. The distribution of fallout cesium-137 in southern Saskatchewan, Canada. J. Environ. Qual. 17:445-452.

Kiss, J.J., E. de Jong, and H.P.W. Rostand. 1986. An assessment of soil erosion in West-central Saskatchewan using cesium-137. Can. J. Soil Sci. 66:591-600.

Klechkovdkii, V.M., G.G. Polikarpov, and R.M. Aleksakhi. 1973. Behavior of strontium-90 and cesium-137 in soil, Chapter 4. pp 78-102. *In*: Radioecology, Wiley, New York.

Kleiss, B.A. 1996. Sediment retention in a bottomland hardwood wetland in eastern Arkansas. Wetlands 16(3):321-333.

Klement Jr., A.W. (ed.). 1965. Radioactive fallout from nuclear weapons tests. US Atomic Energy Agency Symposium Series, CONF-765.

Kliashtorin, A.L., F.A. Tikhomirov, and A.I. Shcheglov. 1994. Vertical radionuclide transfer by infiltration water in forest soils in the 30 km Chernobly accident zone. Sci. Total Environ. 157:285-288.

Klimchouk, A.B. and V.V. Gudzenko. 1996. Chernobyl radiocaesium in a karst system, Marble Cave, Crimea. Environ. Geol. 28:161-166.

Kline, J.R., J.A. Colon, and S.S. Brar. 1973. Distribution of ^{137}Cs in soils and vegetation on the island of Puerto Rico. Health Phys. 24:469-475.

Klobe, W.D. and R.G. Gast. 1970. Conditions affecting cesium fixation and sodium entrapment in hydrobiotite and vermiculite. Soil Sci. Soc. Am. Proc. 34:746-750.

Klusek, C.S. 1987. Strontium-90 in food and bone from fallout. J. Environ. Qual. 16:195-199.

Knapinska-Skiba, D., R. Bojanowski, Z. Radecki, and M. Lotocka. 1995. The biological and physico-chemical uptake of radiocesium by particulate matter of natural origin (Baltic Sea). Netherlands J. Aquatic Ecol. 29:283-290.

Knatko, V.A., V.V. Gurkov, V.D. Asimova, E.B. Shpakovskaya, and E.A. Shimanovich. 1994. Soil milk transfer of Cs-137 in an area of Byelarus after the Chernobyl accident. J. Environ. Radioact. 22:269-278.

Knatko, V.A., A. Skomorkhov, V.D. Asimova, L.I. Strakh, A.P. Bogdanov, and V.P. Mironov. 1996. Characteristics of ^{90}Sr, ^{137}Cs and ^{239,240}Pu migration in undisturbed solid of southern Belarus after the Chernobyl accident. J. Environ. Radioact. 30:185-196.

Kodaira, K., M. Kato, and M. Ishikawa. 1973. Radiochemical analysis of ^{210}Pb, as well as distribution of ^{210}Pb, ^{90}Sr, and ^{137}Cs in soil profiles. Radioisotopes, Tokyo 22:331-336.

Koh, M. and J.R. McHenry. 1987. Determining sediment rates using cesium-137 fallout at Larto Lake. J. Korean Soc. Soil Sci. Fertility 15:207-212.

Koide, M., K.W. Bruland, and E.D. Goldberg. 1973. Th-238/Th-232 and Pb-210 geochronologies in marine and lake sediments. Geochim. Cosmochim. Acta 37:1171-1187.

Koide, M., A. Soutar, and E.D. Goldberg. 1972. Marine geochronology with ^{210}Pb. Earth Planet. Sci. Lett. 14:442-446.

Komarneni, S. 1978. Cesium sorption and desorption behavior of kaolinites. Soil Sci. Soc. Am. J. 42:531-532.

Konitzer, K. 1992. Sedimentroerelsers betydekse foer foerdelning och tillgaenglighet av Cs-137 I en mellansvensk skogssjoe (*Redistribution of Cs-137 in sediment caused by sediment movements*), Limnilogiska Institutionen Report No. NEI-SE-139, 24pp. Uppsala, Sweden.

Konitzer, K. and M. Meili. 1995. Retention and horizontal redistribution of sedimentary Chernobyl Cs-137 in a small Swedish forest lake. Marine and Freshwater Res. 46:153-158.

Konoplev, A.V. and A.A. Bulgakov. 1995. Modelling of the transformation of speciation processes of Chernobyl origin ^{137}Cs and ^{90}Sr in the soil and in bottom sediments, p.311-321. *In*: Proceedings of a Symposium on Environmental Impact of Radioactive Releases. IAEA, Vienna, Austria.

Konoplev, A.V., L.P. Kopylova, Ts.I. Bobovnikova, A.A. Bulgakov, and A.A. Siverina. 1992. 90Sr and 137Cs distribution in the bottom sediment-water reservoir system in the Chernobyl close-in zone. Soviet Meteorology and Hydrology 1:27-33.

Konshin, O.V. 1992a. Transfer of ^{137}Cs from soil to grass - analysis of possible sources of uncertainty. Health Phys. 63:307-315.

Konshin, O.V. 1992b. Applicability of the convection-diffusion mechanism for modeling migration of ^{137}Cs and ^{90}Sr in soil. Health Phys. 63:219-300.

Konshin, O.V. 1992c. Mathematical model of ^{137}Cs migration in soil: analysis of observations following the Chernobyl accident. Health Phys. 63:301-306.

Konshin, O.V. 1992d. Transfer of ^{137}Cs from soil to grass - analysis of possible sources of uncertainty. Health Phys. 63:307-315.

Korhonen, R. 1990. Modelling transfer of Cs-137 fallout in a large Finnish water course. Health Phys. 59:443-454.

Korobova, E.M. and V.G. Linnik. 1994. Geochemical landscape strategy in monitoring the areas contaminated by the Chernobyl radionuclides. Landscape and Urban Planning 27:91-96.

Korschgen, C.E., G.A. Jackson, L.F. Muessig, and D.C. Southworth. 1987. Sedimentation on Lake Onalaska, Navigation Pool 7, Upper Mississippi River, since impoundment. Water Resour. Res. 23:221-226.

Kotwicki, V. and P. Isdale. 1991. Hydrology of Lake Eyre, Australia - El Nino Link. Paleo. Pollut. 84:87-98.

Kozhevnikova, T.L., N.N. Mishenkov, L.N. Martyushova, and D.A. Krivolutskii. 1993. Accumulation of Sr-90 and Cs-137 by fruit bodies of mushrooms. Russian J. Ecol. 24:391-394.

Kramer, K.J.M., R. Misdrop, C. Berger, and R. Duyts. 1991. Maximum pollutant concentration at the wrong depth - a misleading pollutant history in a sediment core. Mar. Chem. 36:183-198.

Krey, P.W., E.P. Hardy, and M. Heit. 1980. Nevada test site fallout in the area of Enterprise, Utah. EML-372, 30 pp. Environmental Monitoring Laboratory, New York.

Krey, P.W., M. Heit, and K. Miller. 1990. Radioactive fallout reconstruction from contemporary measurement of reservoir sediments. Health Phys. 59:541-554.

Krezoski, J.R., S.C. Mozley, and J.A. Robbins. 1978. Influence of benthic macroinvertebrates on mixing of profundal sediments in southeastern Lake Huron. Limnol. Oceanogr. 23:1011-1016.

Krezoski, J.R., M. Oladipo, L. Adjarova, C. Shick, and T. Tisue. 1995. Cesium-labeled phlogopite as a tracer for in situ studies of sediment burial, reworking, and resuspension rates. Internal. J. Environ. Analy. Chem. 59:213-223.

Krezoski, J.R. and J.A. Robbins. 1985. Vertical distribution of feeding and particle-selective transport of ^{137}Cs in lake sediment by lumbriculid Oliqochaetes. J. Geophys. Res. 90:11999-12006.

Krezoski, J.R., J.A. Robbins, and D.S. White. 1984. Dual radiotracer measurement of zoobenthos-mediated solute and particle transport in freshwater sediments. J. Geophys. Res. 89:7937-7947.

Krishnaswami, S., L.K., Benninger, R.C. Aller, and K.L. Von Damm. 1980. Atmospherically-derived radionuclides as tracers of sediment mixing and accumulation in near-shore marine and lake sediments: evidence from ^{7}Be, ^{210}Pb and $^{239,240}Pu$. Earth Planet. Sci. Lett. 47:307-318.

Krishnaswami, S. and D. Lal. 1978. Radionuclide limnochronology, pp. 153-177. *In*: A. Lerman (ed.), Lakes chemistry, geology, and physics, Springer-Verlag, New York.

Krishnaswami, L.K., D. Lal, J.M. Martin, and M. Maybeck. 1971. Geochronology of lake sediments. Earth Planet. Sci. Lett. 11:407-414.

Krivolutskii, D.A., V.L. Usachev, I.A. Ryabtsev, and O.V. Tarasov. 1989. Global sediment radionuclide migration in trophic chains of arid zone biogeocenoeses. Zh. Obshch Biol. 50:595-605. (Russian)

Krom, M.D., A. Kaufman, and H. Hornung. 1994. Industrial mercury in combination with natural Pb-210 as time-dependent tracers of sedimentation and mercury removal from Haifa Bay, Israel. Estuar. Coastal Shelf Sci. 38:625-642.

Ku, W.C. 1973. Aquatic sediments. J. Water Poll. Control Fed. 45:1301-1310.

Kudelsky, A.V., J.T. Smith, S.V. Ovsiannikova, and J. Hilton. 1996. Mobility of Chernobyl-derived ^{137}Cs in a peatbog system within the catchment of the Pripyat River, Belarus. Sci. Total Environ. 188(2-3):101-113.

Kudo, A. and E.F. Gloya. 1971. Transport of ^{137}Cs - II Interaction with bed sediments. Water Res. 5:71-79.

Kuhn, W., J. Handl, and P. Schuller. 1984. The influence of soil parameters on $^{137}Cs^{+}$-uptake by plants from long-term fallout on forest clearing and grassland. Health Phys. 46:1083-1093.

Kulander, L. and L. Strömquist. 1989. Exploring the use of top-soil ^{137}Cs content as indicator of sediment transfer rates in a small Lesotho catchment. Z. Geomorph. N.F. 33:455-456.

Kuznetsov, M.S., L.F. Litvin, A.D. Kim, V.V. Demidov, A.D. Fless, and E.N. Esafova. 1994. The assessment of soil erosion hazard in polluted areas of Tula region. Pochvovedenie 49:15-29.

Kuznetzov, M.S., M.M. Pushkaryova, A.D. Fless, L.F. Litvin, Ye L. Blokhin and V.V. Demidov. 1996. Forecasting water erosion and radionuclides migration rates in polluted area of Bryanskaya region. Eurasian Soil Sci. 28:121-132.

Labadz, J.C., T.P. Burt, and A.W.R. Potter. 1991. Sediment yield and delivery in the Blanket Peat Moorelands of the southern Pennines. Earth Surf. Processes Landforms 16:255-271.

Laflen, J.M., W.J. Elliot, J.R. Simanton, C.S. Holzhey, and K.D. Kohl. 1991. WEPP Soil erodibility experiment for rangeland and cropland soil. J. Soil Water Conserv. 46:39-44.

Laflen, J.M., L.J. Lane, and G.R. Foster. 1991. WEPP A new generation of erosion prediction technology. J. Soil Water Conserv. 46:34-38.

Lal, D. 1991. Cosmic-ray labeling of erosion surfaces, insitu nuclide production rates and erosion models. Earth Planet. Sci. Lett. 104:424-439.

Lal, D., E. Barg, A.J.T. Jull, M. Pavich, J. Southon, M.W. Caffee, and R.C. Finkel. 1993. Cosmogenic nuclear methods for determining soil erosion and formations rates. *In*: Proceeding international symposium on applications of isotope techniques in studying past and current environmental changes in the hydrosphere and atmosphere. (In Press), International Atomic Energy Agency, Vienna, Austria.

Lal, D., E. Barg, and M. Pavich. 1991. Development of cosmogenic nuclear methods for the study of soil erosion and formation rates. Current Sci. 61:636-640.

Lal, D., V.N. Nijampurkar, and S. Rama. 1970. Silicon-32. Proceeding Hydrology 1970, pp. 847-868, International Atomic Energy Agency, Vienna, Austria.

Lambert, C.P. and D.E. Walling. 1987. Floodplain sedimentation: a preliminary investigation of contemporary deposition within the lower reaches of the River Culm, Devon, UK. Geografiska Annaler 69A:393-404.

Lance, J.C., S.C. McIntyre, D.G. DeCoursey, P.G. Sharpe, S.S. Rousseva, and B.L. Campbell. 1986. Using cesium-137 to estimate erosion rates on rangeland, pp. 79-89. *In*: Erosion control: protecting our future, International Erosion Control Association.

Lance, J.C., S.C. McIntyre, R.R. Lowrance, B.L. Campbell, and R.L. Miller. 1986. Cesium-137 measures erosion rates and sediment movement. 4th Federal Interagency Sedimentation Conference, pp. 4-1 to 4-9.

Lance, J.C., S.C. McIntyre, J.W. Naney, and S.S. Rousseva. 1986. Measuring sediment movement at low erosion rates using cesium-137. Soil Sci. Soc. Am. J. 50:1303-1309.

Larson, R.J. 1985. Worldwide fallout of Sr-90 through 1983. USDOE Rep. EML-444, Environmental Monitoring Laboratory, New York.

Lehman, J.T. 1975. Reconstructing the rate of accumulation of lake sediment: the effect of sediment focusing. Quat. Res. 5:541-550.

Lehotský, M., M. Stankoviansky, and V. Linkeš. 1992. Detection of water erosion-accumulation processes with the use of the ^{137}Cs method. Geograficky časopis 3. (In Slovak)

Lehotský, M., M. Stankoviansky, and V. Linkeš. 1993. Use of caesium-137 in study of pedogentic processes, pp. In: S. Wicherek (ed.), Farmland erosion, Elsevier, Amsterdam.

Leland, H.V., S.N. Leoma, J.F. Elder, and D.J. Wilkes. 1978. Heavy metals and related trace elements - Review. J. Water Poll. Control Fed. 50:1469-1514.

Lemmin, U. and D.M. Imboden. 1987. Dynamics of bottom currents in a small lake. Limnol. Oceanogr. 32:62-75.

Lentsch, J.W. 1974. The fate of gamma-emitting radionuclides released into the Hudson River estuary and an evaluation of their environmental significance. Ph.D. Thesis, New York Univ., New York.

Leonard, E.M. 1986. Varve studies at Hector Lake, Alberta, Canada, and the relationship between glacial activity and sedimentation. Quat. Res. 25:199-214.

Lerman, A. 1979. Geochemical processes: water and sediment. Wiley, New York.

Lerman, A. and T.A. Lietzke. 1975. Uptake and migration of tracers in lake sediment. Limnol. Oceanogr. 20:497-510.

Lewin, J. 1977. Floodplain geomorphology. Prog. Phys. Geog. 1:408-437.

Li, Y. H., L. Burkhardt, M. Bucholtz, P. O'Hara, and P.H. Santschi. 1984. Partition of radiotracers between suspended particles and sea water. Geochim. Cosmochim. Acta 48:2011-2020.

Li, P. and Y. Yu. 1992. Investigations of natural and artificial radioactive isotopes in seawater and sediments in the Yellow Sea and adjacent southeast area. Chin. J. Oceanol. Limnol. 10:325-330.

Lieser, K.H. and Th. Steinkopff. 1989. Chemistry of radioactive cesium in the hydrosphere and in the geosphere. Radiochem. Acta. 46:39-47.

Linder, G., M. Becker, R. Eckmann, P. Frenzel, J. Kleiner, D. Petermann-Seyboldt, W. Pfeiffer, U. Wahl, and E. Recknagel. 1990. Biological transfer and sedimentation of Chernobyl radionuclides in Lake Constance, pp. 265-287. *In*: M.M. Tilzer and C. Serruya (eds.), Large lakes: ecological structure and function, Springer-Verlag, Berlin.

Linder, G., W. Pfeiffer, U. Wahl, J. Kleiner, H.H. Stabel, P. Frenzel, J.A. Robbins, F. Giovanoli, A. Lenhard, and E. Recknagel. 1989. Sedimentation of long-lived radionuclides in Lake Constance, pp. 449-452. *In*: J.P. Vernet (ed.), Heavy metals in the environment, CEP Consultants, Edinburgh, UK.

Linkeš, V., M. Lehotský, and M Stankoviansky. 1992. Contribution to the knowledge on development of water erosion in Danube hilly land with the use of caesium-137. Vedecké práce VÚPÚ 17, VÚPÚ, Bratislava. (In Slovak)

Linsalata, P., H.J. Simpson, C.R. Olsen, N. Cohen, and R.M. Trier. 1985. Plutonium and radiocaesium in the water column of the Hudson River estuary. Environ. Geol. Water Sci. 7:193-204.

Livens, F.R. and M.S. Baxter. 1988a. Particle size and radionuclide levels in some west Cumbrian soils. Sci. Total Environ. 70:1-17.

Livens, F.R. and M.S. Baxter. 1988b. Chemical associations of artificial radionuclides in Cumbrian soils. J. Environ. Radioact. 9:75-86.

Livens, F.R., D. Fowler, and A.D. Horrill. 1992. Wet and dry deposition of I-131, Cs-134 and Cs-137 at an upland site in Northern England. J. Environ. Radioact. 16:243-254.

Livens, F.R., A.D. Horrill, and D.L. Singleton. 1991. Distribution of radiocaesium in soil plant systems of upland areas of Europe. Health Phys. 60:539-545.

Livens, F.R., M.T. Howe, J.D. Hemingway, K.W.T. Goulding, and B.J. Howard. 1996. Forms and rates of release of ^{137}Cs in two peat soils. European J. Soil Sci. 47:105-112.

Livens, F.R. and P.J. Loveland. 1988. The influence of soil properties on the environmental mobility of caesium in Cumbria. Soil Use Manage. 4:69-75.

Livens, F.R. and D. Rimmer. 1988. Physico-chemical controls on artificial radionuclides in soil. Soil Use Manage. 4:63-69.

Livingston, D. 1984. The preservation of algal remains in recent lake sediment, pp. 191-202. *In:* E.Y. Haworth and J.W.G. Lund (eds.), Lake sediment and environmental history, Univ. Minnesota Press, Minneapolis, MN.

Livingston, H.D. and T. Bowen. 1979. Pu and ^{137}Cs in coastal sediments. Earth Planet. Sci. Lett. 43:29-45.

Livingston, D. and R.S. Cambry. 1978. Confirmation of ^{137}Cs dating by algal stratigraphy in Rostherne Mere. Nature 276:259-261.

Llaurado, M., M. Vidal, G. Rauret, C. Roca, J. Fons, and V.R. Vallejo. 1994. Radiocesium behaviour in Mediterranean conditions. J. Environ. Radioact. 23:81-100.

Lobb, D.A., R.G. Kachanoski, and M.H. Miller. 1995. Tillage translocation and tillage erosion on shoulder slopes landscape positions measured using ^{137}Cs as a tracer. Canadian J. Soil Sci. 75:211-218.

Lomenick, T.F. and T. Tamura. 1965. Naturally occurring fixation of cesium-137 on sediments of lacustrine origin. Soil Sci. Soc. Am. Proc. 27:383-386.

Longmore, M.E. 1982. The caesium-137 dating technique and associated applications in AustraliaC A review, pp. 310-321. *In*: W. Ambrose and P. Duerden (eds.), Archaeometry: an Australasian perspective, Australian National Univ. Press, Canberra, Australia.

Longmore, M.E., J.G. Luly, and B.M. O'Leary. 1986. Cesium-137 redistribution in the sediment of the Playa, Lake Tyrrell, Northwestern Victoria. II. Patterns of cesium-137 and pollen redistribution. Palaeogeography, Palaeoclimatology, Palaeoecology 54:197-218.

Longmore, M.E., B.M. O'Leary, and C.W. Rose. 1983. Caesium-137 in the sediments of a partial-meromictic lake on Great Sandy Island (Fraser Island), Queensland, Australia. Hydrobiologia 103:21-27.

Longmore, M.E., B.M. O'Leary, C.W. Rose, and A.L. Chandica. 1983. Mapping erosion and accumulation with the fallout isotope caesium-137. Aust. J. Soil Res. 21:373-385.

Longmore, M.E., T. Torgersen, B.M. O'Leary, and J.G. Luly. 1986. Cesium-137 redistribution in the sediment of the Playa, Lake Tyrrell, Northwestern Victoria. I. Stratigraphy and Cesium-137 mobility in the Upper sediments. Palaeogeography, Palaeoclimatology, Palaeoecology 54:181-195.

Lõnsj, H. 1989. Depth distribution of radiocesium in agricultural soils in Chernobyl fallout areas of Sweden in 1987-1988, pp. 134-142. *In*: M.H. Gerzabek (ed.), Proceedings of the XIXth ESNA Conference, Austrian Research Center, Seibersdorf, Report No. 4489.

Loughran, R.J. 1989. The measurement of soil erosion. Prog. Phys. Geog. 13:216-233.

Loughran, R.J. and B.L. Campbell. 1983. The determination of sedimentation depth by caesium-137. Search 14:157-158.

Loughran, R.J., B.L. Campbell, and G.L. Elliott. 1980. Sediment dynamics in Maluna Creek catchment at Pokolbin, N.S.W. Papers of the Newcastle (16th) Conference of the Institute of Australian Geographers, pp. 245-254.

Loughran, R.J., B.L. Campbell, and G.L. Elliott. 1981. Sediment erosion, storage and transport in a small steep drainage basin at Pokolbin, NSW, Australia. IAHS Publ. No. 132:252-268.

Loughran, R.J., B.L. Campbell, and G.L. Elliott. 1982. The identification and quantification of sediment source using ^{137}Cs. IAHS Publ. No. 137:361-369.

Loughran, R.J., B.L. Campbell, and G.L. Elliott. 1983. The determination of sedimentation depth by cesium-137. Search 14:5-6.

Loughran, R.J., B.L. Campbell, and G.L. Elliott. 1986a. A nuclear technique measures soil erosion. Nucl. Spectrum 2:2-4.

Loughran, R.J., B.L. Campbell, and G.L. Elliott. 1986b. Sediment dynamics in a partially cultivated catchment in New South Wales, Australia. J. Hydrol. 83:282-297.

Loughran, R.J., B.L. Campbell, and G.L. Elliott. 1986c. The use of tracer caesium-137 for studying sediment movement in drainage basins, pp. 151-160. *In*: E. Frankel, J.B. Keene, and A.E. Waltho (eds.), Recent sediments in Eastern Australia - Marine through terrestrial. Geological Society of Australia, Univ. Sidney, Sidney, Australia.

Loughran, R.J., B.L. Campbell, and G.L. Elliott. 1988. Determination of erosion and accretion rates using caesium-137, pp. 87-103. *In*: R.F. Warner (ed.), Fluvial geomorphology of Australia, Academic Press, Sidney, Australia.

Loughran, R.J., B.L. Campbell, and G.L. Elliott. 1990. The calculation of net soil loss using cesium-137, pp. 119-126. *In*: J. Broadman, I.D.I. Foster, and J.A. Dearing (eds.), Soil erosion on agricultural land, Wiley, New York.

Loughran, R.J., B.L. Campbell, G.L. Elliott, D. Cummings, and D.J. Shelly. 1989. A cesium-137 sediment hillslope model with test from south-eastern Australia. Z. Geomorph. N.F. 33:235-250.

Loughran, R.J., B.L. Campbell, G.L. Elliott, and D.J. Shelly. 1990. Determination of the rate of sheet erosion on grazing land using caesium-137. Appl. Geography 10:125-133.

Loughran, R.J., B.L. Campbell, A.T. Pilgrim, and A.J. Conacher. 1987. Caesium-137 in soils in relation to the nine unit landsurface model in a semi-arid environment of Western Australia, pp. 398-406. *In*: A. Conacher (ed.), Readings in Australian Geography, Proceedings of the 21st Institute of Australian Geographer's Conference, Univ. Western Australia, Perth, Australia.

Loughran, R.J., B.L. Campbell, D.J. Shelly, and G.L. Elliott. 1992. Developing a sediment budget for a small drainage basin in Australia. Hydrol. Process. 6:145-158.

Loughran, R.J., B.L. Campbell, and D.E. Walling. 1987. Soil erosion and sedimentation indicated by caesium 137: Jackmoor Brooke catchment Devon, England. Catena 14:201-212.

Loughran, R.J., B.L. Campbell, D.E. Walling, and G.L. Elliott. 1985. Caesium redistribution and sediment movement in two catchments in England and Australia. First international conference on geomorphology, Manchester, UK.

Loughran, R.J., S.J. Curtis, G.L. Elliott, B.L. Campbell, K. Kiernan, and M.G. Temple-Smith. 1992. A reconnaissance survey of soil erosion in Australia. 7th. International Soil Conservation Organization Conference Proceedings, Vol. 2.1, pp. 52-63.

Loughran, R.J. and G.L. Elliott. 1996. Rates of soil erosion in Australia determined by the caesium-137 technique: a national reconnaissance survey. IAHS Publ. No. 236:275-282.

Loughran, R.J., G.L. Elliott, B.L. Campbell, S.J. Curtis, D. Cummings, and D.J. Shelly. 1993. Estimation of erosion using radionuclide caesium-137 in three diverse areas in eastern Australia. Appl. Geogr. 13:169-188.

Loughran, R.J., G.L. Elliott, B.L. Campbell, and D.J. Shelly. 1988. Estimation of soil erosion from caesium-137 measurements in a small cultivated catchment in Australia. J. Appl. Radiat. Isot. 39:1153-1157.

Loughran, R.J., D.J. McFarlane, B.L. Campbell, and R. Sheppard. 1993. The distribution of caesium-137 in rangeland soils at three sites in Western Australia. Rangeland J. 15:24-38.

Low, K. and K. Edvardson. 1960. Content of caesium-137 and (zirconium + niobium)-95 in Swedish soils. Nature 187:736-738.

Lowrance, R., S. McIntyre, and C. Lance. 1988. Erosion and deposition in a field/forest system estimated using cesium-137 activity. J. Soil Water Conserv. 43:195-199.

Lu, N., C.F.V. Mason, and W.R.J. Turney. 1996. Characterization and immobilization of cesium-137 in soil at Los Alamos National Laboratory. Report No.: LA-UR-96-1322; CONF-9606219-1, 16p.Department of Energy, Washington, DC.

Ludlam, S.D. 1984. Fayetteville Green Lake, New York, U.S.A. VII. Varve chronology and sediment focusing. Chem. Geol. 44:85-100.

Lund, J.W.G. 1984. Winifred Tutin - a personal note, pp. 1-10. *In*: E.Y. Haworth and J.W.G. Lund (eds.), Lake sediment and environmental history, Univ. Minnesota Press, Minneapolis, MN.

Lynch, D.R. and C.B. Officer. 1984. Nonlinear parameters estimation for sediment cores. Chem. Geol. 44:203-225.

Lynch, J.C., J.R. Meriwether, B.A. McKee, F. Vera-Herrera, and R.R. Twilley. 1989. Recent accretion in mangrove ecosystems based on ^{137}Cs and ^{210}Pb. Estuar. 12:284-299.

Lyons, W.B., P.B. Armstrong, and H.E. Gaudette. 1983. Trace metal concentrations and fluxes in Bermuda sediments. Marine Pollut. Bull. 14:65-68.

Mackenzie, A.B., M.S. Baxter, I.G. McKinley, D.S. Swan, and W. Jack. 1979. The determination of ^{134}Cs, ^{137}Cs, '"Pb, ^{226}Ra, and ^{228}Ra concentrations in nearshore marine sediments and seawater. J. Radioanal. Chem. 48:29-47.

Maguire, S., I.D. Pulford, G.T. Cook, and A.B. Mackenzie. 1992. Caesium sorption-desorption in clay-humic acid systems. J. Soil Sci. 43:689-696.

Mahara, Y. 1993. Storage and migration of fallout strontium-90 and cesium-137 for over 40 years in surface soil of Nagasaki. J. Environ. Qual. 22:722-730.

Mahara, Y., A. Kudo, T. Kauri, D. Santry, and S. Miyahara. 1988. Mobile Pu in reservoir sediment of Nagasaki, Japan. Health Phys. 54:107-111.

Mahara, Y. and H. Matsuzuru. 1989. Mobile and immobile plutonium in a ground water environment. Water Res. 23:43-50.

Mahara, Y. and S. Miyahara. 1984. Residual plutonium migration in soil of Nagasaki. J. Geophys. Res. 89:7931-7936.

Makhon'ko, K.P., T.I. Bobovnikova, A.S. Avramenko, A.V. Dibtseva, and A.A. Volokitin. 1975. Vertical distribution of Sr^{90} and Cs^{137} in bottom deposits of lakes and rivers. Ekologiya 3:90-93.

Makhon'ko, K.P., F.A. Rabotnova, and A.A. Volokitin. 1990. Analysis of soil contamination by ^{137}Cs in USSR in 1988. Atomnaya Energiya 68:262-264.

Malanca, A. V. Pessina, and G. Dallara. 1966. Consequences of the Chernobyl fallout on some Italian underbrush produces: A ten-year study. J. Environ. Sci. Health Part A Environmental Science and Engineering & Toxic and Hazardous Substance Control 31:2583-2593.

Malmgren, L. and M. Jansson. 1995. The fate of Chernobyl radiocesium in the River Ore catchment, northern Sweden. Aquatic Sci. 57:144-160.

Mamas, C.J.V., L.G. Earwaker, R.S. Sohki, K. Randle, P.R. Bereeesford-Hartwell, and J.R. West. 1995. An estimation of sedimentation rates along the Ribble Estuary, Lancashire, UK, based on radiocaesium profiles preserved in intertidal sediments. Environ. Internat. 21:151-165.

Mamikhin, S.V. 1995. Mathematical model of ^{137}Cs vertical migration in forest soils. J. Environ. Radioact. 28:161-170.

Mamikhin, S.V., F.A. Tikhomirov, and A.I. Shcheglov. 1994. Dynamics of Cs-137 content in forest biogeocenoses subjected to radioactive contamination as a result of the Chernobyl accident. Russian J. Ecol. 25:106-110.

Manchester-Neesvig, J.B., A.W. Andren, and D.N. Edgington. 1996. Patterns of mass sedimentation and of deposition of sediment contaminated by PCBs in Green Bay. J. Great Lakes Res. 22:444-462.

Mangini, A., U. Christian, M. Barth, W. Schmitz, and H.H. Stabel. 1990. Pathways and residence times of radiotracers in Lake Constance, pp. 245-264. *In*: M.M. Tilzer and C. Serruya (eds.), Large lakes: ecological structure and function, Springer-Verlag, New York.

Mann, D.R. and S.A. Casso. 1984. In-situ chemisorption of radiocesium from seawater. Mar. Chem. 14:307-318.

Maringer, F.J. and P. Jachs. 1996 On the radioecology of the River Danube: A new approach for dating solid particles. Archiv fuer Hydrobiologie Supplement 113:389-395.

Martin, D.B. 1985. Accumulation of sediment, nutrients, and cesium-137 in prairie potholes in cultivated and noncultivated watersheds, pp. 274-275. *In*: Perspectives in nonpoint source pollution, USEPA, Washington, DC.

Martin, D.B. and W. Hartman. 1987. The effect of cultivation on sediment composition and deposition in prairie pothole wetlands. Water Air Soil Pollut. 34:45-53.

Martin, J. 1985. The Pavin Crater lake, pp. 169-188. *In*: W. Strumm, (ed.), Chemical processes in lakes, Wiley, New York.

Martz, L.W. 1992. The variation of soil erodibility with slope position in a cultivated Canadian prairie landscape. Earth Surface Process and Landform 17:543-556.

Martz, L.W. and E. de Jong. 1985. The relationship between land surface morphology and soil erosion and deposition in a small Saskatchewan basin, pp. 1-19. *In*: Proceedings of the seventh hydrotechnical conference, Canadian Society for Civil Engineering Annual Conference 1985.

Martz, L.W. and E. de Jong. 1987. Using cesium-137 to assess the variability of net soil erosion and its association with topography in a Canadian prairie landscape. Catena 14:439-451.

Martz, L W and E de Jong 1991 Using cesium-137 and landform classification to develop a net soil erosion budget for a small Canadian prairie watershed Catena 18 289-308

Mathewes, R W and J M D'Auria 1982 Historic changes in an urban watershed determined by pollen and geochemical analyses of lake sediment Can J Earth Sci 19 2114-2125

Matisoff, G 1984 Mathematical models of bioturbation, pp 289-330 *In* P L McCall and M J S Tevesz (eds), Animal sediment relations the biotic alteration of sediment, Plenum Press, New York

Matisoff, G and J A Robbins 1987 A model for biological mixing of sediments J Geol Education 35 144-149

Matschullat, V J , H Heinrichs, J Schneider, and M Strum 1987 Schwermetallgehalte in Seesedimenten des Westharzes (BRD) Chem Erde 47 181-194 (German)

Matsunami, T , A Mizohata, and T Mamuro 1979 Observations of deposition and atmospheric concentration of ^{210}Pb, ^{7}Be, and ^{137}Cs in Osaka Annual Rept Radiat Cent Osaka Perfect 20 1-4

Matthews, K M 1989 Radioactive fallout in the South Pacific A history Part 1 Deposition in New Zealand National Radiation Laboratory, Christchurch, Report NRL 1989/2, 78pp

Matthews, K M 1995 Measurements of residual traces of Cs-137 in the atmosphere in New Zealand J Environ Radioact 27 221-229

Matthews, K W and K Potipin 1985 Extraction of fallout ^{210}Pb from soils and its distribution in soil profiles J Environ Radioact 2 319-331

Maulé, C P and M J Dudas 1989 Preliminary identification of soil separates associated with fallout ^{137}Cs Can J Soil Sci 69 171-175

McCabe, W J and W J Mason 1982 A falls dam, Otago, sedimentation rates measured by caesium-137 profiles Institute of Nuclear Studies INS-R-309, Lower Hutt, New Zealand

McCall, P L , J A Robbins, and G Matisoff 1984 ^{137}Cs and ^{210}Pb transport and geochronologies in urbanized reservoirs with rapidly increasing sedimentation rates Chem Geol 44 33-65

McCall, P L , M J S Tevesz, X S Wang, and J R Jackson 1995 Particle mixing rates of freshwater bivalves Anodonta grandis (Unionidae) and Sphaerium striatinum (Pisidiidae) J Great Lakes Res 21 333-339

McCallan, M E , B M O'Leary, and C W Rose 1980 Redistribution of caesium-137 by erosion and deposition on an Australian soil Aust J Soil Sci 18 119-128

McCallan, M E and C W Rose 1977 The construction of a geochronology for alluvial deposits in the Condamine Plain and the estimation of the areal variation in erosion intensity in the Upper Condamine drainage basin Technical Report 2/77, Griffith Univ , Australia, 16 pp

McCartney, M , P J Kershaw, D S Woodhead, and D C Denoon 1994 Artificial radionuclides in the sediments of the Irish Sea Sci Total Environ 141 103-138

McDougall, S , J Hilton, and A Jenkins 1991 A dynamic model of cesium transport in lakes and their catchment Water Res 25 437-445

McFarlane, D J , R J Loughran, and B L Campbell 1992 Soil erosion of agricultural land in western Australia estimated by caesium-137 Aust J Soil Res 30 533-546

McGee, E J , M J Keatinge, H J Synnott, and P A Colgan 1995 The variability in fallout content of soil and plants and the design of optimum field sampling strategies Health Physics 68 320-327

McGee, E J , H J Synnott, and P A Colgan 1993 A new method for prediction of radiocesium levels in vegetation evidence from Irish upland J Environ Radioact 18 53-70

McGee, E J , H J Synnott, M Keatinge, and P A Colgan 1993 Persistence and prediction of radiocaesium levels in animals grazing in semi-natural environments Sci Total Environ 138 91-99

McHenry, J R 1968 Use of tracer techniques in soil erosion research Trans Am Soc Agric Engr 11 619-625

McHenry, J R 1975 Reservoir sedimentation Water Resour Bull 10 329-337

McHenry, J R and G D Bubenzer 1985a Estimating erosion from ^{137}Cs activity measurements Am Soc Agric Engr Paper No 82-2034

McHenry, J R and G D Bubenzer 1985b Field erosion estimated from ^{137}Cs activity measurements Trans Am Soc Agric Engr 28 480-483

McHenry, J R , C M Cooper, and J C Ritchie 1982 Sedimentation in Wolf Lake, Lower Yazoo River Basin, Mississippi J Freshwater Ecol 1 547-558

McHenry, J R and S C McIntyre 1984 Recent sedimentation rates in two North America impoundments with watershed predominantly in cropland, pp 205-211 *In* R J Loughran (ed), Drainage basin erosion and sedimentation, Univ Newcastle, New South Wales, Australia

McHenry, J R and J C Ritchie 1975 Redistribution of Cs-137 in southeastern watersheds, pp 452-461 *In* F G Howell, J B Gentry, and M H Smith (eds), Mineral cycling in southeastern ecosystems, Symposium Series CONF-740513, Environmental Research and Development Administration, Washington, DC

McHenry, J R and J C Ritchie 1977a Estimating field erosion losses from fallout Cs-137 measurements IAHS Publ No 122 26-33

McHenry, J R and J C Ritchie 1977b Physical and chemical parameters affecting transport of ^{137}Cs in arid watersheds Water Resour Res 13 923-925

McHenry, J R and J C Ritchie 1980 Dating recent sediments in impoundments Symposium on surface water impoundments Am Soc Civil Engr , New York pp 1279-1289

McHenry, J R , J C Ritchie, and G B Bubenzer 1978 Redistribution of Cs-137 due to erosional processes in a Wisconsin watershed pp 495-503 *In* D C Adriano and I L Brisbin Jr (eds), Environmental chemistry and cycling processes USDOE CONF-760429, US Department of Energy, Washington, DC

McHenry, J.R., J.C. Ritchie, and C.M. Cooper. 1980. Rate of recent sedimentation in Lake Pepin. Water Resour. Bull. 16:1049-1056.

McHenry, J.R., J.C. Ritchie, C.M. Cooper, and J. Verdon. 1984. Recent rates of sedimentation in the Mississippi River, pp. 99-117. *In*: J.G. Wiener, R.V. Anderson, and D.R. McConville (eds.), Contaminants in the upper Mississippi River, Butterworth Publishers, Boston, MA.

McHenry, J.R., J.C. Ritchie, and A.C. Gill. 1973a. Nitrogen, phosphorus, and other chemicals in sediments from reservoirs in North Mississippi. Mississippi Water Resour. Conf. Proc., pp. 1-13.

McHenry, J.R., J.C. Ritchie, and A.C. Gill. 1973b. Accumulation of fallout cesium 137 in soils and sediments in selected watersheds. Water Resour. Res. 9:676-686.

McHenry, J.R., J.C. Ritchie, and J. May. 1975. Recent sedimentation rates in the lower Mississippi River Valley: Lake Verret-Lake Palourde, Louisiana. Mississippi Water Resour. Conf. Proc., pp. 13-23.

McHenry, J.R., J.C. Ritchie, and J. Verdon. 1976. Sedimentation rates in the Upper Mississippi River, pp. 1339-1349. *In*: River '76 symposium on inland waterways for navigation, flood control and water diversion. American Society of Civil Engineers, New York.

McHenry, J.R., F.R. Schiebe, J.C. Ritchie, and C.M. Cooper. 1984. Deposited sediments in Lake Chicot, pp. 18-47. *In*: J.F. Nix and F.R. Schiebe (eds.), Limnological studies of Lake Chicot, Arkansas. Quachita Baptist College, Arkadelphia, AR.

McIntyre, S.C. 1993. Reservoir sedimentation rates linked to long-term changes in agricultural land use. Water Resour. Bull. 29:487-495.

McIntyre, S.C. 1995. Linking land use and reservoir sedimentation by two approaches utilizing ^{137}Cs. IAEA-TECHDOC-828, pp. 99-110.

McIntyre, S.C., J.C. Lance, B.L. Campbell, and R.L. Miller. 1987. Using cesium-137 to estimate soil erosion on a clearcut hillside. J. Soil Water Conserv. 42:117-120.

McIntyre, S.C. and J.W. Naney. 1990. Reelfoot Lake sedimentation rates and sources. Water Resour. Bull. 26:227-232.

McIntyre, S.C. and J.W. Naney. 1991. Sediment deposition in a forested inland wetland with a steep-farmed watershed. J. Soil Water Conserv. 46:64-66.

McIntyre, S.C., J.W. Naney, and W.R. Berkas. 1988. Measurement of recent sediment deposition in Lake Taneycomo using cesium-137. Abstracts of Papers for the 1988 Annual Meeting of the American Society of Limnology and Oceanography, Boulder, CO.

McIntyre, S.C., J.W. Naney, and J.R. Cooper. 1991. Long-term Cs-137 and soil loss from field plots. Proc. Fifth Federal Interagency Sedimentation Conference, pp. 5-33 - 5-39.

McIntyre, S.C., J.W. Naney, and J.R. McHenry. 1989. Quantification of lake sedimentation rates utilizing radioisotopes present in the environment, pp. 1-5. *In*: Offsite assessment, EPA Publ. 440/5-89-001, USEPA, Washington, DC.

McKay, W.A. and M.S. Baxter. 1985. The partitioning of Sellafield derived radiocaesium in Scottish coastal sediments. J. Environ. Radioact. 2:93-114.

McKinley, I.G., M.S. Baxter, D.J. Ellett, and W. Jack. 1981a. Tracer applications of radiocesium in the sea of the Herbies. Estuar. Coastal Shelf Sci. 13:69-82.

McKinley, I.G., M.S. Baxter, and W. Jack. 1981b. A simple model of radiocesium transport from Windscale to the Clyde Sea area. Estuar. Coastal Shelf Sci. 13:59-67.

McLean, R.I., J.K. Summers, R.S. Olsen, S.C. Domotor, I.L. Larson, and H. Wilson. 1991. Sediment accumulation rates in Conowingo Reservoir as determined by man-made and natural radionuclides. Estuar. 14:148-156.

McMurtry, G.M., A. Snidvongs, and C.R. Glenn. 1995. Modeling sediment accumulation and soil erosion with ^{137}Cs and ^{210}Pb in the Ala Wai Canal and Central Honolulu watershed, Hawaii. Pacific Science 49:412-451.

Meili, M. 1994. Radiocaesium as ecological tracer in aguatic systems- A review, pp. 127-139. *In:* H. Dahlgaard (ed.), Studies in Environmental Science 62. Nordic Radioecology: The transfer of radionuclides through nordic ecosystems to man, Elsevier, New York.

Meisel, S., M.H. Gerzabek, and H.K. Müller. 1991. Influence of plowing on the depth distribution of different radionuclides in soil. Zeitschrift fhr Pflanzenernährung und Bodenkundle 154:211-215.

Mélières, M.A., M. Pourchet, J.F. Pinglot, R. Bouchez, and M. Piboule. 1988. Chernobyl ^{134}Cs, ^{137}Cs and ^{210}Pb in high mountain lake sediment: measurements and modeling of mixing process. J. Geophys. Res. 93:7055-7061.

Melin, J., L. Wallberg, J. Suomela. 1994. Distribution and retention of cesium and strontium in Swedish boreal forest ecosystems. Sci. Total Environ. 157:93-105.

Menzel, R.G. 1960. Transport of strontium-90 in runoff. Sci. 131:499-500.

Menzel, R.G. 1965. Soil plant relationships of radioactive elements. Health Phys. 11:1325-1332.

Menzel, R.G. 1974. Land surface erosion and rainfall as sources of strontium-90 in streams. J. Environ. Qual. 3:219-223.

Menzel, R.G., P. Jung, K. Ryu, and K. Um. 1987. Estimating soil erosion losses in Korea with fallout cesium-137. J. Appl. Radiat. Isot. 38:451-454.

Merefield, J.R. 1981. Caesium in up-estuary transport of sediment. Marine Geol. 39:M45-M55.

Merefield, J.R. 1986. Alkali metals in the permo-triassic as geochemical indicators of surficial processes. Chem. Geol. 56:143-158.

Meriwether, J.R., J.N. Beck, D.F. Keeley, M.P. Langley, R.H. Thompson, and J.C. Young. 1988. Radionuclides in Louisiana soils. J. Environ. Qual. 17:562-568.

Mihelcic, G., B. Surija, M. Juracic, D. Barisic, and M. Branica. 1996. History of the accumulation of trace metals in sediments of the saline Rogoznica Lake (Croatia). Sci Total Environ. 182:105-115.

Milan, C.S., E.M. Swenson, R.E. Turner, and J.M. Lee. 1995. Assessment of the ^{137}Cs method for estimating sediment accumulation rates: Louisiana salt marshes. J. Coastal Res. 11:296-307.

Miller, K.M. and M. Heit. 1986. A time resolution methodology for assessing the quality of lake sediment cores that are dated by ^{137}Cs. Limnol. Oceanogr. 31:1292-1300.

Miller, K.M., J.L. Kuiper, and I.K. Helfer. 1990. ^{137}Cs fallout depth distributions in forest versus field sites: implications for external gamma dose rates. J. Environ. Radioact. 12:23-47.

Miller, J.R. and R.F. Reitemeier. 1963. The leaching of radiostrontium and radiocesium through soils. Soil Sci. Soc. Am. Proc. 27:141-144.

Mishra, U.C. and S. Sadasivan. 1972. Fallout radioactivity in Indian soils. Health Phys. 23:55-62.

Mitchell, J.K., G.D. Bubenzer, J.R. McHenry, and J.C. Ritchie. 1980. Soil loss estimation from fallout cesium-137 measurements, pp. 393-401. *In:* M. DeBoodt and D. Grabriels (eds.), Assessment of erosion, Wiley, London.

Mitchell, J.K., S. Mostaghimi, D.S. Freeny, and J.R. McHenry. 1983. Sediment deposition estimation from cesium-137 measurements. Water Resour. Bull. 19:549-555.

Mitchell, P.I., W.R. Schell, A. McGarry, T.P. Ryan, J.A. Sanchez-Cabaza, and A. Vidal-Quadras. 1992. Studies of the vertical distribution of ^{134}Cs, ^{137}Cs, ^{238}Pu, ^{240}Pu, ^{241}Pu, ^{241}Am, and ^{210}Pb in ombrogenous mires at midlatitudes. J. Radiat. Nucl. Art. 156:361-387.

Moeller, R.E., F. Oldfield, and P.G. Appleby. 1984. Biological mixing and its stratigraphic implications in Mirror Lake (New Hampshire, U.S.A.). Verhalt Internat. Verein. Limnol. 22:567-572.

Móesy, I.S. Sălăgean, and I. Uray. 1989. Urmărirea acumulării unor radionuclizi in sediment şi seston. Igiena, Medicina Muncii şi Mediciniă Socială 38:49-52. (Romanian)

Mohamad, D.B. 1982. Application of Cs-137 techniques to problems of sediment redistribution in Sungai Lui representative basin, Selangor, Malaysia: Part I. Regional Cooperative Agreement Report MAL 2623/RI/AG, 5 pp. International Atomic Energy Agency, Vienna, Austria.

Molchanova, I.V., E.N. Karavaeva, V.N. Pozolotina, P.I. Yushkov, and L.N. Mikhailovskaya. 1994. Behavior patterns of radionuclides in floodplain landscapes of the Techa river in the Urals. Russian J. Ecol. 25:181-186. (Translated from Ikologiya 3:43-49, 1994)

Molero, J., J.A. Sanchez-Cabeza, J. Merino, L. Pujol, P.I. Mitchell, and A. Vidal-Quadras. 1995. Vertical distribution of radiocaesium, plutonium and americium in the Catalan Sea (Northwestern Mediterranean). J. Environ. Radioact. 26:205-216.

Momoshima, N. and E.A. Bondietti. 1994. The radial distribution of Sr-90 and Cs-137 in trees. J. Environ. Radioact. 22:93-109.

Monte, K. 1996. Analysis of models assessing the radionuclide migration from catchments to water bodies. Health Phys. 70:227-237.

Morgan, I.J., P. Tytler, and M.V. Bell. 1993. The accumulation of 137-caesium from fresh water by alevins and fry of Atlantic salmon and brown trout. J. Fish Biol. 43:877-888.

Moore, P.D. 1974. Lead accretion in alluvial deposits. Nature 250:288-289.

Morris, C.D. and R.J. Loughran. 1994. Distribution of caesium-137 in soils across a hillslope hollow. Hydrological Proc. 8:531-541.

Morris, J.D. 1991. Application of cosmogenic ^{10}Be to problems in the earth sciences. Ann. Rev. Earth Planet. Sci. 19:313-350.

Moulin, A.P., D.W. Anderson, and M. Mellinger. 1994. Spatial variability of wheat yield, soil properties and erosion in hummocky terrain. Can. J. Soil Sci. 74:219-228.

Muir, D.C.G., A. Omelchenko, N.P. Grift, D.A. Savoie, W.L. Lockhart, P. Wilkinson, and G.J. Brunskill. 1996. Spatial trends and historical deposition of polychlorinated biphenyls in Canadian midlatitude and Arctic lake sediments. Environ. Sci. Technol. 30:3609-3617.

Muller, R.N., D.G. Spurgel, and B. Kohn. 1977. Behavior and transport of industrially deprived plutonium in the Great Miami River, Ohio. Health Phys. 33:411-416.

Muller, R.N., D.G. Spurgel, and B. Kohn. 1978. Erosional transport and deposition of plutonium and cesium in two small midwestern watersheds. J. Environ. Qual. 7:171-174.

Müller, V.J., R. Winkler, and C. Sossau. 1991. Untersuchungen zur ^{137}Cs-activität von schwebstoiffen und zum partikularen ^{137}Cs-flux im Ammersee (Oberbayern). Zeit. Wasser Abwasser Forschung 24:165-171. (German)

Mundschenk, V.H. 1983. Zur sorption cäsium von schwebstoff an sediment des Rheins am beispiel der nuklide ^{133}Cs, ^{134}Cs und ^{137}Cs. Deutsche Gewasserkundliche Mitteilungen 27:62-68. (German)

Mundschenk, H. 1996a. Occurrence and behavior of radionuclides in the Moselle River. Part I. Entry of natural and artificial radionuclides. J. Environ. Radioact. 30:199-213.

Mundschenk, H. 1996b. Occurrence and behavior of radionuclides in the Moselle River. Part II. Distribution of radionuclides between aqueous phase and suspended matter. J. Environ. Radioact. 30:215-232.

Mundschenk, H. 1996c. Occurrence and behaviour of radionuclides in the Moselle River: Part IV: Deposition of radioactive particulate matter in high-sedimentation areas. J. Environ. Radioact. 32(3):193-212.

Munita, C.S., I.I.L. Cunha, R.P. Paiva, and R.C.L. Figueira. 1995. Trace elements and artificial radionuclides in Brazilian environmental samples. Fresenius Environ. Bull. 4:97-102.

Murdock, R.N., M.S. Johnson, J.D. Hemingway, and S.R. Jones. 1993. Physicochemical characteristics of radionuclides associated with sediment from a contaminated fresh water stream. Environ. Tech. 14:639-648.

Murdock, R.N. M.S. Johnson, J.D. Hemingway, and S.R. Jones. 1995. The distribution of radionuclides between the dissolved and particulate phases of a contaminated freshwater stream. Environ. Technol. 16:1-12.

Murray, A.S., G. Caitcheon, J.M. Olley, and H. Crockford. 1990. Methods of determining the source of sediments reaching reservoirs: targeting soil conservation. ANCOLD Bull. 85:61-70.

Murray, A.S., R. Marten, A. Johnston, and P. Martin. 1987. Analysis of naturally occurring radionuclides at environmental levels with gamma spectrometry. J. Radiat. Nucl. Chem. 115:263-288.

Murray, A.S., L.J. Olive, J.M. Olley, G.G. Caitcheon, R.J. Wasson, and P.J. Wallbrink. 1993. Tracing the source of suspended sediment in the Murrumbridgee River, Australia. IAHS Publ. No. 215:293-302.

Murray, A.S., J.M. Olley, and P.J. Wallbrink. 1992. Natural radionuclide behavior in fluvial environments. Radiat. Prot. Dosim. 45:285-288.

Murray, A.S., R. Stanton, J.M. Olley, and R. Morton. 1993. Determining the origins and history of sedimentation in an underground river system using natural and fallout radionuclides. J. Hydrol. 146:341-359.

Murray, J.W. 1987. Mechanisms controlling the distribution of trace elements in oceans, pp. 153-183. *In*: R.A. Hites and S.J. Eisenreich (eds), Sources and fates of aquatic pollutants, Advances Chem. Series 216:153-183.

Myttenaere, C., W.R. Schell, Y. Thiry, L. Sombre, C. Ronneau, and J.V. Deschrieck. 1993. Modelling of Cs-137 cycling in forests - recent developments and research needed. Sci. Total Environ. 136:77-91.

Nagaya, Y. and M. Saiki. 1967. Accumulation of radionuclides in coastal sediments of Japan (I) fallout radionuclides in some coastal sediments in 1964-1965. J. Radiat. Res. 8:37-43.

Nair, S.K., F.O. Hoffman, and K.M. Thiessen, and A.V. Konoplev. 1996 Modeling the washoff of ^{90}Sr and ^{137}Cs from an experimental plot established in the vicinity of the Chernobyl reactor. Health Phys. 71:896-909.

Nakamura, K. and Y. Nagaya. 1975a. Accumulation of radionuclides in coastal sediments of Japan (II) Content of fission products in some coastal sediments collected in 1966-1972. J. Radiat. Res. 16:184-192.

Nakamura, K. and Y. Nagaya. 1975b. Dispersion and accumulation of radionuclides in sediments of Urazoko Bay (I). J. Oceanographical Soc. Japan 31:145-153.

Nakamura, K. and Y. Nagaya. 1985. Accumulation of cesium-137 and plutonium-239, 240 in sediments of the coastal sea and the north Pacific, pp. 171-180. *In*: A. Hattori (ed.), Marine estaurine geochemistry, Lewis Publishers., Chelsea, MI.

Namiotko, T., B. WiÑniewka, and A. Mi»osek. 1993. Changes of Lake Ha½cza (NE Poland) ecological state in the last fifty years with particular attention being paid to the profundal Ostracoda fauna. Polskie Archiwum Hydrobiologii 40:267-290.

National Academy of Science. 1971. Radioactivity in the marine environment. National Academy of Science, Washington, DC.

Natural Environmental Research Council (UK). 1993. Radiocaesium in natural systems - a UK coordinated study. J. Environ. Radioact. 18:133-149.

Navas, A. and J. Machin. 1991. A preliminary research on the use of cesium-137 to investigate soil erosion in semiarid landscapes in central Ebro river valley, pp.191-202. *In:* M. Sala, L. Rubio, and J.M. Carcia-Ruiz (eds.), Soil erosion studies in Spain, Geoforma Ediciones Logrono.

Navas, A. and D.E. Walling. 1992. Using caesium-137 to assess sediment movement on slopes in a semiarid upland environment in Spain. IAHS Publ. No. 209:129-138.

Navosha, Y.Y., S.G. Prokhorov, V.P. Strigutskiy, and A.E. Tomson. 1992. Interaction of humic substances with metal ions. Eurasian Soil Sci. 24:1-6. (Translated from Pochvovedeniye 1:109-113, 1992)

Neil, D.T. and R.K. Mazori. 1993. Sediment yield mapping using small dam sedimentation surveys, Southern Tablelands, New South Wales. Catena 20:13-25.

Nelin, P. and T. Nylen. 1994. Factors influencing the changes in Cs-137 levels with time in boreal-forest plants in Sweden Sci. Total Environ. 157:73-81.

Nelson, J.L., R.W. Perkins, J.M. Neilsen, and W.L. Hausheld. 1966. Reaction of radionuclides from Hanford reactors with Columbia River sediments, pp. 139-161. *In*: Disposal of radioactive waste in seas, oceans, and surface waters. STI/PUB/126-139-161, International Atomic Energy Agency, Vienna, Austria.

Nifontova, M.G. and V.N. Alexashenko. 1992. Content of Sr-90 and Cs-134, Cs-137 in fungi, lichens, and mosses in the vicinity of the Chernobyl Nuclear Power Plant. Soviet J. Ecol. 23:152-155.

Nifontova, M.G. and V.I. Makovskii. 1995. Content of radionuclides in the peat deposit of swamps. Russian J. Ecol. 26:418-424. (Translated from Ekologiya 26:448-454.)

Nijampurkar, V.N. and D.K. Rao. 1990. Evidence of Chernobyl fallout on a temperate Himalayan glacier. Current Sci. 59:1239-1241.

Nisbet, A.F., B. Salbu, and S. Shaw. 1993. Association of radionuclides with different molecular size fractions in soil solution: implications for plant uptake. J. Environ. Radioact. 18:71-84.

Nisbet, A.F. and S. Shaw. 1994a. Summary of a 5-year lysimeter study on the time-dependent transfer of Cs-137, Sr-90, Pu-239, Pu-240 and Am-241 to crops from three contrasting soil types. 1. Transfer to the edible portion. J. Environ. Radioact. 23:1-17.

Nisbet, A.F. and S. Shaw. 1994b. Summary of a 5-year lysimeter study on the time dependent transfer of Cs-137, Sr-90, Pu-239, Pu-240 and Am-241 to crops from three contrasting soil types. 2. Distribution between different plant parts. J. Environ. Radioact. 23:171-187.

Nishita, H., B.W. Kowalewsky, A.J. Steen, and K.H. Larson. 1956. Fixation and extractibility of fission products contaminating various soils and clays: 1. ^{90}Sr, ^{91}Y, ^{106}Ru, ^{137}Cs, and ^{144}Ce. Soil Sci 81:317-326.

Nishita, H., A.J. Steen, and K.H. Larson. 1958. Release of Sr^{90} and Cs^{137} from Vina Loam upon prolonged cropping. Soil Sci. 86:195-201.

Nolin, M.C., Y.Z. Cao, D.R. Coote, and C. Wang. 1993. Short-range variability of fallout ^{137}Cs in an uneroded forest soil. Can. J. Soil Sci. 73:381-385.

Nordlinder, S., U. Bergstr`m, J. Hammar, and M. Notter. 1993. Modelling turnover of Cs-137 in two subarctic salmonid ecosystems. Nordic J. Freshw. Res. 68:21-33.

Norris, V. and S.J. Perrens. 1990. Analysis of variability of caesium-137 in soils in northern N.S.W., pp. 187-191. *In*: Proceedings of conference on agricultural engineering, Hawkesbury Agricultural College, Australia.

Norton, S.A. 1986. A review of the chemical record in lake sediment of energy related air pollution and its effects on lakes. Water Air Soil Pollut. 30:331-345.

Noureddine, A. and B. Baggoura. 1997. Plutonium isotopes, ^{137}Cs, ^{90}Sr and natural radioactivity in marine sediments from Ghazaouet (Algeria). J.Environ. Radioact. 34:127-138.

Nozaki, Y., D.J. DeMaster, D.M. Lewis, and K.K. Turekain. 1978. Atmospheric ^{210}Pb fluxes determined from soil profiles. J. Geophys. Res. 83(C8):4047-4051.

Nriagu, J.O. 1984. Role of inland water sediments as sinks for anthropogenic sulfur. Sci. Total Environ. 38:7-13.

Nriagu, J.O., A.L.W. Kemp, H.K.T. Wong, and N. Harper. 1979. Sedimentary record of heavy metal pollution in Lake Erie. Geochim. Cosmochim. Acta 43:247-258.

Nyffeler, U.P., Y.H. Li, and P.H. Santschi. 1984. A kinetic approach to describe trace element distribution between particles and solution in natural aquatic systems. Geochim. Cosmochim. Acta 48:1513-1522.

Nygren, P., P. Hari, T. Raunemaa, M. Kulmala, S. Luokkanen, M. Holmberg, and E. Nikinmaa. 1994. Behaviour of Cs-137 from Chernobyl fallout in a scots pine canopy in Southern Finland. Can. J. Forest Res. - J. Can. de La Recherche Forestiere 24:1210-1215.

Nyhan, J.W., G.C. White, T.G. Schonfeld, and G. Trujillo. 1983. An evaluation of soil sampling for ^{137}Cs using various field-sampling volumes. Health Phys. 44:541-552.

Nyman, J.A., R.D. DeLaune, S.R. Pezeshki, and W.H. Patrick, Jr. 1995. Organic matter fluxes and marsh stability in a rapidly submerging estuarine marsh. Estuaries 18:207-218.

Oenema, O. and R.D. DeLaune. 1988. Accretion rates in salt marshes in Eastern Scheldt, South-west Netherlands. Estaur. Coast. Shelf Sci. 26:379-394.

Officer, C.B. 1982. Mixing, sedimentation rates and age dating for sediment cores. Marine Geol. 46:261-278.

Officer, C.B. and D.R. Lynch. 1982. Interpretation procedures for the determination of sediment parameters from time-dependent flux inputs. Earth Planet. Sci. Lett. 61:55-62.

Officer, C.B., D.R. Lynch, G.H. Setlock, and G.R. Helz. 1984. Recent sedimentation rates in Chesapeake Bay, pp. 131-157. *In:* V.S. Kennedy (ed.), The Estuary as a Filter.

O'Hara, S.L., F.A. Street-Perrott, and T.P. Burt. 1993. Accelerated soil erosion around a Mexican highland lake caused by prehistoric agriculture. Nature 362:48-51.

Ohno, T. and C.T. Hess. 1994. Levels of Cs-137 and K-40 in wood ash-amended soils. Sci. Total Environ. 152:119-123.

Okuda, S. 1982. Sedimentary environments in Lake Biwa. Estimates of recent sedimentation rates. Kankyo Gijutsu 11:401-403. (Japanese)

Oldfield, F. 1977. Lakes and their drainage basins as units of sediment-based ecological studies. Prog. Phys. Geog. 1:460-504.

Oldfield, F. 1981. Peats and lake sediments: formation, stratigraphy, description and nomenclature. *In*: A. Gourdie (ed.), Geomorphological techniques, George Allen and Unwin, London.

Oldfield, F. and P.G. Appleby. 1984. A combined radiometric and mineral magnetic approach to recent geochronology in lakes affected by catchment disturbance and sediment redistribution. Chem. Geol. 44:67-83.

Oldfield, F., P.G. Appleby, and R.W. Battarbee. 1978. Alternative ^{210}Pb dating: results from New Guinea Highlands and Lough Erne. Nature 271:339-342.

Oldfield, F., P.G. Appleby, R.S. Cambray, J.D. Eakins, K.E. Barber, R.W. Battarbee, G.R. Pearson, and J.M. Williams. 1979. ^{210}Pb, ^{137}Cs, and ^{239}Pu profiles in ombrotrophic peat. Oikos 33:40-45.

Oldfield, F., P.G. Appleby, and D. Petit. 1980. A re-evaluation of lead-210 chronology and the history of the total influx in a small South Belgium pond. Ambio 9:97-99.

Oldfield, F., P.G. Appleby, and R. Thompson. 1980. Palaeoecological studies of lakes in the highland of Papua New Guinea. I. The chronology of sedimentation. J. Ecol. 68:457-477.

Oldfield, F., R.W. Battarbee, and J.A. Dearing. 1983. New approaches to recent environmental change. Geographical J. 149:167-181.

Oldfield, F. and B. Maher. 1984. A mineral magnetic approach to erosion studies, pp. 161-168. *In*: R.J. Loughran (ed.), Drainage basin erosion and sedimentation, Univ. Newcastle, New South Wales, Australia.

Oldfield, F., B. Maher, and P.G. Appleby. 1989. Sediment source variation and led-210 inventories in recent Potomac Estuary sediment cores. J. Quat. Sci. 3:189-200.

Oldfield, F., N. Richardson, and P.G. Appleby. 1995. Radiometric dating (^{210}Pb, ^{137}Cs, ^{241}Am) of recent ombrotrophic peat accumulation and evidence for changes in mass balance. Holocene 5:141-148.

Oldfield, F., N. Richardson, P.G. Appleby, and L. Yu. 1993. Am-241 and Cs-137 activity in fine grained saltmarsh sediments from parts of the Near Irish Sea Shoreline. J. Environ. Radioact. 19:1-24.

Oldfield, F., A.T. Worsley, and P.G. Appleby. 1985. Evidence from lake sediments for recent erosion rates in the highlands of Papua New Guinea, pp. 185-196. *In*: I. Douglas and T. Spencer (eds.), Environmental change and tropical geomorphology, Allen and Unwin, London.

Olive, L.J., J.M. Olley, A.S. Murray, and P.J. Wallbrink. 1994. Spatial variation in suspended sediment transport in the Murrumbidgee River, New South Wales, Australia. IAHS Publ. 224:241-249.

Olley, J.M., A.S. Murray, D.H. Mackenzie, and K. Edwards. 1993. Identifying sediment sources in a gullied catchment using natural and anthropogenic radioactivity. Water Resour. Res. 29:1037-1043.

Olley, J.M., A.S. Murray, and P. Wallbrink. 1996. Determining sediment sources in a partially logged catchment usingnatural and anthropogenic radioactivity. Z. Geomorphol. Suppl. 105:111-127.

Olley, J.M., A.S. Murray, P. Wallbrink, G. Caitcheon, and R. Stanton. 1991. The use of fallout nuclides as chronometers, pp. 51-55. *In*: Workshop on quaternary dating, Australian National Univ., Canberra.

Olsen, C.R. 1979. Radionuclides, sedimentation and the accumulation of pollutants in the Hudson estuary. Ph.D. Thesis, New York Univ., New York.

Olsen, C.R., N.H. Cutshall, and I.L. Larsen. 1982. Pollutant-particle associations and dynamics in coastal marine environments: a review. Marine Chem. 11:501-533.

Olsen, C.R., N.H. Cutshall, I.L. Larsen, H.J. Simpson, R.M. Trier, and R.F. Bopp. 1985. An estuarine fine-particle budget determined from radionuclide tracers. Geo-Marine Lett. 4:157-160.

Olsen, C.R., I.L. Larsen, N.H. Cutshall, J.F. Donoghue, O.P. Bricker, and H.J. Simpson. 1981. Reactor-released radionuclides in Susquehanna River sediments. Nature 294:242-245.

Olsen, C.R., I.L. Larsen, P.D. Lowry, and N.H. Cutshall. 1986. Geochemistry and deposition of ^{7}Be in river-estuarine and coastal water. J. Geophys. Res. 91:896-908.

Olsen, C.R., I.L. Larsen, P.D. Lowry, N.H. Cutshall, J.F. Todd, G.T.F. Wong, and W.H. Casey. 1985. Atmospheric fluxes and marsh-soil inventories of ^{7}Be and ^{210}Pb. J. Geophys. Res. 90:10487-10495.

Olsen, C.R., I.L. Larsen, P.J. Mulholland, K.L. Von Damme, J.M. Grebmeier, L.C. Schaffner, R.J. Diaz, and M.M. Nichols. 1993. The concept of an equilibrium surface applied to particle source and contaminant distributions in estuarine sediments. Estuar. 16:683-696.

Olsen, C.R., H.J. Simpson, and R.E. Good. 1990. Rates od sediment accumulation in a tidal freshwater marsh. J. Sediment Petrology 19:849-869.

Olsen, C.R., H.J. Simpson, T.H. Peng, R.F. Bopp, and R.M. Trier. 1981. Sediment mixing and accumulation rates effects on radionuclide depth profiles in Hudson estuary sediments. J. Geological Resour. 86:11020-11028.

Olsen, C.R., H.J. Simpson, and R.M. Trier. 1981. Plutonium, radiocesium and radiocobalt in sediments of the Hudson river estuary. Earth Planet. Sci. Lett. 55:377-392.

Olson, K.R., L.D. Norton, T.E. Fenton, and R. Lal. 1994. Quantification of soil loss from eroded soil phases. J. Soil Water Conserv. 49:591-596.

Olsson, I.U. 1986. Radiometric dating, pp. 273-312. *In*: B.E. Berglund (ed.) Handbook of Holocene paleoecology and paleohydrology, Wiley, London.

Osborne, P.L. and B. Moss. 1977. Paleolimnology and trends in phosphorus and iron budgets of an old man-made lake, Barton Broad Norfolk. Freshwater Biol. 7:213-233.

Oscarson, B.W., H.B. Hume, and F. King. 1994. Sorption of cesium on compacted bentonite. Clays and Clay Minerals 42:731-736.

Ostlund, P. and R.O. Hallberg. 1991. Plutonium in sediments apparent half-lives. Environ. Geol. Water 17:195-200.

Ostrova, I.V., A.N. Silant'ev, L.F. Litvin, V.N. Golosov, and I.G. Shkuratova. 1990. Assessing the intensity of erosional accumulation processes by the content of caesium-137 in soils. Geografiya 5:79-85. (Russian)

Oughton, D.H. and B. Salbu. 1994. *Influence of physio-chemical forms on transfer*, pp. 165-184. *In:* H. Dahlgaard (ed.), Studies in Environmental Science 62. Nordic Radioecology: The transfer of radionuclides through nordic ecosystems to man, Elsevier, New York.

Owens, P.N., 1990. Valley sedimentation at Slapton, South Devon, and its implications for the estimation of lake-based erosion rates, pp. 193-200. *In*: J. Boardman, I.D.L. Foster, and J.A. Boardman (eds.), Soil erosion on agricultural land, Wiley, Chichester, UK.

Owens, P.N. 1994. Towards imporved interpretation of caesium-137 measurements in soil erosion studies. Ph.D. Thesis, University of Exeter, United Kingdom.

Owens, P.N. and O. Slaymaker. 1993. Lacustrine sediment budgets in the Coast Mountains of British Columbia, Canada, pp. 105-123. *In:* J. MacManus and R.W. Duck (ed.) Geomorphology and sedimentology of lakes and reservoirs, Wiley, Chichester, UK.

Owens, P.N. and D.E. Walling. 1996. Spatial variability of caesium-137 inventories at reference sites: an example from two contrasting sites in England and Zimbabwe. Appl. Radiat. Isot. 47:699-707.

Owens, P.N., D.E. Walling, and Q. He. 1996.The behaviour of bomb-derived caesium-137 fallout in catchment soils. J. Environ. Radioact. 32:169-191.

Page, M.J., N.A. Trustrum, and R.C. Derose. 1994. A high resolution record of storm-induced erosion from lake sediment. J. Paleolomno. 11:333-348.

Paliouris, G., H.W. Taylor, R.W. Wein, J. Svoboda, and B. Mierzynski. 1995. Fire as an agent in redistributing fallout ^{137}Cs in the Canadian boreal forest. Sci. Total Environ. 160/161:153-166.

Papastefanou, C., A. Ioannidou, S. Stoulos, and M. Manolopoulou. 1995. Atmospheric deposition of cosmogenic Be-7 and Cs-137 from fallout of the Chernobyl accident. Sci. Total Environ. 170:151-156.

Papastefanou, C., M. Manolopoulou, and S. Charalamnous. 1988. Cesium-137 in soil from Chernobyl fallout. Health Phys. 55:985-987.

Papastefanou, C., M. Manolopoulou, and T. Sawidis. 1992. Residence time and uptake rates of Cs-137 in lichens and mosses at temperature Latitude (40-Degrees-N). Environ. Internat. 18:397-401.

Pardue, J.H., R.D. DeLaune, W.H. Patrick, and J.H. Whitcomb. 1989. Effect of redox potential on fixation of ^{137}Cs in lake sediment. Health Phys. 47:781-789.

Parise, G., G. Paleologo, G. Premazzi, P. Pulici, A. Riva, T. Ruaro, R. Bugini, L. De Capitani, and A. Maccagni. 1981. Lake Como (Northern Italy): mineralogical, chemical and biological characteristics of the sediments. European Applied Research Rept. Environ. and Nat. Res. Sect. 1:385-416.

Parise, G. and G. Premazzi. 1986. I fenomeni di compattazione nella geocronologia dei sedimenti lacustri. Acqua-Aria 8:783-790. (Italian)

Parker J.I. and D.N. Edgington. 1976. Concentration of diatom frustules in Lake Michigan sediment cores. Limnol. Oceanogr. 21:887-893.

Parkinson, R.W., R.D. Delaune, and J.R. White. 1994. Holocene sea-level rise and the fate of mangrove forest within the wider Caribbean region. J. Coastal Res. 10:1077-1086.

Passeck, U., G. Lindner, and W. Zech. 1995. Distribution of Cs-137 in water leachates of forest humus. J. Environ. Radioact. 28:223-238.

Patel, B., C.D. Mulay, and A.K. Ganguly. 1975. Radioecology of Bombay Harbour- A tidal estuary. Estuar. Coast. Marine Sci. 3:13-42.

Patel, B., S. Patel, and S. Pawar. 1978. Desorption of radioactivity from nearshore sediment. Estuar. Coast. Marine Sci. 7:49-58.

Patrick, W.H. Jr and R.D. DeLaune. 1990. Subsidence, accretion, and sea level rise in south San Francisco Bay marshes. Limnol. Oceanogr. 35:1389-1395.

Pattenden, N. and W.A. McKay. 1994. Studies of artificial radioactivity in the coastal environment of northern Scotland: A review. J. Environ. Radioact. 24:1-51.

Paul, B., D.L. Deb, M.S. Sachdev, and P. Sachdev. 1996. Effect of cations and anions on ^{137}Cs and ^{65}Zn adsorption in soils. J. Nucl. Agr. Biol. 25:144-150.

Payne, B.R. 1985. Measurement of rates of accumulation of sediments from radionuclide data, pp. 219-224. *In*: Methods of computing sedimentation in lakes and reservoirs. UNESCO Technological Reports in Hydrology, UNESCO, Paris.

Peart, M.R. and D.E. Walling. 1986. Fingerprinting sediment source: the example of a drainage basin in Devon, UK. IAHS Publ. No. 159:41-55.

Peart, M.R. and D.E. Walling. 1988. Techniques for establishing suspended sediment sources in two drainage basins in Devon, UK: a comparative assessment. IAHS Publ. No. 174:269-279.

Pegoyev, A.N. and S.D. Fridman. 1978. Vertical profiles of cesium-137 in soils. Pochvovedeiye 8:77-81.

Peirson, D.H. 1975. The passage of nuclear weapon debris through the atmosphere, p 81-88. *In:* M.J. Chadwick and G.T. Goodman (eds.), The ecology of resource degradation and renewal, John Wiley and Sons, New York.

Pempkowiak, J. 1991. Enrichment factors of heavy metals in the southern Baltic surface sediments dated with ^{210}Pb and ^{137}Cs. Environ. Internat. 17:421-428.

Pempkowiak, J., J. Kozuch, and M. Szymelfenig. 1996. Meiobenthic organisms as indicators of mixing processes in the Baltic surface sediments. Marine Ecol. 17:175-179.

Pempkowiak, J. and D. Skiba. 1988. The determination of accumulation rates in the recent Baltic Sea sediments on the basis of ^{210}Pb and ^{137}Cs profiles, pp. 824-832. *In*: Proceedings. XVI Conference Baltic Oceanographers Vol. 2. Institute of Marine Research, Kiel, Russia.

Pendleton, R.C. and W.C. Hanson. 1958. Absorption of cesium-137 by components of an aquatic community, pp. 419-422. *In*: Proceedings of the international conference on the peaceful use of atomic energy 18. U.N., Geneva, Switzerland.

Peng, T.H., W.S. Broecher, and W.H. Berger. 1979. Rates of benthic mixing of deep-sea sediments as determined by radioactive tracers. Quat. Res. 11:141-149.

Pennington, W. 1972. The recent sediments of Windermere. Freshwater Biol. 3:363-382.

Pennington, W. 1974. Seston and sediment formation in Five Lake District lakes. J. Ecol. 62:215-251.

Pennington, W. 1978. Responses of some British lakes to past changes in land use on their catchments. Verh. Internat. Verein. Limnol. 20:636-641.

Pennington, W. 1979. The origins of pollen in lake sediment: an enclosed lake compared with one receiving inflow streams. New Phytol. 83:189-213.

Pennington, W. 1981. Records of a lake's life time: the sediments. Hydrobiologia 79:197-219.

Pennington, W., R.S. Cambray, J.D. Eakins, and D.D. Harkness. 1976. Radionuclide dating of the recent sediment in Blelham Tarn. Freshwater Biol. 6:317-331.

Pennington, W., R.S. Cambray, and E.M. Fisher. 1973. Observations of lake sediment using fallout ^{137}Cs as a tracer. Nat. 242:324-326.

Pennock, D.J., D.W. Anderson, and E. de Jong. 1994. Distribution of cesium-137 in uncultivated black chernozemic landscapes. Can. J. Soil Sci. 74:115-117.

Pennock, D.J. and E. de Jong. 1987. The influence of slope curvature on soil erosion and deposition in hummock terrain. Soil Sci. 144:209-217.

Pennock, D.J. and E. de Jong. 1990a. Regional and catenary variations in properties pf Borolls of Southern Saskatchewan, Canada. Soil Sci. Soc. Am. J. 54:1697-1701.

Pennock, D.J. and E. de Jong. 1990b. Rates of soil redistribution associated with soil zones and slope classes in southern Saskatchewan. Can. J. Soil Sci. 70:325-334.

Pennock, D J and E de Jong 1991 Spatial pattern of soil redistribution in Boroll landscapes, southern Saskatchewan, Canada Soil Sci 150 867-873

Pennock, D J , D S Lemmon, and E de Jong 1995 Cesium-137 measured erosion rates for five parent-material groups in southwestern Saskachewan Can J Soil Sci 75 205-210

Penttila, S , T Kairesalo, and A Uusirauva 1993 The occurrence and bioavailability of radioactive Cs- 137 in small forest lakes in Southern Finland Environ Pollut 82 47-55

Perkins, R W and C W Thomas 1980 Worldwide fallout, pp 53-82 *In* W C Hanson (ed), Transuranic elements in the environment DOE/TIC-22800 Department of Energy, Washington, DC

Perry, R and J W Lucas 1972 Caesium-137 in plant produce II Distribution of ^{137}Cs in the soil and produce of an experimental farm Pl Fds hum Nutr 2 193-199

Persicani, D 1995 Analysis of potential radiocaesium soil contamination A case study using two different simulation models J Environ Radioact 27 161-180

Persson, C , R Henning, and L E de Geer 1987 The Chernobyl accident-A meteorological analysis of how radionuclides reached and were deposited in Sweden Ambio 16 20-31

Petersen, R C Jr, L Lander, and H Blanck 1986 Assessment of the impact of the Chernobyl reactor accident on the biota of Swedish streams and lakes Ambio 15 327-331

Peterson, S A 1982 Lake restoration by sediment removal Water Resour Bull 18 423-435

Peterson, W , H D Knauth, and R Pepelnick 1990 Vertical distribution of Chernobyl isotopes and their correlation with heavy metals and organic carbon in sediment cores of the Elbe estuary Sci Total Environ 97/98 531-547

Petit, D , M Thomas, and L Lamberts 1987 Origin of heavy metal fluxes to the Meuse river in Southern Belgium using ^{210}Pb-dated water-meadow sediments J Environ Radioact 5 303-316

Phillips, F M , G I Smith, H W Bentley, D Elmore, and H E Gove 1983 Chlorine-36 dating of saline sediments preliminary results from Searles Lake, California Science 222 925-927

Pickering, R J 1969 Distribution of radionuclides in bottom sediment of the Clinch River Eastern Tennessee USGS Professional Paper 433-H, 25 pp, Washington, DC

Pickering, R J , P H Carrigan Jr , and F L Parker 1965 The Clinch River Study - an investigation of the fate of the radionuclides released to the surface streams USGS, Circular 497, 12 pp, Washington, DC

Pickering, R J , P H Carrigan Jr , T Tamura, H H Abee, J W Beverage, and R W Andrews, Jr 1966 Radioactivity in the bottom sediments of the Clinch and Tennessee Rivers, pp 57-86 *In* Disposal of radioactive waste in seas, oceans and surface waters, International Atomic Energy Agency, Vienna, Austria

Pierson, D H , R S Cambray, P A Cawse, J D Eakins, and N J Patterden 1982 Environmental radioactivity in Cumbria Nature 300 27-31

Pierson, D H , R N Crookes, and E M R Fisher 1960 Radioactive fallout in air and rain AERE-R 3358 HMSO, London

Pierson, D H and L Salmon 1959 Gamma radiation from deposited fallout Nature 184 1678-1679

Pietilainen, O P and P Ekholm 1993 Origin of eroded material in a small agricultural drainage basin in southwestern Finland Aqua Fenn 22 105-110

Pinder, J E III, J W Bowling R F Lide, and L M Beatty 1995 The distribution of ^{137}Cs in sediments of the littoral zone of a former reactor cooling pond J Environ Radioact 28 57-71

Pinder, J E III, C T Garten Jr , and D Paine 1980 Factors affecting radiocesium uptake by plants inhabiting a contaminated floodplain Acta Ècologica 1 3-10

Pinglot, J F and M Pourchet 1995 Radioactivity measurements applied to glaciers and lake sediments Sci Total Environ 173/174 211-223

Pioch, M and C Madozescande 1995 Effect of rainwater on the remobilization and dissolution of Cs-134 and Sr-85 contained in aerosols similar to those discharged in a nuclear accident and deposited in an urban environment J Environ Radioact 26 51-61

Pisarev, V V , I A Koloskov, V M Kuznetsova, and I S Tsybizov 1972a Leaching of strontium-90 from soil by surface water Pochvovedeniye 3 66-75 (Russian)

Pisarev, V V , I A Koloskov, V M Kuznetsova, and I S Tsybizov 1972b Leaching of strontium-90 from soil by surface water Soviet Soil Sci 3 193-201

Pittillo, J D and G L Plummer 1965 Accumulation of radioisotopes in *Juniperus virginiana* L Bull Ga Acad Sci 23 7-20

Plato, P A 1972 Distribution of cesium-137 and naturally occurring radionuclides in sediments of Lake Michigan Radiat Health Data Reports 13 181-188

Plato, P A 1974 Use of rivers to predict accumulation in sediment of radionuclides discharged from nuclear power plants Health Phys 26 489-496

Plato, P A 1975 Reply "Use of rivers to predict accumulation in sediment of radionuclides discharged from nuclear power plants" Health Phys 28 635-636

Plato, P A and G C Goldman 1972 Use of fallout cesium-137 as a tracer to define the recent deltaic facies of a river Radiat Health Data Reports 13 635-657

Plato, P A and A P Jacobson 1976 Cesium-137 in Lake Michigan sediment areal distribution and correlation with other man-made materials Environ Pollut 10 19-34

Playford, K , G N J Lewis, and R C Carpenter 1992 Radioactive fallout in air and rain results to the end of 1990 AEA-EE-0362, 27 pp United Kingdom Atomic Energy Authority, Harwell, UK

Playford, K J Toole, and I Adsley 1993 Radıoactıve fallout ın aır and raın results to the end of 1991 AEA-EE-0498, 30 pp Unıted Kıngdom Atomıc Energy Authorıty, Harwell, UK

Pımentel, D J Allen, A Beers, L Guınand, R Lınder, P McLaughlın, B Meer, D Musonda, D Perdue, S Poısson, S Sıebert, K Stone, R Salazar, and A Hawkıns 1987 World agrıculture and soıl erosıon Bıoscı 37 277-283

Plummer, G L and F Helseth 1965 Movement and dıstrıbutıon of radıonuclıdes on granıtıc outcrops wıthın the Georgıa Pıedmont Health Phys 11 1423-1428

Polıkarpov, G G , G E Lazorenko, A A Korotkov, A Mırzoeva, and A O Yu 1995 Role of suspended matter and bottom sedıments of the aquatıc ecosystem of the Northern-Crımean Canal ın mıgratıon of ^{90}Sr, ^{137}Cs, ^{238}Pu, $^{239+240}$Pu Dopovıdı Natsıonal=noyı Akademıyı Nauk Ukrayıng 7 148-152 (Russıan)

Popov, V Ye , I V Kutnyakov, V G Zhırnov, Ye P Vırchenko, A A Sıverına, and Ts I Bonovnıkova 1995 Vertıcal dıstrıbutıon of ^{90}Sr and ^{137}Cs ın alluvıal sod soıls ın the near zone of the Chernobyl nuclear power statıon Eurasıan Soıl Scı 27 65-73 (Translated from Pochovoedenıye 27 40-44)

Popp, C J , J W Hawley, D W Love, and M Dehn 1988 Use of radıometrıc (Cs-137, Pb-210), geomorphıc, and stratıgraphıc technıques to date recent oxbow sedıments ın the Rıo Puerco draınage Grants Uranıum Regıon, New Mexıco Envıron Geol Water Scı 11 253-269

Porter, C R , C R Phıllıps, M W Carter, and B Kahn 1967 The cause of relatıvely hıgh ^{137}Cs concentratıons ın Tampa, Florıda mılk, pp 95-101 *In* B Aberg and J R Hungate (eds), Radıoecologıcal concentratıon processes Pergamon Press, New York

Pourchet, M , P Mourguıart, J -F Pınglot, N Preıss, J Argollo, and D Wırrmann 1994 Sédımentatıon rJcente dans le lac Tıtıcaca (Bolıvıe) Comptes Rendus de L academıe des Scıences Parıs T 319 Serıe II A Scıences de la Terre et des Planetes 319 477-482 (French)

Pourchet, M , P Mourguıart, J -F Pınglot, N Preıss, J Argollo, and D Wırrmann 1995 Évaluatıon des vıtesses de sédımentatıon dans les hautes vallées des Andes bolıvıennes Son ınterêt dans l'estımatıon des paléo-pollutıons atmosphérıque Comptes Rendus de L'academıe des Scıences Parıs T 320 Serıe II A Scıences de la Terre et des Planetes 320 477-482 (French)

Pourchet, M , J F Pınglot, and M A Melıeres 1989 Cesıum-137 and lead-210 ın Alpıne sedıments measurements and modelıng of mıxıng processes J Geophys Res 94 12761-12770

Pourchet, M , J F Pınglot, L Reynaud, and G Holdsworth 1988 Identıfıcatıon of Chernobyl fallout as a new reference level ın Northern Hemısphere glacıers J Glacıology 34 183-187

Powers, F , F S Stay, and W D Sanvılle 1975 Aquatıc sedıments J Water Pollut Control Fed 47 1611-1617

Prandle, D 1984 A modellıng study of the mıxıng of ^{137}Cs ın the seas of the European contınental shelf Phıl Trans R Soc London A 310 407-436

Premazzı, G 1978 Metodo dı valutazıone della rate dı sedımentazıone Attı del Convego sulla "Eutrofızzazıone ın Italıa", Roma, 3-4 Ottobre 1978 AC/2/55 pp 181-195 (Italıan)

Premazzı, G 1979 The Cs-137 technıque to evaluate recent sedımentatıon rates, pp 181-196 *In* R Marchettı (ed), Convegno Sulla Eutrofızzazıone ın Italıa AC/2/45-70, Roma, Italy

Premazzı, G and G Marengo 1982 Sedımentatıon rates ın a Swıss-Italıan lake measured wıth sedıment traps Hydrobıologıa 92 603-610

Premazzı, G , A Provını, G F Gaggıno, and G Parıse 1986 Geochemıcal trends ın sedıments from 13 Italıan subalpıne lakes, pp 157-165 *In* P G Sly, (ed), Sedıment and water ınteractıons, Sprınger-Verlag, New York

Premazzı, G and O Ravera 1977 Chemıcal characterıstıcs of Lake Lugano sedıments, pp 121-124 *In* H L Golterman (ed), Interactıon between sedıment and fresh water, W Junk B V Publıshers, Wagenıngen, The Netherlands

Preston, A 1968 The control of radıoactıve pollutıon ın a North Sea oyster fıshery Helgoländer wıss Meeresunters 17 269-279

Pretı, L , C Lubello, and I Becchı 1993 Joınt monıtorıng of hydrosedımentologıcal events and transport of caesıum-137 ın a small basın Water Scı Tech 28 707-711

Prokhorov, V M 1975 Forecastıng Cs^{137} mıgratıon ın soıls Pochvovedenıye 11 60-67

Prokhorov, V M , M V Ryzhınskıy, R M Aleksakhın, and V F Gol tsev 1974 Forecast of the vertıcal mıgratıon of Sr^{90} ın the soıl usıng a mathematıcal model Soıl Chemıstry 1 47-54 (translated from Pochvovedenıye 1 52-60

Provını, A and G F Gaggıno 1984 Metal contamınatıon and hıstorıcal records ın Lake Orta sedıments (Northern Italy), pp 318-321 *In* Proceedıngs 3rd ınternatıonal symposıum on the ınteractıons between sedıments and water, Geneva, Swıtzerland

Provını, A and G F Gaggıno 1985 Sedıment as a record of copper pollutıon ın Lake Orta Verh Internat Vereın Lımnol 22 2390-2393

Provını, A and G F Gaggıno 1986 Depth profıles of Cu, Cr, and Zn ın Lake Orta sedıments (Northern Italy), pp 167-174 *In* P G Sly (ed), Sedıment and water ınteractıons, Sprınger-Verlag, New York

Provını, A , G Premazzı, and G F Gaggıno 1987 Valutazıone del rıschıo potenzıale da metallı pesantı neı laghı medıante l'analısı deı sedımentı Ingegnerıa Ambıentale 16 68-76 (Italıan)

Provını A , G Premazzı, S Galassı, and G F Gaggıno 1987 Dıstrıbutıon of nutrıents, PAHs, and radıonuclıdes ın sedıment cores from Lake of Varese (N Italy) Proceedıngs of 4th ınternatıonal symposıum ın ınteractıon between sedıment and water, Melbourne Australıa

PuıgdomPnech, I and U Bergstr`m 1995 Calculatıon of dıstrıbutıon coeffıcıents for radıonuclıdes ın soıls ands sedıments Nucl Safety 36 142-154

Purtymum, W D 1974 Storm runoff and transport of radıonuclıdes ın DP Caynon, Los Alamos County, New Mexıco Los Alamos Scıentıfıc Laboratory, LA-5744, 9pp

Quine, T.A. 1989. Use of a simple model to estimate rates of soil erosion from caesium-137 data. J. Water Resour. 8:54-81.

Quine, T.A. 1995. Estimation of erosion rates from caesium-137 data: the calibration question, pp: 307-329. *In*: I.D.L. Foster, A.M. Gurnell, and B.W. Webb (eds.), Sediment and Water Quality in River Catchments, John Wiley, London.

Quine, T.A., P.J.J. Desmet, G. Govers, K. Vandaele, and D.E. Walling. 1994. A comparison of the role of tillage and water erosion in landform development and sediment export on agricultural land near Leuven, Belgium. IAHS Publ. 224:77-86.

Quine, T.A., A. Navas, D.E. Walling, and J. Machin. 1994. Soil erosion and distribution on cultivated land near Las Barenas in the central Ebro River basin, Spain. Land Degradation and Rehabilitation 5:41-55.

Quine, T.A. and D.E. Walling. 1991. Rates of soil erosion on arable fields in Britain: quantitative data from caesium-137 measurements. Soil Use Manage. 7:169-176.

Quine, T.A. and D.E. Walling. 1992a. Use of caesium-137 measurements to investigate the relationships between erosion rates and topography, pp. 31-48. *In*: R.J. Allison and D.S.G. Thomas (eds.), Environmental sensitivity, Wiley, Chichester, UK.

Quine, T.A. and D.E. Walling. 1992b. Patterns and rates of contemporary soil erosion derived using caesium-137, pp. 185-196. *In*: M. Bell and J. Boardman (eds.), Past and present soil erosion: archeological and geographical perspectives, Oxbow Books, Oxford, England.

Quine, T.A. and D.E. Walling. 1993. Use of caesium-137 measurements to investigate relationships between erosion rates and topography, pp. 31-48. *In*: D.S.G. Thomas and R.J. Allison (eds.) Environmental sensitivity, J. Wiley and Sons, Chichester, UK.

Quine, T.A. and D.E. Walling. 1993. Assessing recent rates of soil loss from areas of arable cultivation in the UK, pp. 357-371. In: S. Wicherek(ed.), Farm land erosion and temperate plains environment and hills, Elsevier, London.

Quine, T.A., D.E. Walling, and G. Grovers. 1996. Simulation of radiocaesium redistribution on cultivated hillslopes using mass-balance models: An aid to process interpretation and erosion rate estimation, pp: . *In*: M.G. Anderson and S.M. Brooks (eds.), Advances in Hillslope Processes.

Quine, T.A., D.E. Walling, and O.T. Mandiringana. 1993. An investigation of the edaphic, topographic, and land-use controls on soil erosion on agricultural land in the Borrowdale and Chinamora areas, Zimbabwe, based on caesium-137 measurements. IAHS Publ. No. 217:185-196.

Quine, T.A., D.E. Walling, and X. Zhang. 1993. The role of tillage in soil redistribution within terraced fields of the Loess Plateau, China: An investigation using caesium-137, pp. 149-155. *In*: K. Banasik and A. Zbikowski (eds.), Runoff and sediment yield modelling. Warsaw Agricultural University Press, Warsaw, Poland.

Quine, T.A., D.E. Walling, X. Zhang, and Y. Wang. 1992. Investigation of soil erosion on terraced fields near Yanting, Sichuan Province, China, using caesium-137. IAHS Publ. No. 209:155-168.

Rafferty, B., D.E. Dawson, and P.A. Colgan. 1994a. Seasonal variations in the transfer of Cs-137 and K- 40 to pasture grass and its ingestion by grazing animals. Sci. Total Environ. 145:125-134.

Rafferty, B., D.E. Dawson, and P.A. Colgan. 1994b. Assessment of the role of soil adhesion in the transfer of Cs-137 and K-40 to pasture grass. Sci. Total Environ. 145:135-141.

Rafferty, B., D.E. Dawson, and P.A. Colgan. 1994c. Soil and radiocaesium contamination of winter fodders. Sci. Total Environ. 153:69-76.

Rapin, F. 1981. Chronologie et evolution de la contamination par les meteux lourds des sediment de la Baie des Anges (Mediterranee, France). Environ. Tech. Lett. 2:253-262. (French)

Ratnikov, A.N., R.M. Aleksakhin, T.L. Zhigareva, N.I. Sanzharova, and G.I. Popova. 1993. Effectiveness of meliorative measures in decreasing levels of Cs-137 in harvests after the accident at the Chernobyl Nuclear Power Plant - Data from Bryansk Province, Russia. Eurasian Soil Sci. 25:123-127.

Ravera, O. 1961. Sediment, pp. 31-37. *In*: Accumulation of fission products from fall-out in lake biota (Lake Maggiore). Contract 59, Report CNI-109, International Atomic Energy Agency, Vienna, Austria.

Ravera, O. and G. Premazzi. 1971a. A method to study the history of any persistent pollution in a lake by the concentration of ^{137}Cs from fall-out. Publ. Biol. Directorate, Comm. European Communities 679:1-16.

Ravera, O. and G. Premazzi. 1971b. A method to study the history of any persistent pollution in a lake by the concentration of ^{137}Cs from fall-out, pp. 703-719. *In*: Radioecology applied to the protection of man and his environment. EUR 4800.

Ravera, O. and M. Viola. 1977. Sedimentation rate in a basin (Agno) of Lake Lugano, pp. 174-178. *In*: H.L. Golterman (ed.), Interaction between sediment and fresh water, W. Junk B.V. Publishers, Wageningen, The Netherlands.

Ravera, O. and S. Zarini. 1987. A century of variations in some zooplankton and zoobenthos organisms in Lake Comabbio (Northern Italy) 'read' from their remains in the lake sediment. Schweiz. Z. Hydrol. 49:93-101.

Rea, D.K., R.A. Bourbonniere, and P.A. Meyers. 1980. Southern Lake Michigan sediments: changes in accumulation rates, mineralogy, and organic content. J. Great Lakes Res. 6:321-330.

Realo, E., J. Jogi, R. Koch, and K. Realo., 1995. Studies on radiocaesium in Estonian soils. J. Environ. Radioact. 29:111-119.

Reddy, K.R., R.D. DeLaune, W.F. DeBusk, and M.S. Koch. 1993. Long-term nutrient accumulation rates in the Everglades. Soil Sci. Soc. Am. J. 57:1147-1155.

Rember, W.C., T.W. Erdman, M.L. Hoffmann, V.E. Chamberlain, and K.F. Sprenke. 1993. Dating of mine waste in lacustrine sediments using cesium-137. Environ. Geol. 22:242-245.

Renard, K.G., G.R. Foster, G.A. Weesies, and J.P. Porter. 1991. RUSLE Revised universal soil loss equation. J. Soil Water Conserv. 46:30-33.

Richter, T., G. Schroeder, S. Kaminski, and G. Linder. 1993. Transport of particles contaminated with cesium radionuclides into the sediment of Lake Constance. Water Sci. Tech. 28:117-121.

Rickard, W.H. 1966a. Cesium-137 in litter and understory vegetation. Northwest Science 40:25-30.

Rickard, W.H. 1966b. Accumulation of ^{137}Cs in litter and understory plants of forest stands from various climatic zones of Washington, p. 527-531. *In*: B. Aberg and F.P. Hungate (eds.) Radioecological concentration processes, Pergamon Press, London

Ridgeway, I.M. and N.B. Price. 1987. Geochemical associations and post-depositional mobility of heavy metals in coastal sediments: Loch Etive, Scotland. Marine Chem. 21:229-248.

Rieger, E.M., B. Claus, E. Peters, M. Schirmer, and I. Schmitz-Feuerhake. 1993. Cesium isotope-activity in the Weser ecosystem three years after the disaster at Chernobyl. Neth. J. Aquat. Ecol. 27:197-203.

Riel, G.K. 1970. Radioactive cesium in estuaries. Radiat. Health Data Reports 11:659-665.

Ritchie, J.C. 1996. Measuring sediment deposition and erosion rates using environmentally distributed fallout ^{137}Cesium. International Conference on Reservoir Sedimentation 1996 pp. 233-246

Ritchie, J.C. 1988. Organic matter content in sediments of three navigation pools along the upper Mississippi River. J. Freshwater Ecol. 4:343-349.

Ritchie, J.C. 1989. Carbon content of sediments in agricultural reservoirs. Water Resour. Bull. 25:301-308.

Ritchie, C.A., J.C. Ritchie, and G.L. Plummer. 1971. Distribution of fallout cesium-137 in Cladonia mounds. Bryologist 74:359-362.

Ritchie, J.C., E.E.C. Clebsch, and W.K. Rudolph. 1970. Distribution of fallout and natural gamma radionuclides in litter, humus, and surface mineral soils under natural vegetation in the Great Smoky Mountains, North Carolina-Tennessee. Health Phys. 18:479-491.

Ritchie, J.C., C.M. Cooper, and J.R. McHenry. 1979. Recent sediment accumulation in natural lakes in Bear Creek watershed in the Mississippi Delta. Southeastern Geol. 20:173-180.

Ritchie, J.C., C.M. Cooper, and J.R. McHenry. 1986. Sediment accumulation rates in lakes and reservoirs in the Mississippi River valley, pp. 1357-1365. *In*: S.Y. Wang, H.W. Shen, and L.Z. Ding (eds.), River sedimentation, Vol. III, Univ. Mississippi, Oxford, MS.

Ritchie, J.C., C.M. Cooper, J.R. McHenry, and F.R. Schiebe. 1983. Sediment accumulation in Lake Chicot, Arkansas. Environ. Geol. 5:79-82.

Ritchie, J.C., A.C. Gill, and J.R. McHenry. 1975. A comparison of nitrogen, phosphorus, and carbon in sediments and soils of cultivated and noncultivated watershed of the North Central States. J. Environ. Qual. 4:339-341.

Ritchie, J.C. and P.H. Hawks. 1979. Natural gamma radioactivity in the soils of North Mississippi. J. Mississippi Acad. Sci. 24:92-103.

Ritchie, J.C., P.H. Hawks, and J.R. McHenry. 1972. Thorium, uranium, and potassium in the Upper Cretaceous, Paleocene, and Eocene sediments of the Little Tallahatchie River Watershed in northern Mississippi. Southeastern Geol. 14:221-232.

Ritchie, J.C., P.H. Hawks, and J.R. McHenry. 1975. Deposition rates in valleys determined using fallout Cs-137. Geol. Soc. Am. Bull. 86:1128-1130.

Ritchie, J.C. and J.R. McHenry. 1973a. Determination of fallout Cs-137 and natural gamma-ray emitting radionuclides in sediments. Internat. J. Appl. Radiat. Isot. 24:575-578.

Ritchie, J.C. and J.R. McHenry. 1973b. Vertical distribution of fallout cesium-137 in cultivated soils. Radiat. Health Data Reports 14:727-728.

Ritchie, J.C. and J.R. McHenry. 1975a. Fallout Cs-137: a tool in conservation research. J. Soil Water Conserv. 30:283-286.

Ritchie, J.C. and J.R. McHenry. 1975b. Fallout cesium-137 in estuarine sediments. J. Mississippi Acad. Sci. 20:34-39.

Ritchie, J.C. and J.R. McHenry. 1976. Fallout Cs-137 in soils and sediments of some Texas watershed ecosystems, pp. 299-303. *In*: C.E. Cushing (ed.), Radioecology and energy resources. The Ecological Society of America Special Publication No. 1, Dowden, Hutchinson and Ross, Stroudsburg, PA.

Ritchie, J.C. and J.R. McHenry. 1977a. The distribution of Cs-137 in some watersheds in the eastern United States. Health Phys. 32:101-105.

Ritchie, J.C. and J.R. McHenry. 1977b. A rapid method for determining recent deposition rates of freshwater sediments. pp. 203-207. *In*: H.L. Golterman (ed.), Interaction between sediment and fresh water, W. Junk B. V. Publishers, The Hague, The Netherlands.

Ritchie, J.C. and J.R. McHenry. 1977c. Nitrogen, carbon and phosphorus in soil and sediments of some small watersheds in the eastern United States. J. Mississippi Acad. Sci. 22:7-14.

Ritchie, J.C. and J.R. McHenry. 1978. Fallout Cs-137 in cultivated and noncultivated North Central United States watersheds. J. Environ. Qual. 7:40-44.

Ritchie, J.C. and J.R. McHenry. 1981. Distribution of fallout cesium-137 in small watersheds in the United States, pp. 104-105. *In*: International symposium on migration in the terrestrial environments of long-lived radionuclides from the nuclear fuel cycle. International Atomic Energy Agency, Vienna, Austria.

Ritchie, J.C. and J.R. McHenry. 1982. Redistribution of fallout cesium-137 in small watersheds in the United States, pp. 809-810. *In*: Environmental migration of long-lived radionuclides, Proceeding Series STI/PUB/597, International Atomic Energy Agency, Vienna, Austria.

Ritchie, J.C. and J.R. McHenry. 1984. Cesium-137 and sediment deposition, pp. 183-188. *In*: R.J. Loughran (ed.), Drainage basin erosion and sedimentation, Univ. Newcastle, Newcastle, Australia.

Ritchie, J.C. and J.R. McHenry. 1985. A comparison of three methods for measuring recent rates of sediment accumulation. Water Resour. Bull. 21:99-103.

Ritchie, J.C. and J.R. McHenry. 1989. Application of radioactive fallout cesium-137 for measuring soil erosion and sediment accumulation rates and patterns: a review and bibliography. Hydrology Laboratory Technical Report No. 15, 67 pp, US Department of Agriculture, Agriculture Research Service, Beltsville, MD.

Ritchie, J.C. and J.R. McHenry. 1990. Application of radioactive fallout cesium-137 for measuring soil erosion and sediment accumulation rates and patterns: a review. J. Environ. Qual. 19:215-233.

Ritchie, J.C., J.R. McHenry, and G.B. Bubenzer. 1982. Distribution of fallout Cs-137 in Brunner Creek watershed in Wisconsin. Trans. Wisconsin Acad. Sci., Arts, Lett. 70:161-167.

Ritchie, J.C., J.R. McHenry, and A.C. Gill. 1970. Distribution of cesium-137 in the upper 4 inches of soil in relation to vegetation type. ASB Bulletin 17:60.

Ritchie, J.C., J.R. McHenry, and A.C. Gill. 1972a. Dating recent reservoir sediment using radioactive fallout. ASB Bulletin 19:95.

Ritchie, J.C., J.R. McHenry, and A.C. Gill. 1972b. The distribution of Cs-137 in litter and the upper 10 centimeters of soil under different vegetation types in northern Mississippi. Health Phys. 22:197-198.

Ritchie, J.C., J.R. McHenry, and A.C. Gill. 1972c. Dose rates over reservoirs due to fallout Cs-137. Health Phys. 23:406-407.

Ritchie, J.C., J.R. McHenry, and A.C. Gill. 1973. Dating recent reservoir sediments. Limnol. Oceanogr. 18:255-264.

Ritchie, J.C., J.R. McHenry, and A.C. Gill. 1974. Fallout Cs-137 in the soils and sediments of three small watersheds. Ecol. 55:887-890.

Ritchie, J.C., J.R. McHenry, A.C. Gill, and P.H. Hawks. 1970a. The use of fallout cesium-137 as a tracer of sediment movement and deposition. Mississippi Water Resour. Conf. Proc. pp. 149-163.

Ritchie, J.C., J.R. McHenry, A.C. Gill, and P.H. Hawks. 1970b. Distribution of fallout cesium-137 in sediment profiles. Health Phys. 19:334.

Ritchie, J.C., J.R. McHenry, A.C. Gill, and P.H. Hawks. 1972. Fallout Cs-137 in reservoir sediments. Health Phys. 22:97-98.

Ritchie, J.C., J.R. McHenry, A.C. Gill, and P.H. Hawks. 1973. Distribution of Cs-137 in a small watershed in northern Mississippi, pp. 129-133. *In*: D.J. Nelson (ed.), Proceedings of the third national symposium on radioecology. USAEC CONF-710501-p1, US Atomic Energy Commission, Washington, DC.

Ritchie, J.C. and G.L. Plummer. 1969. Natural gamma radiation in northeast and east-central Georgia. Bull. Georgia Acad. Sci. 27:173-194.

Ritchie, J.C. and C.A. Ritchie. 1995. ^{137}Cs use in erosion and sediment deposition studies: Promises and problems. IAEA-TECHDOC-828, pp. 111-124.

Ritchie, J.C. and C.A. Ritchie. 1995. Bibliography of publications of ^{137}Cesium studies related to erosion and sediment deposition. IAEA-TECHDOC-828, pp. 125-201.

Ritchie, J.C., J.A. Spraberry, and J.R. McHenry. 1973. Estimating soil erosion from the redistribution of Cs-137 fallout. Agronomy Abstracts 1973 Annual Meeting. p. 129.

Ritchie, J.C., J.A. Spraberry, and J.R. McHenry. 1974. Estimating soil erosion from the redistribution of fallout Cs-137. Soil Sci. Soc. Am. Proc. 38:137-139.

Robbe, D., P. Marchandise, and A. Thomas. 1983. DJtermination de l'origine des pollutions mJtalliques par datation des carottes de sJdiments. Bull. Laison Lab Ponts Chaussees 127:81-92. (French)

Robbins, J.A. 1978. Geochemistry and geophysical application of radioactive lead, pp. 285-393. *In*: J.O. Nriagu (ed.) The Biochemistry of lead in the environment. Elsevier, Amsterdam.

Robbins, J.A. 1980. Sediments of southern Lake Huron: elemental composition and accumulation rate. USEPA, Ecological Research Series, EPA-600/3-80-080, August 1980, 309 pp. (Plus Appendix, 198 pp.)

Robbins, J.A. 1982. Stratigraphic and dynamic effects of sediment reworking by Great Lake zoobenthos. Hydrobiologia 92:611-622.

Robbins, J.A. 1985a. Great Lakes regional fallout source functions. NOAA Technical Memorandum ERL GLERL-56, Ann Arbor, MI.

Robbins, J.A. 1985b. The coupled lake model for estimating the long-term response of the Great Lakes to time-dependent loadings of particle-associated contaminants. NOAA Technical Memorandum ERL GLERL-57, Ann Arbor, MI.

Robbins, J.A. 1986a. Sediment in Saginaw Bay, Lake Huron: elemental composition and accumulation rates. Great Lakes and Marine Waters Center, Special Report No. 102 of the Great Lakes Research Division, Univ. Michigan, Ann Arbor, MI

Robbins, J.A. 1986b. A model for particle-selective transport of tracers in sediment with conveyors belt deposit feeders. J. Geophys. Res. 91:8542-8558.

Robbins, J.A., E. Callendar, and N.R. Morehead. 1988. Records of fallout Cs-137 in Lake Oahe Reservoir South Dakota. EOS Trans. 69:68.

Robbins, J.A. and B.J. Eadie. 1991. Seasonal cycling of trace elements ^{137}Cs, ^{7}Be, and $^{239+240}$Pu in Lake Michigan. J. Geophys. Res. 96:17081-17104.

Robbins, J.A. and D.N. Edgington. 1972. The use of natural and fallout radionuclides to measure recent sedimentation rates in Southern Lake Michigan, pp. 31-53. *In*: Argonne National Lab. Rep. ANL-7960, Part 3., Argonne National Laboratory, Argonne, IL.

Robbins, J A and D N Edgington 1973 Stable lead geochronology of fine-grained sediments in southern Lake Michigan, pp 32-39 *In* Radiological and environmental research division annual report, ecology, January-December 1973, Argonne National Laboratory, Argonne, IL

Robbins, J A and D N Edgington 1974 The distribution of trace elements in the clay silt sediments of Grand Haven, pp 78-85 *In* Radiological and environmental research division annual report, ecology, January-December 1973 Argonne National Laboratory, Argonne, IL

Robbins, J A and D N Edgington 1975 Determination of recent sedimentation rates in Lake Michigan using Pb-210 and Cs-137 Geochim Cosmochim Acta 39 285-304

Robbins, J A and D N Edgington 1976 Depositional processes and determination of recent sedimentation rates in Lake Michigan, pp 378-390 In Proceedings second federal conference on the Great Lakes, Ann Arbor, MI

Robbins, J A , D N Edgington, J Gustinis, and J O Karttune 1974 Geochronology of Lake Michigan sediments anomalies in lead-210 distribution, pp 40-50 *In* Radiological and environmental research division annual report, ecology, January-December 1974 Argonne National Laboratory, Argonne, IL

Robbins, J A , D N Edgington, and L W Kemp 1977 Comparative lead-210, cesium-137 and pollen geochronologies of recent sediments from Lake Erie and Ontario, pp 87-92 *In* Radiological and environmental research division annual report, ecology, January-December 1976 Argonne National Laboratory, Argonne, IL

Robbins, J A , D N Edgington, and L W Kemp 1978 Comparative ^{210}Pb, ^{137}Cs, and pollen geochronologies of sediments from Lake Ontario and Erie Quat Res 10 256-278

Robbins, J A , K Husby-Coupland, and D S White 1984 Precise radiotracer measurements of the rate of sediment reworking by *Stylodrilus heringianus* and the effects of variable dissolved oxygen concentration J Great Lakes Res 10 335-347

Robbins, J A , T Keilty, D S White, and D N Edgington 1989 Relationship among Tubificid abundances, sediment composition, and accumulation rates in Lake Erie Can J Fish Aquat Sci 46 223-231

Robbins, J A , J R Krezoski, and S C Mozley 1977 Radioactivity in sediments of the Great Lakes post-depositional redistribution by deposit-feeding organism Earth Planet Sci Lett 36 325-333

Robbins, J A , G Lindner, W Pfeiffer, J Kleiner, H H Stabel, and P Frenzel 1992 Epilimnetic scavenging of Chernobyl radionuclides in Lake Constance Geochim Cosmochim Acta 56 2339-2361

Robbins, J A , P L McCall, J B Fisher, and J R Krezoski 1979 Effect of deposit feeders on migration of ^{137}Cs in lake sediment Earth Planet Sci Lett 42 277-287

Robbins, J A , A Murdock, and B G Oliver 1990 Transport and storage of ^{137}Cs and ^{210}Pb in sediments of Lake St Clair Can J Fish Aquat Sci 47 572-587

Robbins, J A and C L Schelske 1988 Biogenic silica deposition in Lake Erie since 1800 EOS Trans 69 1143

Rogowski, A S and E R Eastwood 1967 Differential movement of 137Cs and 134Cs on runoff plots Health Physics Division Annual Report for Pereiod Ending July 31, 1967, ORNL-4168 3-7

Rogowski, A S and T Tamura 1965 Movement of ^{137}Cs by runoff, erosion and infiltration on the alluvial Captina silt loam Health Phys 11 1333-1340

Rogowski, A S and T Tamura 1970a Environmental mobility of cesium-137 Radiat Bot 10 35-45

Rogowski, A S and T Tamura 1970b Erosional behavior of cesium-137 Health Phys 18 467-477

Rood, B E , J F Gottgens, J J Delfino, C D Earle, and T L Crisman 1995 Mecury accumulation in Florida Everglades and Savannas and Marsh flooded soils Water Air Soil Pollut 80 981-990

Rose, C W , M E McCallan, B M O Leary, and G Sander 1980 Testing a model of field-scale soil erosion and deposition on a plane land element using the fallout isotope ^{137}Cs Conference on agricultural engineering, Geelong, Australia

Rose, K A , A L Brenkert, G A Schohl, Y Onishi, J S Hayworth, F Holly, W Perkins, L Beard, R B Cook, and W Waldrop 1993 Multiple model analysis of sediment transport and contaminant distribution in the Clinch River Watts Bar Reservoir, Tennessee, USA Water Sci Tech 28 65-78

Rosen, K 1996 Field studies on the behaviour of radiocaesium in agricultural environments after the Chernobyl accident Rapport - Institutionen for Radioekologi, Sveriges Lantbruksuniversitet (No 78) 65 pp

Rowan, D J , R J Cornett, K King, and B Risto 1995 Sediment focusing and ^{210}Pb dating a new approach J Paleolimnol 13 107-118

Rowan, J S , S B Bradley, and D E Walling 1992 Fluvial redistribution of Chernobyl fallout - reservoir evidence in the Severn Basin J Inst Water Environ Manage 6 659-666

Rowan, J S , D L Higgitt, and D L Walling 1993 Incorporation of Chernobyl-derived radiocaesium in reservoir sedimentary sequences, pp 55-71 *In* J McManus and R Duck (eds), Geomorphology and sedimentology of lakes and reservoirs, Wiley, London

Rowan, J S and D E Walling 1992 The transport and fluvial redistribution of Chernobyl-derived radiocaesium within the River Wye Basin, UK Sci Total Environ 121 109-131

Ruhm, W , L Kammerer, L Hiersche, and E Wirth 1996 Migration of ^{137}Cs and ^{134}Cs in different forest soil layers J Environ Radioact 33 63-75

Rummery, T A , J Bloemendal, J Dearing, F Oldfield, and R Thompson 1979 The persistence of fire-induced magnetic oxides in soils and lake sediments Ann Geophys 35 103-107

Ryabinin, A I , V P Popov, B F Andryushchenko, N A Konovalenko, and S A Shibaeva 1995 Caesium-137 content in Dnieper drowned area sediments in 1993 Dopovidi Natsional'noyi Akademiyi Nauk Ukrayiny 4 133-136 (Russian)

Rysgaard, S., K. Finster, and H.Dahlgaard. 1996. Primary production, nutrient dynamics and mineralisation in a northeastern Greenland fjord during the summer thaw. Polar Biol. 16(7):497-506.

Sabater, S. And E.Y. Haworth. 1995. An assessment of recent trophic changes in Windermere South Basin (England) based on diatom remains and fossil pigment. J. Paleolimnol. 14:151-163.

Sachdev, P., M.S. Sachdev, and D.L. Deb. 1995.Adsorption-desorption of radiocaesium (^{137}Cs) in semi-arid and tropical soils. J. Nucl. Agric. Biol. 24(4):201-209.

Saiers, J.E. and G.M. Hornberger. 1996a. The role of colloidal kaolinite in the transport of cesium through laboratory sand columns. Water Res. Res. 32:33-41.

Saiers, J.E. and G.M. Hornberger. 1996b. Migration of ^{137}Cs through quartz sand: Experimental results and modeling approaches. J. Contaminant Hydrol. 22 (3-4):255-270.

Salazar, A. And P. Mora. 1996 The distribution of fallout ^{137}Cs in Costa Rica. Health Phys. 71 (2):215-218.

Salo, A., R. SaxJn, and M. Puhakainen. 1984. Transport of airborne ^{90}Sr and ^{137}Cs deposited in the basins of the five largest rivers in Finland. Aqua Fennica 14:21-31.

Salo, A., K. Tuomainen, and A. Voipio. 1986. Inventories of some long-lived radionuclides in the Baltic Sea. Sci. Total Environ. 54:247-260.

Salt, C.A. and R.W. Mayes. 1991. Seasonal variations in radiocaesium uptake by reseeded hill pasture grazed at different intensities by sheep. J. Appl. Ecol. 28:947-962.

Salt, C.A. and R.W. Mayes. 1993. Plant uptake of radiocaesium on heather moorland grazed by sheep. J. Appl. Ecol. 30:235-246.

Salt, C.A., R.W. Mayes, and D.A. Elston. 1992. Effects of season, grazing intensity and diet composition on the radiocaesium intake by sheep on reseeded hill pasture. J. Appl. Ecol. 29:378-387.

Salvadori, G., S.P. Ratti, and G. Belli. 1996. Modelling the Chernobyl radioactive fallout (II): Multifractal approach in some European countries. Chemosphere 33:2359-2371.

Sanchez-Cabeza, J.A., J. Molero, J. Merino, L. Pujol, and P.I. Mitchell. 1995. Cs-137 as a tracer of the Catalan current. Oceanologica Acta 18:221-226.

Sanders, G., K.C. Jones, J. Hamilton, and H. Dörr. 1992. Historical input of polychlorinated-biphenyls and other organochlorides to a dated lacustrine sediment core in rural England. Environ. Sci. Tech. 26:1815-1821.

Sandman, O., A. Lichu, and H. Simola. 1990. Drainage ditch erosion history as recorded in the varved sediment of a small lake in East Finland. J. Paleolimnology 3:161-169.

Santschi, P. 1984a. Particle flux and trace metal residence times in natural waters. Limnol. Oceanogr. 29:1100-1108.

Santschi, P. 1984b. Radionuclides as tracers for sedimentation and remobilization processes in the ocean and in lakes, pp. 437-449. *In*: P.G. Sly (ed.), Sediment and water interactions, Springer-Verlag, London.

Santschi, P.H. 1987. Chernobyl radionuclides in the environment: tracers for the tight coupling between atmospheric, terrestrial and aquatic geochemical processes. EAWAG News 22/23:1-6.

Santschi, P.H. 1989. Use of radionuclides in the study of contaminant cycling processes. Hydrobiologia 176/177:307-320.

Santschi, P.H., S. Bollhalder, K. Farrenkothen, A. Lueck, S. Zingg, and M. Strum. 1988. Chernobyl radionuclides in the environment: tracers for the tight coupling between atmospheric, terrestrial, and aquatic geochemical processes. Environ. Sci. Tech. 22:510-516.

Santschi, P.H., S. Bollhalder, S. Zingg, A. Lueck, and K. Farrenkothen. 1990. The self-cleaning capacity of surface waters after radioactive fallout. Evidence from European waters after Chernobyl. Environ. Sci. Tech. 24:519-527.

Santschi, P.H. and B.D. Honeyman. 1989. Radionuclides in aquatic environments. Radiat. Phys. Chem. 34:213-240.

Santschi, P.H., Y.H. Li, D.M. Adler, M. Amdurer, J. Bell, U.P. Nyffeler. 1983. The relative mobility of natural (Th, Pb, Po) and fallout (Pu, Am, Cs) radionuclides in the coastal marine environments: results from model ecosystems (MERL) and Narragansett Bay. Geochim. Cosmochim. Acta 47:201-210.

Santschi, P.H., Y.H. Li, and S. Carson. 1980. The fate of trace metals in Narragansett Bay, Rhode Island: radiotracer experiments in microcosms. Estuar. Coast. Marine Sci. 10:635-654.

Santschi, P.H., Y.H. Li, P. O'Hara, M. Amdurer, D. Adler, and P. Doering. 1987. The relative mobility of radioactive trace elements across the sediment-water interface of the MERL model ecosystem of Naragansett Bay. J. Marine Res. 45:1007-1048.

Santschi, P.H., S. Nixon, M. Pilson, and C. Hunt. 1984. Accumulation of sediment, trace metals (Pb, Cu) and hydrocarbons in Narragansett Bay, Rhode Island. Estuar. Coast. Shelf. Sci. 19:427-450.

Santschi, P.H., U.P. Nyffeler, R.F. Anderson, S.L. Schiff, and P. O'Hara. 1986. Response of radioactive trace metals to acid-base titration in controlled experimental ecosystems: evaluation of transport parameters for application to whole lake experiments. Can. J. Fish. Aquat. Sci. 43:60-77.

Santschi, P.H. and P.W. Schindler. 1977. Chemical and geochemical studies of Lake Biel. I. A mass balance for Lake Biel and its implications for the rates of erosion in the drainage area. J. Hydrol. 39:181-200.

Santschi, P.H., C. Schuler, and M. Strum. 1987. Natural and Chernobyl radionuclides as tracers of particle settling and resuspension in Lake Zurich, Switzerland. Terra Cognita 7:185.

Santschi, P.H., C. Schuler, M. Strum, A. Lueck, K. Farrenkothen, S. Bollhalder, and E. Wieland. 1988. Natural radionuclides in Lake Zurich: tracers for particle and tracer element dynamics. EOS Trans. 69:1085.

Sanzharova, N.I., V.A. Kotik. A.N. Arkhipov, G.A. Sokolik, Yu.A. Ivanov, S.V. Fesenko and S.E. Levchuk. 1996. Quantitative parameters of radionuclide vertical migration in the soils on different meadow types. Radiatsionnaya Biologiya Radioekologiya 36(4): 488-497. (RUSSIAN)

Sarkka, J., A. Jamsa, and A. Luukko. 1995. Chernobyl-derived radiocaesium in fish as dependent on water quality and lake morphometry. J. Fish Biol. 46:227-240.

Sarkka, J., A. Keskitalo and A. Luukko. 1996. A temporal changes in concentration of radiocaesium in lake sediment and fish of southern Finland as related to environmental factors. Sci. Total Environ. 191:125-136.

Sauras, T. M.C. Roca, J. Tent, M. Llaurado, M. Vidal, G. Rauret, and V.R. Vallejo. 1994. Migration study of radionuclides in a mediterranean forest soil using synthetic aerosols. Sci. Total Environ. 157:231-238.

Sawhney, B.L. 1964. Sorption of cesium from dilute solutions. Soil Sci. Soc. Am. Proc. 28:25-28.

Sawhney, B.L. 1966. Kinetics of cesium sorption by clay minerals. Soil Sci. Soc. Am. Proc. 30:565-569.

Sawhney, B.L. 1972. Selective sorption and fixation of cations by clay minerals: a review. Clays and Clay Minerals 20:93-100.

Saxen, R. 1995. Transport of ^{137}Cs in large Finnish drainage basin, pp. 63-78. *In:* H. Dahlgaard (ed.), Studies in Environmental Science 62. Nordic Radioecology: The transfer of radionuclides through nordic ecosystems to man, Elsevier, New York.

Saynor, M.J., R.J. Loughran, W.D. Erskine, and P.F. Scott. 1994. Sediment movement on hillslopes measured by caesium-137 and erosion pins. IAHS Publ. No. 224:87-93.

Sbrignadello, G., S. Degetto, G.A. Battiston, and R. Gerbasi. 1994. Distribution of Pb-210 and Cs-137 in snow and soil samples from Antarctica. Internat. J. Environ. Analyt. Chem. 55:235-242.

Schaffner, L.C., R.J. Diaz, C.R. Olsen, and I.L. Larsen. 1987. Faunal characteristics and sediment accumulation processes in the James River estuary, Virginia. Estuar. Coastal Shelf Sci. 25:211.226.

Schimmack, W. and K. Bunzl. 1986. Migration of solutes in a cultivated soil: effects of ploughing. Geoderma 38:155-163.

Schimmack, W. and K. Bunzl. 1992a. Migration of radiocesium in two forest soils as obtained from field and column investigations. Sci. Total Environ. 116:93-107.

Schimmack, W. and K. Bunzl. 1992b. Transport of ^{85}Sr, ^{60}Co, ^{65}Zn and ^{109}Cd in two forest soils, as observed in undisturbed soil columns. Radiochim. Acta 58/59:297-303.

Schimmack, W., K. Bunzl, and H. Bachhuber. 1993. Variability of the sorption of Cs, Zn, Sr, Co, Cd, Ce, Ru, Tc, and I at trace concentrations by a forest soil along a transect. Environ. Internat. (In Press).

Schimmack, W., K. Bunzl, F. Dietl, and D. Klotz. 1994. Infiltration of radionuclides with low mobility (^{137}Cs and ^{60}Co) into a forest soil. Effect of irrigation intensity. J. Environ. Radioact. 24:53-63.

Schimmack, W., K. Bunzl, and H. Flessa. 1994. Short-term and long-term effects of ploughing on the vertical distribution of radiocesium in two Bavarian soils. Soil Use and Manage. 10:165-168.

Schimmack, W., K. Bunzl, and L. Zelles. 1989. Initial rates of migration of radionuclides from the Chernobyl fallout in undisturbed soils. Geoderma 44:211-218.

Schimmack, W., H. Foerster, K. Bunzl, and K. Kreutzer. 1993. Deposition of radiocesium to the soil by stemflow through fall and leaf-fall from beech trees. Radiat. Environ. Biophys. 32:137-150.

Schlesinger, W.H., P.J. Fonteyn, and W.A. Reiners. 1989. Effects of overland flow on plant water relations, erosion, and soil water percolation on a Mojave Desert landscape. Soil Sci. Soc. Am. J. 53:1567-1572.

Schmidt, R., H. Hollerer, and G. Wallner. 1995. A vacuum sampler for subsampling freeze-dried laminated sediments with the application to in situ frozen varves of Mondsee, Austria. J. Paleolimnology 14:93-96.

Schoenburg, M. 1987. Radiometric dating and quantitative analysis of elements in depth profiles of sediments by means of nuclear physical as well as x-ray fluorescence and atomic emission spectroscopic methods. Fachbereich 12-Physik., Rep. GKSS-87/E/54, Hamburg Univ., Germany. (German)

Schoer, J. 1988. Investigation of transport processes along the Elbe River using Chernobyl radionuclides as tracers. Environ. Tech. Lett. 9:317-324.

Schreiber, B. 1967a. Ecology of Acantharia in relation of Sr circulation in the sea. Final Report Contract US/62, International Atomic Energy Agency, Vienna, Austria.

Schreiber, B. 1967b. Radionuclides in marine plankton and in coastal sediments, pp. 753-770. *In*: B. Aberg and F.P. Hungate (eds.) Radioecological concentration processes, Pergamon Press, London.

Schreiber, B. 1968. Essay of a method of absolute dating of the coastal marine sediments by means of the vertical distribution of the fallout radionuclides. Accademia Nazionale Dei Lincei 45:251-257.

Schreiber, B. 1969. Significance of sediments in evaluating the radioactive contamination of the sea. Fourth Internat. Colloq. Medical Oceanography, Naples, Italy, October 1969.

Schreiber, B. 1974. Plankton and sediment: first and last step of the radioactivity diffusion in the area. Ciencia e Cultura 27:197-206.

Schreiber, B., E. Cerrai, C. Triulzi, L.T. Pelati, and M.G. Mezzadri. 1969. Ricerche sulla distribuzione verticale della radioattivita nei sedimenti del Mar Ligure. Giornale di Fisica Sanitaria e Protezione Contro le Radiazioni 13:1-19. (Italian)

Schreiber, B., L.T. Pelati, E. Cerrai, and C. Triulzi. 1964. Gross beta radioactivity of littoral sediments of the Ligurian Sea. Energ. Nucl. (Milan) 11:616-624.

Schreiber, B., L.T. Pelati, M.G. Mezzadri, and G. Motta. 1968. Gross beta radioactivity in sediments of the North Adriatic Sea: a possibility of evaluating the sedimentation rate. Arch. Oceanogr. Limnol. 16:45-62.

Schroeder, R.A. 1985. Sediment accumulation rates in Irondequoit Bay, New York based on lead-210 and cesium-137 chronology. Northeastern Environ. Sci. 1:23-29.

Schuler, C., E. Wieland, P.H. Santschi, M. Sturm, A. Lueck, S. Bollhalder, J. Beer, G. Bonani, H.J. Hofmann, M. Suter, and W. Wolfi. 1991. A multitracer study of radionuclides in Lake Zurich, Switzerland 1. Comparison of atmospheric and sedimentary fluxes of ^{7}Be, ^{10}Be, ^{210}Pb, ^{210}Po, and ^{137}Cs. J. Geophys. Res. 96:17051-170965.

Schuller, P. and A. Ellies. 1994. Einful8 des Jahresniederschlags und der bodenart auf die 137Cs tiefenverteilung in b`den Shdchiles (The influence of mean annual rainfall and soil texture on the ^{137}Cs vertical distribution in soils from southern Chile). Zeitschrift Fuer Pflanzenernaehrung und Bodenkunde 157:429-432. (German)

Schultz, R.K. 1965. Soil chemistry of radionuclides. Health Phys. 11:1317-1324.

Schultz, R.K., R. Overstreet, and I. Barshad. 1960. On the soil chemistry of cesium-137. Soil Sci. 89:19-27.

Shalhevet, J. 1973. Effect of mineral type and soil moisture content on plant uptake of ^{137}Cs. Radiat. Bot. 13:165-171.

Shand, C.A., M.V. Cheshire, S. Smith, C.D. Campbell, P. Anderson, C.M. Davidson, D. Littlejohn, and N. Jamieson. 1995. Radiocaesium in an organic soil and the effect of treatment with the fungicide 'Captan'. Plant Soil 170:315-322.

Shand, C.A., M.V. Cheshire, S. Smith, M. Vidal, and G. Rauret. 1994. Distribution of radiocesium in organic soils. J. Environ. Radioact. 23:285-302.

Sharma, P., L.R. Gardner, W.S. Moore, and M.S. Bollinger. 1987. Sedimentation and bioturbation in a salt marsh as revealed by ^{210}Pb, ^{137}Cs and ^{7}Be studies. Limnol. Oceanogr. 32:313-326.

Shenber, M.A. and C. Eriksson. 1993a. Sorption behavior of caesium in various soils. J. Environ. Radioact. 19:41-51.

Shenber, M.A. and C. Eriksson. 1993b. Exchangebility of caesium un various soils. Sci. Total Environ. 138:271-279.

Sholkovitz, E.R. 1985. Redox-related geochemistry in lakes: alkali metals, alkaline-earth elements, and ^{137}Cs, pp. 119-142. *In*: W. Strumm (ed.), Chemical processes in lakes, Wiley, New York.

Sholkovitz, E.R., J.K. Cochran, and A.E. Carey. 1983. Laboratory studies of the digenesis and mobility of $^{239,240}Pu$ and ^{137}Cs in nearshore sediments. Geochim. Cosmochim. Acta 47:1369-1379.

Sholkovitz, E.R. and D.R. Mann. 1984. The pore water chemistry of $^{239,240}Pu$ and ^{137}Cs in sediments of Buzzards Bay, Massachusetts. Geochim. Cosmochim. Acta 48:1107-1114.

Shutov, V.N., T.A. Bekyasheva, L.N. Basalaeva, G.Y. Bruk, and I.Y. Pavlov. 1993. Influence of soil properties on cesium-137 and strontium-90 radionuclides uptake by natural grasses. Pochvovedeniye 8:67-71. (Russian)

Sibley, T.H., A.L. Sanchez, E.A. Wurtz, and W.R. Schell. 1982. Distribution coefficients for radionuclides in aquatic environments. U.S. Nuclear Reg. Comm., NUREG/CR-1853.4, 52 pp.

Sidorchuk, A. Yu. and V.N. Golosov. 1995. Calibrating of soil erosion models by studies of radioactive atmospheric fall out. Pochvovedenie 7:862-869.(in Russian)

Sidorchuk, A. Yu. and V.N. Golosov. 1996. Calibrating of soil erosion models by studies of radioactive atmospheric fall out. Eurasian Soil Sci. 28(10):383-395.

Sigg, L., M. Strum, and D. Kistler. 1987. Vertical transport of heavy metals by setting particles in Lake Zurich. Limnol. Oceanogr. 32:112-130.

Simpson, H.J., R.F. Bopp, B.L. Deck, and R.J. Larsen. 1986. Regional accumulation amounts per unit area of persistent pollutants derived from analysis of recent sediments. Mem. Soc. Geol. Ital. 27:423-445.

Simpson, H.J., C.R. Olsen, R. Bopp, R.M. Trier, and S.C. Williams. 1978. Cesium-137 as a tracer for reactive pollutants in estuarine sediments. First American-Soviet Symposium on Chemical Pollution of Marine Environment, EPA-600/9-78-038, EPA, Gulf Breeze, FL.

Simpson, H.J., C.R. Olsen, R.M. Trier, and S.C. Williams. 1976. Man-made radionuclides and sedimentation in the Hudson river estuary. Sci. 194:179-183.

Simpson, H.J., R.M. Trier, and C.R. Olson. 1980. Transport of plutonium by rivers, pp. 684-690. In: W.C. Hanson (ed.), Transuranics elements in the environment. US Department of Energy, Washington, DC.

Simpson, H.J., S.C. Williams, C.R. Olsen, and D.E. Hammond. 1977. Nutrient and particle matter budgets in urban estuary, pp. 94-103. *In*: Estuaries, geophysics and the environment, National Academy of Science, Washington, DC.

Singh, B. and R.J. Gilkes. 1990. Sorption-desorption behavior of caesium in some Western Australian Soils. Aust. J. Soil Res. 28:929-946.

Skagius, K. and I. Neretnieks. 1988. Measurements of cesium and strontium diffusion in biotite gneiss. Water Resour. Res. 24:75-84.

Smith, C.J., R.D. DeLaune, and W.H. Patrick Jr. 1983. Carbon dioxide emissions and carbon accumulation in coastal wetlands. Estuar. Coast. Shelf Sci. 17:21-29.

Smith Smith, J.N. and K.M. Ellis. 1982. Transport mechanism for Pb-210, Cs-137 and Pu fallout radionuclides through fluvial-marine systems. Geochim. Cosmochim. Acta 46:941-954.

Smith, J.N. and K.M. Ellis. 1988. Transport mechanism for fallout ^{137}Cs to estuarine sediments. SM-248, pp. 119-130, International Atomic Energy Agency, Vienna, Austria.

Smith, J.N., K.M. Ellis, K. Maes, S. Dahle, and D. Matishov. 1995. Sedimentation and mixing rates of radionuclides in Barents Sea sediment off Novaya Zemlya. Deep Sea Res. Part II Topical Studies in Oceanography 42:1471-1493.

Smith, J.N., K.M. Ellis, and D.M. Nelson. 1987. Time-dependent modeling of fallout radionuclide transport in drainage basin: significance of "slow" erosional and "fast" hydrological components. Chem. Geol. 63:157-180.

Smith, J.N. and C.T. Schafer. 1987. A 20th-century record of climatologically modulated sediment accumulation rates in a Canadian fjord. Quat. Res. 27:232-247.

Smith, J.N. and A. Walton. 1980. Sediment accumulation rates and geochronologies measured in the Saguenay Fjord using Pb-210 dating method. Geochim. Cosmochim. Acta 44:225-240.

Smith, J.T. and R.N.J. Comans. 1996. Modelling the diffusive transport and remobilisation of ^{137}Cs in sediments: The effects of sorption kinetics and reversibility. Geochimica et Cosmochimica Acta 60:995-1004.

Smith, J T , J Hilton, and R N J Comans 1995 Application of two simple models to the transport of ^{137}Cs in an upland organic catchment Sci Total Environ 168 57-61

Smith, M L , H W Taylor, and H D Sharma 1993 Comparison of the post-Chernobyl Cs-137 contamination of mushrooms from Eastern Europe, Sweden, and North America Appl Environ Microbiol 59 134-139

Smith, R A , R B Alexander, and M G Wolman 1987 Water-quality trends in the nation's rivers Sci 235 1607-1615

Smith, S J , J R McHenry, R G Menzel, and N H Welsh 1986 Agricultural chemicals and heavy metals in upland soils and valley alluviums of the Little Washita River basin J Soil Water Conserv 41 333-336

Smolders, E , L Sweeck, J Buysse, K Van den Brande, and R Merckx 1993 Analysis of the genotypic variation in radiocaesium uptake from soil Plant and Soil 155/156 431-434

Sobocinski, R W , T E Cerling, and S J Morrison 1990 Sediment transport in a small stream based on ^{137}Cs inventories of the bed load fraction Water Resour Res 26 1177-1187

Sobotovich, E V 1992 Geochemistry of radionuclides in the region of the Chernobyl NPP, pp 170-175 *In* Scientific conference on problems of Chernobyl, Kiev, Ukraine, Dokl Akad Naul UKR (Russian)

Soileau, J M , B F Hajek, and J T Touchton 1990 Soil erosion and deposition evidence in a small watershed using fallout cesium-137 Soil Sci Soc Am J 54 1712-1719

Soszka, G J D Grzybowska, J Rostek, A Pietruszewski, T Wardaszko, A Kalinowska, and J Tomczak 1986 IX Radioecological characteristics of Lake ðarnowieckie Polish Ecological Studies 12 363-381

Southard, R E and R C Graham 1992 Cesium-137 distribution in a California Pelloxerert evidence of pedoturbation Soil Sci Soc Am J 56 202-207

Spalding, B P 1994 Volatilization of cesium-137 from soil with chloride amendments during heating and vitrification Environ Sci Tech 28 1116-1123

Spezzano, P , S Bortoluzzi, R Giacomelli, and L Massironi 1994 Seasonal variations of Cs-137 activities in the Dora Baltea River (Northwest Italy) after the Chernobyl accident J Environ Radioact 22 77-88

Spezzano, P , J Hilton, J P Lishman, and T R Carrick 1993 The variability of Chernobyl Cs retention in the water column of lakes in the English Lake District two years and four years after deposition J Environ Radioact 19 213-232

Spomer, R G , J R McHenry, and R F Piest 1985 Sediment movement and deposition using cesium-137 tracer Trans Am Soc Agric Engr 28 767-772

Spraberry, J A and A J Bowie 1969 Predicting sediment yield from complex watersheds Trans Am Soc Agric Engr 12 199-201

Spurgel, D G and G E Bartelt 1978 Erosional removal of fallout plutonium from a large midwestern watershed J Environ Qual 7 175-177

Squire, H M and L J Middleton 1966 Behavior of ^{137}Cs in soils and pastures - a long term experiment Radiat Bot 6 413-423

Sreekumaran, C K C Pillai, and T R Folsom 1968 The concentration of lithium, potassium, rubidium and cesium in some western American rivers and marine sediments Geochim Cosmochim Acta 32 1229-1234

Stanners, D A and S R Aston 1981a An improved method for determining sedimentation rates by use of artificial radionuclides Estuar Coast Shelf Sci 13 101-106

Stanners, D A and S R Aston 1981b ^{134}Cs, ^{137}Cs and ^{106}Ru ^{137}Cs ratios in intertidal sediments from the Cumbria and Lancashire Coasts, England Estuar Coast Shelf Sci 13 409-417

Stanners, D A and S R Aston 1981c Factors controlling the interaction of Cs-137 with suspended and deposited sediments in estuarine and coastal environments, pp 131-141 *In* Impacts of radionuclide releases to the marine environment, International Atomic Energy Agency, Vienna, Austria

Stanners, D A and S R Aston 1982 Desorption of Ru-106, Cs-134, Cs-137 and Am-241 from intertidal sediments contaminated by nuclear fuel reprocessing effluents Estuar Coastal Shelf Sci 14 687-692

Stanners, D A and S R Aston 1984 The use of reprocessing effluent radionuclides in the geochronology of recent sediments Chem Geol 44 19-32

Stanton, R K , A S Murray, and J M Olley 1992 Tracing the source of recent sediment using environment magnetism and radionuclides in the karst of the Jenolan Caves, Australia IAHS Pub No 210 125-133

Staunton, S 1994 Adsorption of radiocaesium on various soils Interpretation and consequences of the effects of soil Solution ratio and solution composition on the distribution coefficient European J Soil Sci 45 409-418

Steenbergen, C L M , G W Berger, H J Korthals, and H Verdouw 1989 Pigment stratigraphy and trophic status an evaluation of radionuclide-dated lacustrine sediment Geomicrobiology J 7 207-222

Steinberg, C , E Hammerle, and J Meihamm 1983 Changes in sedimentary fluxes in Lake Walchensee by anthropogenically caused alterations in its catchment area Z Wasser A B 16 48-54

Steinnes, E and D Njastad 1993 Use of mosses and lichens for regional mapping of ^{137}Cs fallout from the Chernobyl accident J Environ Radioact 21 65-73

Stewart, W D P , T Preston, H G Peterson, and N Christofi 1982 Nitrogen cycling in eutrophic freshwaters Phil Trans Royal Soc London B 296 491-509

Stephenson, M , J Klaverkamp, M Motycka, C Baron, and W Schwartz 1996 Coring artifacts and contaminant inventories in lakes J Paleolimnol 15 99-106

Stihler, S D , D B Stone, and J E Beget 1992 Varve counting vs tephrochronology and Cs-137 and Pb-210 dating - A comparative test at Skilok Lake, Alaska Geology 20 1019-1022

Stiller, M 1979 Sedimentation patterns in Lake Kinneret (Tiberias), pp 273-285 *In* Isotopes in lake studies, Advisory Group Meeting, 29 Aug - 2 Sept 1977, International Atomic Energy Agency, Vienna, Austria

Stiller, M and G Assaf 1973 Sedimentation and transport of particles in Lake Kinneret traced by ^{137}Cs IAHS Publ No 109 383-396

Stiller, M and D M Imboden 1986 ^{210}Pb in Lake Kinneret waters and sediments residence times and fluxes, pp 501-511 *In* P G Sly, (ed), Sediment and water interactions, Springer-Verlag, New York

Stiller, M , N E Yanaki, and J Kronfeld 1985 Comparative isotope study of two short sediment cores from the Dead Sea Chem Geol 58 107-109

Stott, A P 1987 Medium-term effects of afforestation on sediment dynamics in a water supply catchment a mineral magnetic interpretation of reservoir deposits in the Macclesfield Forest, N W England Earth Surf Process Landforms 12 619-630

Stow, C A , R D DeLaune, and W H Patrick Jr 1985 Nutrient fluxes in a eutrophic coastal Louisiana freshwater lake Environ Manage 9 243-252

Stradomskiy 1970 Study of the form of long-lived radionuclides found in Don River water Soviet Hydrology 6 567-569

Strandberg, M and H Knudsen 1994 Mushroom spores and Cs-137 in faeces of the roe deer J Environ Radioact 23 189-203

Sugai, S F 1990 Transport and sediment accumulation of ^{210}Pb and ^{137}Cs in two southeast Alaskan fjords Estuar 13 380-392

Sun, T , K Seff, N H Heo, and V P Petranovskii 1993 A cationic cesium continuum in Zeolite-X Sci 259 495-497

Sundblad, B and L Mathiasson 1994 The turnover of Cesium-137 within a forest ecosystem described by a compartment modelling approach - Gidea study site, Sweden Sci Total Environ 157 139-146

Sutherland, R A 1989 Quantification of accelerated soil erosion using the environmental tracer caesium-137 Land Degradation and Rehabilitation 1 199-208

Sutherland, R A 1991a Examination of caesium-137 areal activities in control (uneroded) locations Soil Tech 4 33-50

Sutherland, R A 1991b Caesium-137 and sediment budgeting within a partiality closed drainage basin Ann Geomorphol 35 47-63

Sutherland, R A 1991c Selective erosion and sediment source identification, Baringo, Kenya Ann Geomorphol 35 293-304

Sutherland, R A 1992 Caesium-137 estimates of erosion in agricultural areas Hydrol Process 6 215-225

Sutherland, R A 1994 Spatial variability of ^{137}Cs and the influence of sampling on estimates of sediment redistribution Catena 21 57-71

Sutherland, R A 1996 Caesium-137 estimates of sediment redistribution and landscape stability when reference locations are under samples The potential for resampling Hydrol Process (In Press)

Sutherland, R A and R B Bryan 1988 Estimation of colluvial reservoir life from sediment budgeting, Katiorin experimental basin, Kenya IAHS Publ no 174 549-560

Sutherland, R A and R B Bryan 1991 Sediment budgeting - a case study in Katioren drainage basin, Kenya Earth Surf Process Landforms 16 383-398

Sutherland, R A and E de Jong 1990a Estimation of sediment redistribution within agricultural fields using caesium-137, Crystal Springs, Saskatchewan, Canada Appl Geography 10 205-221

Sutherland, R A and E de Jong 1990b Quantification of soil redistribution using caesium-137, Outlook, Saskatchewan, Canada, pp 177-193 *In* R B Bryan (ed), Soil erosion - experiments and models Catena Supplement 17

Sutherland, R A and E de Jong 1990c Statistical analysis of gamma emitting radionuclide concentrations for three fields, Southern Saskatchewan, Canada Health Phys 58 417-428

Sutherland, R A , T Kowalchuk, and E de Jong 1991 Cesium-137 estimates of sediment redistribution by wind Soil Sci 151 387-396

Suzuki E 1993 ^{207}Bi and ^{137}Cs in nearshore marine sediments I Distribution of ^{207}Bi and ^{137}Cs in coastal marine sediments collected from the Japan Sea Radioisotopes 42 511-516

Svoboda, J and H W Taylor 1979 Persistence of cesium-137 in Arctic lichens, *Dryas integrifolia*, and lake sediment Arct Alp Res 11 95-108

Swan, D S , M S Baxter, I G McKinley, and W Jack 1982 Radiocesium and ^{210}Pb in Clyde Sea Loch sediment Estuar Coast Shelf Sci 15 515-536

Sweeck, L , J Wauters, E Valcke, and A Cremers 1990 The sensitivity of upland soils to radiocesium contamination, pp 249-258 *In* G Desment, P Nassimbeni, and M Belli (eds), Transfer of radionuclides in natural and semi-natural environments, Proceedings of a CEC workshop, Udine, Italy

Szefer, P , K Szefer, G P Glasby, J Pempkowiak, and R Kaliszan 1966 Heavy-metal pollution in surficial sediments from the Southern Baltic sea off Poland J Environ Sci Health Part A Environmental Science and Engineering & Toxic and Hazardous Substance Control 31(10) 2723-2754

Talibudeen, O 1964 Natural radioactivity in soils Soils Fert 27 347-359

Tamura, T 1964a Consequences of activity release selective sorption reactions of cesium with soil minerals Nucl Safety 5 262-268

Tamura, T 1964b Reaction of cesium-137 and strontium-90 with soil minerals and sesquioxides, pp 465-478 *In* 8th International congress of soil science, Bucharest, Romania

Tamura, T and D G Jacobs 1960 Structural implications in cesium sorption Health Phys 2 391-398

Taylor, H W , J Svoboda, G H R Henry, and R W Wein 1988 Post-Chernobyly ^{134}Cs and ^{137}Cs levels at some localities in northern Canada Arctic 41 293-296

Tegen, I And H Doerr 1996 Mobilization of cesium in organic rich soils Correlation with production of dissolved organic carbon Water Air Soil Pollut 88 133-144

Teksoz, G V Yetis, G Tuncel, and T I Balkas 1991 Pollution chronologies of Golden Horn sediments Marine Pollut Bull 22 447-451

Telfair, D and J Luetzelschwab 1962 Penetration of fallout fission products into Indiana soil Sci 138 829-830

Tenbrinke, W B M , P G E F Augustinus, and G W Berger 1995 Fine-grained sediment deposition on mussel beds in the Oosterschelde (the Netherlands), determined from echosoundings, radio-isotopes and biodeposition field experiments Estuar Coast Shelf Sci 40 195-217

Thiry, Y and C Myttenaere 1993 Behavior of radiocaesium in forest multilayered soils J Environ Radioact 18 247-257

Thiry, Y , M Vanhouche, P Van Der Vaeren, S de Brouwer, and C Myttenaere 1994 Determination of the physio-chemical parameters which influence the Cs availability in forest soils Sci Total Environ 157 267-273

Thomas, M , D Petit, and L Lamberts 1984 Pond sediment as historical record of heavy metals fallout Water Air Soil Pollut 23 51-59

Thorbjarnarson, K W , C A Nittrouer, and D J DeMaster 1986 Accumulation of modern sediment in Quinault Submarine Canyon Marine Geol 71 107-124

Tikhomirov, F A , A L Klyashtorin, and A I Shcheglov 1992 Radionuclides in vertical soil runoff in forest near the Chernobyl nuclear power station Eurasian Soil Sci 24 42-49

Toonen, K , V Ilmavirta, P Uimonen-Simola, H Hartikainen, and J Suksi 1994 Eutrophication history of a small, pelotrophic lake Rusutjarvi, southern Finland Aqua Fennica 24 141-162

Tomlin, A D , D McCabe, and R Protz 1992 Species composition and seasonal variation of earthworms and their effect on soil properties in southern Ontario, Canada Soil Biol Biochem 24 1451-1457

Torgersen, T , A R Chivas, and A Chapman 1983 Chemical and isotopic characterization and sedimentation rates in Princess Charlotte Bay, Queensland J Aust Geol Geophys 8 191-200

Torgersen, T and M E Longmore 1984 ^{137}Cs diffusion in the highly organic sediment of Hidden Lake, Fraser Island, Queensland Aust J Marine Freshwater Res 35 537-548

Tracy, B L and F A Prantl 1983 25 years of fission product input to Lakes Superior and Huron Water Air Soil Pollut 19 15-27

Turner, A , G E Millward, and A O Tyler 1994 The distribution and chemical composition of particles in a macrotidal estuary Estuar Shelf Sci 38 1-17

Turner, L J and L D Delorme 1996 Assessment of Pb-210 data from Canadian lakes using the CIC and CRS Environ Geol 28 78-87

Turner, R R and S E Lindberg 1978 Behavior and transport of mercury in river-reservoir systems downstream of inactive chloralkali plant Environ Sci Tech 12 918-923

Tyler, A N , D C W Sanderson, and E M Scott 1996 Estimating and accounting for ^{137}Cs source burial through in-situ gamma spectrometry in salt marsh environments J Environ Radioact 33 195-212

Tyler, A N , D C W Sanderson, E M Scott, and J D Allyson 1996 Accounting for spatial variability and fields of view in environmental gamma ray spectrometry J Environ Radioac 33 213-235

UNESCO 1993 Hydrological considerations in relation to nuclear power plants, Proceeding of an International Workshop, UNESCO, Paris

Vaithiyanathan, P , C J Richardson, R G Kavanaugh, C B Craft, and T Barkay 1996 Relationships of eutrophication to the distribution of mercury and to the potential for methylmercury production in the peat soils of the Everglades Environ Sci & Tech 30 2591-2597

Vakulovsky, S M , Y V Krasnopevtsev, A I Nikitin, and V B Chumicev 1982 Distribution of ^{137}Cs and ^{90}Sr between the water and bottom sediments in the Black Sea USSR in 1977 Okeanologiya 22 966-969 (Russian)

Vakulovsky, S M , A I Nikitin, and V B Chumicev 1983 ^{137}Cs and ^{90}Sr in bottom sediments of the Baltic Sea Okeanologiya 23 984-989 (Russian)

Vakulovsky, S M , A I Nikitin, V B Chumichev, I Y Katrich, O A Voitsekhovich, V I Medinets, V V Pisarev, L A Bovkum, and E S Khersonsky 1994 Cesium-137 and strontium-90 contamination of water bodies in the areas affected by releases from the Chernobyl Nuclear Power Plant accident - An overview J Environ Radioact 23 103-122

Vanden Berghe, I and H Gulinck 1987 Fallout ^{137}Cs as a tracer for soil mobility in the landscape framework of Belgian loamy region Pedologie 37 5-20

Vanden Bygaart, A J and R Protz 1995 Gamma radioactivity on a chronosequence, Pinery Provincial Park, Ontario Can J Soil Sci 75 73-84

Van Sickle, J , W C Weimer, and D P Larsen 1983 Mixing rates in Shagawa Lake, Minnesota sediments as determined from ^{106}Ru profiles Geochim Cosmochim Acta 47 2189-2197

Varekamp, J C 1991 Trace element geochemistry and pollution history of mudflat and marsh sediments from the Connecticut coastline J Coastal Res 11 105-123

Varskog, P , R NFumann, and E Steinnes 1994 Mobility and plant availability of radioactive Cs in natural soil in relation to stable Cs, other alkali elements and soil fertility J Environ Radioact 22 45-53

Vas Carreiro, M C and M M Sequeria 1987 Cesium-137 in the Portuguese Rivers Douro and Tejo J Environ Radioact 5 363-377

Vassilaki, M , L Salmon, and J A B Gibson 1966 Measurement of radioactivity in soil Geochim Cosmochim Acta 30 610-606

Velasco, R H , M Belli, U Sansone, and S Menegon 1993 Vertical transport of radiocesium in surface soils model implementation and dose-rate computations Health Phys 64 37-44

Verburg, K. and P. Baveye. 1994. Hysteresis in the binary exchange of cations on 2/1 clay minerals - A critical review. Clays and Clay Minerals 42:207-220.

Vernet, J.P., E. Davaud, M. Cosandey, and J. Berlie. 1987. Analyse de la radioactivite gamma des sediments del Lac Lerman et de Morat. Ecol. Geol. Helv. 68:87-96. (French)

Vernet, J.P., J. Dominik, and P.Y. Favarger. 1984. Texture and sedimentation rates in Lake Geneva. Environ. Geol. 5:143-149.

Vernet, J.P. and P.Y. Favarger. 1982. Climatic and anthropogenic effects on sedimentation and geochemistry of Lakes Bourget, Annecy, and Leman. Hydrobiologia 92:643-650.

Vernet, J.P., P.Y. Favarger, and C. Reynuad. 1978. Sedimentation rates in Lakes Morat, Joux, and Leman computed by means of both ^{137}Cs and pollen-analysis methods. Intercol, Second Internat. Congress of Ecology, Jerusalem, Israel.

Villar, H.P. 1981. Distribuicno de ^{137}Cs no solo como fumcno de erosno e outros processos. Centro de Energia Nuclear, Report No. INIS-MF-7374, 115 pp. (Portuguese)

Villar, H.P. 1982. Aplicacoes da distribuicao de ^{137}Cs no estudo da agentes fisicos do solo. INIS-BR-133, 6 pp. (Portuguese)

Voitsekhovitch, O.V., V.V. Kanivets, G.V. Laptev, and I.Y. Biley. 1993. Hydrological processes and their influence on radionuclide behaviour and transport by surface water pathways as applied to water protection after the Chernobyl accident, pp. 83-105. *In*: Hydrological considerations in relation to nuclear power plants, Proceeding of an International Workshop, UNESCO, Paris.

Volchok, H.L. and N. Chieco (ed.). 1986. A compendium of the Environmental Measurement Laboratory's research projects related to Chernobyl nuclear accident. USDOE Rep. EML-460, Environmental Monitoring Laboratory, New York.

von Damm, K.L., L.K. Benninger, and K.K. Turekian. 1979. The ^{210}Pb chronology of a core from Mirror Lake New Hampshire. Limnol. Oceanogr. 24:434-439.

von Gunten, H.R., M. Strum, H.N. Erten, E. R`ssler, and F. Wegmhller. 1987. Sedimentation rates in the central Lake Constance determined with ^{210}Pb and ^{137}Cs. Schweiz. Z. Hydrol. 49:275-283.

Voronov, S.I. and R.M. Aleksakhi. 1992. Main laws governing the migration of Sr-90 and Cs-137 in natural and cultured framing centers in Uzbekistan (The radioecology of the Tashkent Oasis). Atom. Energy 73:652-657.

Waber, U., H. von Gutern, and U. Krahenbuhl. 1987. The impact of the Chernobyl accident on a river/groundwater aquifer. Radiochima Acta 41:191-199.

Wahlgen, M. and R.C. Thompson. 1980. Pollution records from sediments of three lakes in New York state. Geochim. Cosmochim. Acta 44:333-339.

Wahlgren, M.A. and D.M. Nelson. 1974. Studies of plutonium cycling and sedimentation in Lake Michigan. Proc. 17th Conf. Great Lakes 1974:212-218.

Wahlgren, M.A. and D.M. Nelson. 1975. Plutonium in the Laurentian Great Lakes: comparison of surface waters. Verh. Internat. Verein. Limnol. 19:317-322.

Walker, R., M. Wilder, and C.R. Valeri. 1978. Diatom and pollen studies of a sediment profile from Melynllyn, a mountain tarn in Snowdonea, North Wales. New Phytol. 8:791.

Wallace, A., E.M. Romney, and R.A. Wood. 1982. The role of stable cesium on plant uptake of cesium-137. Soil Sci. 134:71-75.

Wallbrink, P.J. 1989. Fallout of cosmogenic radionuclide ^{7}Be and its subsequent distribution in the soil profile, pp. 30-89. Honours Thesis, Australian National Univ., Forestry Department, Australia.

Wallbrink, P.J. and A.S. Murray. 1993. Use of fallout radionuclide as indicators of erosion processes. Hydrol. Process. 7:297-304.

Wallbrink, P.J. and A.S. Murray. 1996. Distribution and variability of ^{7}Be in soils under different surface cover conditions and its potential for describing soil redistribution processes. Water Res. Res. 32:467-476.

Wallbrink, P.J. and A.S. Murray. 1996. Determining soil loss using the inventory ratio of excess lead-210 to cesium-137. Soil Sci. Soc. Amer. J. 60:1201-1208.

Wallbrink, P.J., J.M. Olley, and A.S. Murray. 1994. Measuring soil movement using ^{137}Cs: Implications of reference site variablilty. IAHS Publ. No. 224:95-105.

Wallbrink, P.J., J.M. Olley, A.S. Murray, and L.J. Olive. 1996. The contribution of subsoil to sediment yield in the Murrumbidgee River basin, New South Wales, Australia. IAHS Publ. No. 236:347-355.

Walling, D.E. 1983. The sediment delivery problem. J. Hydrol. 65:209-237.

Walling, D.E. 1984. Sediment delivery from drainage basins, pp. 71-80. *In*: R.J. Loughran (ed.), Drainage basin erosion and sedimentation, Univ. Newcastle, Newcastle, Australia.

Walling, D.E. 1988. Measuring sediment yield from river basins, pp. 39-73. *In*: R. Lal (ed.), Soil erosion research, Soil Conserv. Society of America, Ankeny, IA.

Walling, D.E. 1989a. Some applications of caesium-137 measurements in sediment budget investigations. J. Water Resour. 8:50-77.

Walling, D.E. 1989b. The struggle against water erosion and a perspective on recent research, pp. 39-60. *In*: K. Ivanov and D. Pechinov (eds.), Water erosion, UNESCO Technical Document in Hydrology, SC-89/WS-57, UNESCO, Paris, France.

Walling, D.E. 1990. Linking the field to the river: Sediment delivery from agricultural lands, pp. 129-152. IN: J. Boardman, I.D.L.Foster, and J.A. Dearnin (eds.), Soil erosion on agricultural land, Wiley, Chichester, U.K.

Walling, D.E. 1995. Suspended sediment yields in a changing environment, pp. 149-176. In: A.M. Gurnell and G.E. Petts (eds.), Changing river channels, Wiley, Chichester, U.K.

Walling, D.E. and S.B. Bradley. 1988a. Transport and redistribution of Chernobyl fallout radionuclides by fluvial processes: some preliminary evidence. Environ. Geochem. Health 10:35-39.

Walling, D.E. and S.B. Bradley. 1988b. The use of caesium-137 measurements to investigate sediment delivery from cultivated areas in Devon, UK. IAHS Publ. No. 174:325-335.

Walling, D.E. and S.B. Bradley. 1989. Rates and patterns of contemporary floodplain sedimentation: a case study of the River Culm, Devon, U.K. Geojournal 19:53-62.

Walling, D.E. and S.B. Bradley. 1990. Some applications of caesium-137 measurements in the study of fluvial erosion, transport and deposition. IAHS Publ. No. 189:179-203.

Walling, D.E., S.B. Bradley, and C.J. Lambert. 1986. Conveyance losses of suspended sediment within a flood plain system. IAHS Publ. No. 159:119-131.

Walling, D.E., S.B. Bradley, and C.J. Wilkinson. 1986. A caesium-137 budget approach to the investigation of sediment delivery from a small agricultural drainage basin in Devon, UK. IAHS Publ. No. 159:423-435.

Walling, D.E. and Q. He. 1992. Interpretation of cesium-137 profile in lacustrine and other sediments - The role of catchment derived inputs. Hydrobiologia 235/236:219-230.

Walling, D.E. and Q. He. 1993a. Toward improved interpretation of caesium-137 profile in lake sediments, pp. 31-53. *In*: J. McManus and R. Duck (eds.), Geomorphology and sedimentology of lakes and reservoirs, Wiley, Chichester.

Walling, D.E. and Q. He. 1993b. Use of cesium-137 as a tracer in the study of rates and patterns of floodplain sedimentation. IAHS Publ. No. 215:319-328.

Walling, D.E. and Q. He. 1994. Rates of overbank sedimentation on the flood plains of several British rivers during the past 100 years. IAHS Publ. 224:203-210.

Walling, D.E. and Q. He. 1996. Use of fallout ^{137}Cs in investigations of overbank sediment deposition on river floodplains. Catena (in press)

Walling, D.E., Q. He, and A.P. Nicholas. 1996. Floodplains as suspended sediment sinks, pp. . In: M. Anderson, D.E. Walling, and P. Bates (eds.), Floodplain Processes, J. Wiley, Chickester, UK.

Walling, D.E., Q. He, and T.A. Quine. 1995. Use of caesium-137 and lead-210 as tracers in soil erosion investigations. IAHS Publ. No. 229:163-172.

Walling, D.E., Q. He, and T.A. Quine. 1996. Use of fallout radionuclides measurements in sediment budget investigations. Proc. of CNRS Conference on Floods, Slopes and River Beds.

Walling, D.E. and P. Kane. 1984. Suspended sediment properties and geomorphological significance, pp. 311-334. *In*: T.P. Burt and D.E. Walling (eds.), Catchment experiments in fluvial geomorphology, Geo Books, Norwich, U.K.

Walling, D.E. and P.W. Morehead. 1989. The particle size characteristics of fluvial suspended sediments: an overview. Hydrobiologia 176/177:125-149.

Walling, D.E., M.R. Peart, F. Oldfield, and R. Thompson. 1979. Suspended sediment sources identified by magnetic measurements. Nature 281:110-113.

Walling, D.E. and T.A. Quine. 1990a. Calibration of caesium-137 measurements to provide quantitative erosion rate data. Land Degradation and Rehabilitation 2:161-175.

Walling, D.E. and T.A. Quine. 1990b. Use of caesium-137 to investigate patterns and rates of soil erosion on arable fields, pp. 33-53. *In*: J. Broadman, I.D.I. Foster, and J.A. Dearing (eds.), Soil erosion on agricultural land, Wiley, London.

Walling, D.E. and T.A. Quine. 1991a. The use of ^{137}Cs measurements to investigate soil erosion on arable fields in the U.K.: potential applications and limitations. J. Soil Sci. 42:147-165.

Walling, D.E. and T.A. Quine. 1991b. Fluvial redistribution of Chernobyl radionuclides. NERC News, July 1991, pp. 22-25.

Walling, D.E. and T.A. Quine. 1991c. Recent rates of soil loss from areas of arable cultivation in the UK. IAHS Publ. No. 203:123-131.

Walling, D.E. and T.A. Quine. 1992. The use of caesium-137 measurement in soil erosion surveys. IAHS Publ. No. 210:143-152.

Walling, D.E. and T.A. Quine. 1993a. Use of caesium-137 as a tracer of erosion and sedimentation: Handbook for the application of the caesium-137 technique. U.K Overseas Development Administration Research Scheme R4579, Department of Geography, Univ. Exeter, Exeter, United Kingdom, 196pp.

Walling, D.E. and T.A. Quine. 1993b. Using Chernobyl-derived fallout radionuclides to investigate the role of downstream conveyance losses in the suspended sediment budget of the River Severn, UK. Physical Geogr. 14:239-253.

Walling, D.E. and T.A. Quine. 1995. The use of fallout radionuclide in soil erosion investigations. Nuclear Techniques in Soil-Plant Studies for Sustainable Agriculture and Environmental Preservation. IAEA Publ. ST1/PUB/947:597-619.

Walling, D.E., T.A. Quine, and Q. He. 1992a. Investigating contemporary rates of floodplain sedimentation, pp. 166-184. *In*: P.A. Carling and G.E. Petts (eds.), Lowland floodplain rivers: Geomorphological perspectives. Wiley, Chichester.

Walling, D.E. T.A. Quine, and Q. He. 1992b. Rates and patterns of contemporary rates of floodplain sedimentation, pp. 185-202. *In*: P.A. Carling and G.E. Petts (eds.), Lowland floodplain Rivers: Geomorphological perspectives. Wiley, Chichester.

Walling, D.E., T.A. Quine, and J.S. Rowan. 1992. Fluvial transport and redistribution of Chernobyl fallout radionuclides. Hydrobiologia 235:231-246.

Walling, D.E., J.S. Roman, and S.B. Bradley. 1989. Sediment associated transport and redistribution of Chernobyl fallout radionuclides. IAHS Publ. No. 184:37-45.
Walling, D.E. and B.W. Webb. 1987. Material transport by the world's rivers: evolving perspectives. IAHS Publ. No. 164:313-329.
Walling, D.E. and J.C. Woodward. 1992. Use of radiometric fingerprints to derive information on suspended sediment sources. IAHS Publ. No. 210:153-164.
Walling, D.E. and J.C. Woodward. 1995. Tracing sources of suspended sediment in river basins. Mar. Freshwater Res. 46:327-336.
Walling, D.E., J.C. Woodward, and A.P. Nicholas. 1993. A multi-parameter approach to fingerprinting suspended sediment sources. IAHS Publ. No. 215:329-340.
Walton, A. 1963. The distribution in soils of radioactivity from weapon tests. J. Geophys. Res. 68:1485-1496.
Wan, G. and P.H. Santschi. 1987. Prediction of radionuclide inventory for sediments in Lake Greifensee, Switzerland. Scientia Geographia Sinica 7:358-363.
Wan, G., P.H. Santschi, K. Farrenkothen, M. Strum, and W. Strum. 1985. Distribution and dating of ^{137}Cs for recent sediments in Lake Greifensee (Switzerland). Acta Scient. Circumstantia 5:360-365.
Wan, G., P.H. Santschi, M. Strum, K. Farrenkothen, A. Lueck, E. Werth, and C. Schuler. 1986. A comparative study on recent sedimentation rates in Lake Greifensee, Switzerland, using varve counting and radionuclide dating. Geochimica 9:259-270.
Wan, G.J., P.H. Santschi, M. Strum, K. Farrenkothen, A. Lucek, E. Werth, and C. Schuler. 1987. Natural (^{210}Pb, ^{7}Be) and fallout (^{137}Cs, $^{239,240}Pu$, ^{90}Sr) radionuclides as geochemical tracers of sedimentation in Greifensee, Switzerland. Chem. Geol. 63:181-196.
Ward, T.E., J. Breeden, K. Komisarcik, R. Porter, J. Czuczwa, R. Kaminski, and B.D. McVeety. 1987. ^{137}Cs radioactive dating of Lake Ontario sediment cores. BNL-40550, 10 pp. Brookhaven National Laboratory, Upton, New York
Wass E. 1992. Foerdelning av Cs-137 I sedimentet I Raaksjoen, en Mellansvensk Skogssjoe, sex aar efter tjernobylolyckan (Distribution of Cs-137 in lake sediment). Uppsala Univ., Sweden Limnologiska Institutionen Report No. NEI-SE-138, 23pp. (Swedish)
Wasson, R.J., R.L. Clark, P.M. Nanninga, and J. Waters. 1987. ^{210}Pb as a chronometer and tracer Burrinjuck Reservoir, Australia. Earth Surf. Process. Landforms 12:399-414.
Wasson, R.J., R.L. Clark, I.R. Willett, J. Waters, B.L. Campbell, and D. Outhet. 1984. Erosion history in Burrinjuck Reservoir, NSW, pp. 221-229. *In*: R.J. Loughran (ed.), Drainage basin erosion and sedimentation, Univ. Newcastle, Newcastle, Australia.
Wauters, J., L. Sweeck, E. Valcke, A. Elsen, and A. Cremers. 1994. Availability of radiocesium in soils: A new methodology. Sci. Total Environ. 157:239-248.
Wenning, R.J., N.L. Bonnevie, and S.L. Huntley. 1994. Accumulation of metals, polychlorinated biphenyls, and polycyclic aromatic hydrocarbons in sediments from the lower Passaic River, New Jersey. Arch. Environ. Contam. Toxicol. 27:64-81.
Wheeler, D.A. 1988. Atmospheric dispersal and deposition of radioactive material from Chernobyl. Atmos. Environ. 22:853-863.
Whicker, F.W. 1983. Radionuclide transport processes in terrestrial ecosystems. J. Radiat. Res. 94:135-150.
Whicker, F.W., W.C. Nelson, and A.F. Gallegos. 1972. Fallout ^{137}Cs and ^{90}Sr in trout from mountain lakes in Colorado. Health Phys. 23:519-527.
Whicker, F.W., J.E. Pinder III, J.W. Bowling, J.A. Alberts, and I.L. Brisbin Jr. 1990. Distribution of long-lived radionuclides in an abandoned reactor cooling reservoir. Ecol. Monographs 60:471-496.
Whicker, F.W. and V. Schultz. 1982. Radioecology: nuclear energy and the environment. CRC Press, Boca Raton, FL.
Whicker, J.J., F.W. Whicker, and S. Jacobi. 1994. Cs-137 in sediments of Utah lakes and reservoirs - Effects of elevation, sedimentation rate and fallout history. J. Environ. Radioact. 23:265-283.
Whitmore, T.J., M. Brenner, and C.L. Schelske. 1996Highly variable sediment distribution in shallow, wind-stressed lakes: A case for sediment-mapping surveys in paleolimnological studies. J. Paleolimnol. 15:207-221.
Wilock, A. and R.J. Loughran. 1994. Sediment production and storage in an urbanizing basin, Lake Macquarie, New South Wales, Australia. IAHS Publ. 224:103-110.
Wicherek, S.P. and C. Bernard. 1995. Assessment of soil movement in a watershed from Cs-137 and conventional measurements (example: the Parisian Basin). Catena 25:141-151.
Widerlund, A. And P. Roos. 1994. Varved sediment in the Kalix River Esturay, Northen Sweden. Aqua Fennica 24:163-169.
Wieland, E., P.H. Santschi, and J. Beer. 1991. A multitracer study of radionuclides in Lake Zurich, Switzerland. 2. Residence times, removal processes and sediment focussing. J. Geophys. Res. 96:17067-17080.
Wieland, E., P.H. Santschi, P. Hohener, and M. Strum. 1993. Scavenging of Chernobyl ^{137}Cs and ^{210}Pb in Lake Sempach, Switzerland. Geochim. Cosmochim. Acta 57:2959-2979.
Wilken, R.D., I. Moreira, and A. Rebello. 1986. ^{210}Pb and ^{137}Cs fluxes in a sediment core from Guanabara Bay, Brazil. Sci. Total Environ. 58:195-198.
Wilkerson, D.F., S. Arya, and B.L. Wilson. 1993. Investigations of radionuclides in the aqueous sediment environment surrounding a coal burning power plant. J. Environ. Sci. Health A28:1005-1015.
Wilkin, D.C. and S.J. Hebel. 1982. Erosion, redeposition and delivery of sediment to midwestern streams. Water Resour. Res. 18:1278-1282.

Williams, H.L.F. 1995. Assessing the impact of weir construction on recent sedimentation using cesium-137. Environ. Geol. 26:166-171.

Williams, H.F.L. and T.S. Hamilton. 1995. Sedimentary dynamics of an eroding tidal marsh derived from stratigraphic records of Cs-137 fallout, Fraser Delta, British Columbia, Canada. J. Coastal Res. 11:1145-1156.

Wilson, G.C., A.E. Litherland, and J.C. Rucklidge. 1984. Dating of sediments using accelerator mass spectrometry. Chem. Geol. 44:1-17.

Wilson, T.R.S. 1974. Caesium-137 as a water movement tracer in the St. George's Channel. Nature 248:125-127.

Wirth, E. L. Hiersche, L. Kammerer, G. Krajewska, R. Krestel, S. Mahler, and R. Rommelt. 1994. Transfer equations for Cesium-137 for coniferous forest understory plant species. Sci. Total Environ. 157:163-170.

Wischmeier, W.H. 1976. Use and misuse of the universal soil loss equation. J. Soil Water Conserv. 31:5-9.

Wischmeier, W.H. and D.D. Smith. 1965. Predicting rainfall-erosion losses for cropland east of the Rocky Mountains. Agr. Handbook No. 262. USDA, Washington, DC.

Wise, S. 1977. The use of fallout radionuclides Pb-210 and Cs-137 in estimating denudation rates and in soil erosion measurements. Geography Department, King's College, London, Occasional Paper 7, 38 pp.

Wise, S.W. 1980. Caesium-137 and lead-210: a review of the technique and application to geomorphology, pp. 109-127. *In*: R.A. Cullingford, D.A. Davidson, and J. Lewin (eds.), Timescales in geomorphology, Wiley, London.

Witkamp, M. and B. Barzansky. 1968. Microbial immobilization of ^{137}Cs in forest litter. Oikos 19:392-395.

Witkamp, M. and M.L. Frank. 1970. Effects of temperature, rainfall and fauna on transfer of ^{137}Cs, K, Mg and mass in consumer-decomposer microcosms. Ecol. 51:466-474.

Witinok, P.M. 1992. On the relationship between sediment deposition and land use changes in a lacustrine wetland. Doctor's Thesis, Univ. Iowa, Iowa City, Iowa.

Wolfe, B. H.J. Kling, G.J. Brunskill, and P. Wilkinson. 1994. Multiple dating of a freeze core from lake 227, an experimentally fertilized lake with varved sediment. Cand. J. Fisheries Aquatic Sci. 51:2274-2285.

Wong, G.T.F. and C.S. Moy. 1984. Cesium-137, metals and organic carbon in sediments of the James River estuary, Virginia. Estuar. Coast. Shelf Sci. 18:37-49.

Wong, H.K.T., J.O. Nriagu, and R.D. Coker. 1984. Atmospheric input of heavy metals chronicled in lake sediment of the Algonquin Provincial Park, Ontario, Canada. Chem. Geol. 44:187-210.

Woodwell, G.M. 1969. Radioactivity and fallout: The model pollution. Biosci. 19:884-887.

Wooldridge, D.D. 1965. Tracing soil particle movement with Fe-59. Soil Sci. Soc. Am. Proc. 29:469-472.

Worsley, A.T. and F. Oldfield. 1988. Palaeoecological studies of three lakes in the highlands of Papua New Guinea. II. Vegetational history over the last 1600 years. J. Ecol. 76:1-18.

Wrenn, M.E., J.W. Lentsch, M. Eisenbud, G.J. Lauer, and G.P. Howells. 1971. Radiocesium distribution in water, sediment, and biota in the Hudson River estuary from 1964 through 1970. Proceedings third national symposium on radioecology. US Atomic Energy Commission, Oak Ridge, TN.

Yamagata, N., S. Matsuda, and M. Chiba. 1969. Radioecology of cesium-137 and strontium-90 in a forest. J. Radiat. Res. 10:107-112.

Yamagata, N., S. Matsuda, and K. Kodaira. 1963. Run-off of caesium-137 and strontium-90 from rivers. Nat. 200:668-669.

Yan, M., Y. Zhang, Y. Liu, Q. Zhao, X. Zhang, Y. Wang, and S. Li. 1991. Use of cesium-137 to estimate erosion rates, p. 16. *In*: Second international conference on methods and applications of radioanalytical chemistry, Washington, DC.

Yasuda, H., S. Uchida, Y. Muramatsu, and S. Yoshida. 1995. Sorption of manganese, cobalt, zinc, strontium, and cesium onto agricultural soils: Statistical analysis on effects of soil properties. Water Air Soil Pollut. 83:85-96.

Yushkov, P.I., T.A. Chueva, E.N. Karavaeva, I.V. Molchanova, and N.V. Kulikov. 1993. Contents of Cs-134+137 and Sr-90 in the crown of birch trees in the first years after the accident at the Chernobyl Nuclear Power Plant. Russian J. Ecol. 24:70-74.

Zhang, X.B., D.L. Higgitt, and D.E. Walling. 1990. A preliminary assessment of the potential for using caesium-137 to estimate rates of soil erosion in the Loess Plateau of China. Hydrol. Sci. J. 35:243-251.

Zhang, X.B., S. Li, C. Wang, W. Tan, Q. Zhao, Y. Zhang, M. Yan, Y. Liu, J. Jiang, J. Xiao, and J. Zhou. 1989. Use of caesium-137 measurements to investigate erosion and sediment sources in a small drainage basin in the Loess Plateau of China. Hydrol. Process. 3:317-323.

Zhang, X.B., S.L. Li, C.H. Wang, W.P. Tan, Q.C. Zhao, Y.Y. Zhang, M.Q. Yan, Y.L. Liu, J.J. Jiang, J.L. Xiao, and J. Zhou. 1990. A study of sediment delivery from a small catchment in the Loess Plateau by the ^{137}Cs method. Chinese Sci. Bull. 35:38-41. (Chinese)

Zhang, X.B., L. Shaolong, L. Chenghua, T. Wanpei, A. Quingchang, Z. Yiyun, Y. Meiqiong, L. Yalum, J. Jingjiang, X. Jule, and J. Zhou. 1989. Use of caesium-137 measurements to investigate erosion and sediment msources within a small drainage basin on the loess plateau of China. Hydrol. Process. 3:317-323.

Zhang, X.B. T.A. Quine, D.E. Walling, and Z. Li. 1994. Application of the caesium-137 technique in a study of soil erosion on gully slopes in a yaun area of the Loess Plateau near Xifeng, Gansu Province, China. Geografiska Annaler Series A. Physical Geogr. 76A:103-120.

Zucker, C.R., Olsen, I.L. Larsen, and N.H. Cutshall. 1984. Inventories and sorption-desorption trends in radiocesium and radiocobalt in James River estuary sediments. Environ. Geol. Water Sci. 6:171-182.

Zuo, Z.Z., D. Eisma, and G.W. Berger. 1991. Determination of sediment accumulation and mixing rates in the Gulf of Lyons, Mediterranean Sea. Oceanol. Acta 14:253-263.

Zwolsman, J.J.G., G.W. Berger, and G.T.M. van Eck. 1993. Sediment accumulation rates, historical inputs, post-depositional mobility and retention of major elements and trace elements in salt marsh sediments of the Scheldt estuary SW Netherlands. Mar. Chem. 44:73-94.

GLOBAL DISTRIBUTION OF ^{137}Cs INPUTS FOR SOIL EROSION AND SEDIMENTATION STUDIES

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Abstract

GLOBAL DISTRIBUTION OF ^{137}Cs INPUTS FOR SOIL EROSION AND SEDIMENTATION STUDIES

A global distribution of ^{137}Cs deposition from the atmospheric nuclear tests, with estimates for 1996, excluding Chernobyl contribution, is presented, based on the global deposition data for ^{90}Sr. The data can be used to identify areas and countries, especially in the southern hemisphere, where the ^{137}Cs inventories are appropriate for soil erosion and sedimentation studies.

1. INTRODUCTION

Soil erosion is increasing all over the world, as a consequence of deforestation and inadequate agricultural practices. The negative impacts of soil erosion are twofold: loss of fertile top soil, which dramatically reduces food production yields, and environmental problems due to the transference of sediments to surface water bodies, which produces serious siltation problems in lakes and reservoirs.

The use of environmental ^{137}Cs for measuring soil erosion and deposition is well accepted. The average erosion or deposition rate over the last 3-4 decades can be estimated measuring the ^{137}Cs inventories in soil cores. Average siltation rate in lakes and reservoirs can also be estimated if the 1962 ^{137}Cs peak is noticeable in the vertical distribution of this radionuclide in bottom sediment core samples.

Unfortunately this technique can only be used in areas where the total ^{137}Cs deposition in the soil is great enough to allow its precise quantification, as the results are based on differences of concentration among samples. Very long counting times would increase the detection limit, but for practical reasons, counting times longer than 24 hours per sample are not convenient. The use of high efficiency detectors with Compton anticoincidence systems allows also the measurement of very low levels of ^{137}Cs, but their cost is too high for many developing countries.

To identify regions and countries of the world where the ^{137}Cs technique can yield good results for the evaluation of soil erosion and sedimentation processes, it is important to know the global deposition pattern of ^{137}Cs.

2. ACTIVITY OF ^{137}Cs INTRODUCED INTO THE ATMOSPHERE

^{137}Cs has been introduced into the atmosphere by the detonatión of fission nuclear weapons. The activity produced is proportional to the weapon fission yield. It is assumed that the specific production rate for ^{137}Cs is 6.4×10^{15} Becquerel per megaton [1]. From the first atmospheric atomic explosion in Hiroshima in 1945 to the last in October 1980 in China, some 217.2 megatons of fission devices have been detonated in the atmosphere. The total activity of ^{137}Cs introduced into the atmosphere in that period can be estimated at 1400 PBq.

The deposition of this debris onto the surface of the planet is called fallout and it can be grouped into three categories: local, tropospheric and stratospheric. Local fallout, defined as the deposition within 100 miles of the test area, depends on the altitude and power of the detonation. If the fireball reaches the surface of the soil, higher amounts of local fallout are produced due to soil volatilisation. The local fallout consists of particles usually bigger than 50 μm. [2, 3]. Due to the

remoteness of the test sites and to the relatively large particle size of the debris, this fraction is not suited for erosion studies. If local fallout is not considered, the total amount of ^{137}Cs globally dispersed from all the atmospheric nuclear tests is 912 PBq [4].

The distribution of the radioactive debris between troposphere and stratosphere depends on the power of the bomb. For nuclear bombs smaller than about 100 Kt, detonated in temperate latitudes, the radioactivity tends to remain in the troposphere. For detonations greater than 500 Kt, the debris is injected almost completely into the stratosphere [5].

In the stratosphere, at altitudes lower than 20 km, where most of the nuclear detonations have been carried out, the half-life for the transfer of aerosols between the hemispheres through the equator is about 60 months, while the half-life for transfer to the troposphere is only about 10 months, depending on the latitude [1]. Consequently, the bulk of the fallout from one test occurs over the hemisphere of injection.

The distribution of radioactive debris in the troposphere, either that introduced directly there or that transferred from the stratosphere, is governed by atmospheric circulation patterns. In each hemisphere there are two main air circulation cells, between the equatorial high pressure, sub-equatorial high pressure and sub-polar low pressure belts. At low latitudes, between the first two, the air near the surface circulates towards the equator, where it is heated and rises to an altitude of about 10 km. At this altitude, it starts to move horizontally towards the poles, coming down at latitudes of about 30 degrees, closing the first cell. At latitudes higher than 40 degrees, in the second cell, air near the surface moves northward, rising at about 60 degrees. At high altitudes, the air then moves in the direction of the equator, coming down to surface at a latitude of approximately 30 degrees. This circulation pattern explains why fallout is higher at medium latitudes, usually from 40 to 50 degrees and very low near the equator. The mean residence time of the dust introduced into the troposphere is on the average about 30 days [6].

3. ATMOSPHERIC REMOVAL PROCESSES

Fallout can be classified as dry fallout, which is removed from the atmosphere in dry weather, and wet fallout which is removed by precipitating weather conditions (rain or snow). Dry deposition is at least ten times lower than the wet fallout [7].

Rainfall removes aerosols from the troposphere mainly by droplet formation around the particle (rainout) and by scavenging (washout). This last process is not very effective, because the radioactivity concentration in rain remains almost constant along the rain episode [2]. For very small particles ($<0.01\mu m$), Brownian motion may play an important role for the transfer of aerosols to water particles, especially in clouds where small water droplets have a long residence time [2, 5]. The amount of radioactivity removed by the rain depends on the radioactivity concentration in the cloud. [2].

According to these considerations, the total amount of radioactivity deposited on the earth's surface depends on the atmospheric concentration of radioactivity and the amount of rainfall.

4. GLOBAL DEPOSITION OF ^{137}Cs

Radioactive fallout has been monitored all over the world since the early fifties. Studies performed in the late 40s identified ^{90}Sr as the most dangerous radionuclide in fallout, due to its biological fixation in bones and the consequent risk of developing bone cancer. Due to the significance of this radionuclide, its deposition has been monitored worldwide through two networks, one operated by the USA and another one by the UK. These data were used to elaborate a map with cumulative ^{90}Sr deposits in 1967 [8]. Unfortunately, ^{137}Cs deposition is not so widely documented.

It is possible, however to reconstruct the deposition pattern of ^{137}Cs using the ^{90}Sr data. The rate of production of these two nuclides (fission yields) is very well known. It has been proven that there is no fractionation between these radionuclides during the atmospheric transport [5]. The production rate for ^{137}Cs in fission weapon tests is 1.6 higher than for ^{90}Sr [4].

TABLE I. GLOBAL DEPOSITION OF Cs-137 (in Petabecquerels)

Northern Hemisphere				Southern Hemisphere				Global
	Cs-137 deposition				Cs-137 deposition			
year	annual	cumulative (decay corrected)	yearly fraction %	year	annual	cumulative (decay corrected)	yearly fraction %	cumulative
1954	4 7	5	0 59	1954	2 3	2	0 98	7
1955	20	25	2 53	1955	11	13	4 68	38
1956	31	55	3 92	1956	9	22	3 83	77
1957	30	84	3 80	1957	10	31	4 26	115
1958	40	122	5 06	1958	11	42	4 68	164
1959	80	199	10 13	1959	9	50	3 83	249
1960	18	213	2 28	1960	7	56	2 98	268
1961	21	229	2 66	1961	13	67	5 54	296
1962	92	315	11 65	1962	19	85	8 09	400
1963	150	458	18 99	1963	20	103	8 52	561
1964	100	548	12 66	1964	22	123	9 37	670
1965	34	569	4 30	1965	23	143	9 80	712
1966	19	575	2 41	1966	10	149	4 26	725
1967	9	571	1 14	1967	7	153	2 98	724
1968	12	570	1 52	1968	5	155	2 13	725
1969	7	564	0 89	1969	10	161	4 26	725
1970	7	558	0 89	1970	6	163	2 56	722
1971	9	554	1 14	1971	7	167	2 98	721
1972	4	546	0 51	1972	5	168	2 13	714
1973	3	536	0 38	1973	4	168	1 70	704
1974	5	529	0 63	1974	6	170	2 56	699
1975	4	521	0 51	1975	4	170	1 70	691
1976	2	511	0 25	1976	3	169	1 28	680
1977	4	503	0 51	1977	2	168	0 85	671
1978	4	496	0 51	1978	2	166	0 85	662
1979	2	487	0 25	1979	1 5	163	0 64	650
1980	1	476	0 13	1980	1	161	0 43	637
1981	3	469	0 38	1981	0 5	158	0 21	626
1982	1	459	0 13	1982	0 5	154	0 21	613
1983	1	449	0 13	1983	1	152	0 43	601
1984	0 5	440	0 06	1984	0 5	149	0 21	589
1985	0 5	430	0 06	1985	0 5	146	0 21	576
1986	70	490	8 86	1986	0 5	143	0 21	633
1987	0 5	480	0 06	1987	0 5	140	0 21	620
1988	0 5	469	0 06	1988	0 5	138	0 21	607
1989	0 5	459	0 06	1989	0 5	135	0 21	594

Adapted from Playford et al , 1990

The ^{90}Sr data obtained from the worldwide monitoring network of the UK have been transformed into deposition of ^{137}Cs for both hemispheres in Table 1. The yearly global deposition of ^{137}Cs and data for the decay-corrected cumulative deposition are included in this Table. The 70 PBq introduced in the northern hemisphere in 1986 from Chernobyl have also been included. Based on these data, it can be calculated that the amount of ^{137}Cs which was deposited on the earth surface *until 1967 is 82% of the total amount in the northern hemisphere and 74% in the southern.*

From the original map on the global deposition pattern of ^{90}Sr in mCi/km^2, an equivalent one has been elaborated for ^{137}Cs, in mBq/cm^2 (Figure 1). The isolines correspond to the situation observed in 1967 but the values have been corrected taking into account the additional average deposition expected after that date, and the radioactive decay to 1996.

Some changes in the general patterns of the isolines could also be expected, due to the nuclear explosions by China and France, carried out after 1967 in the northern and southern hemispheres.

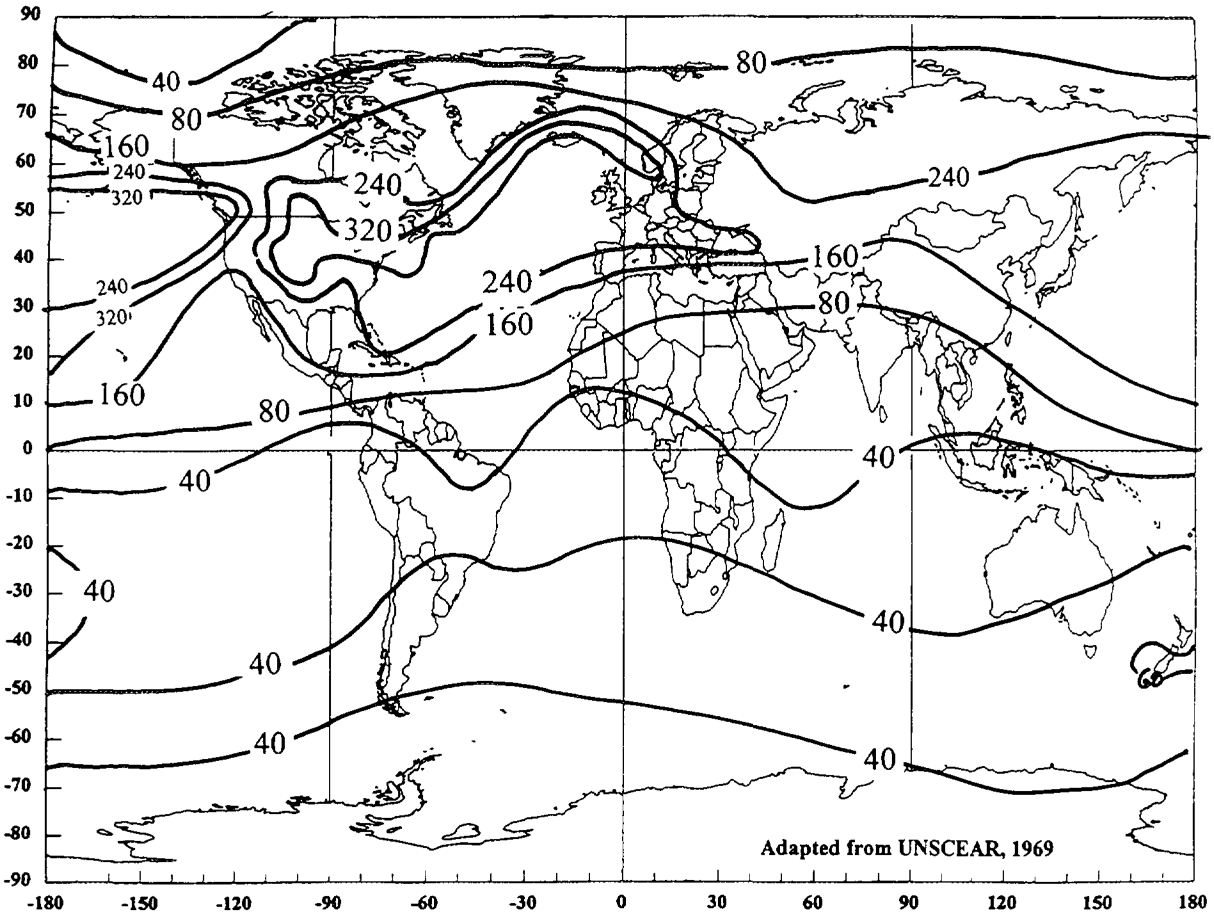

FIG. 1. Global inventory of ^{137}Cs from nuclear tests (in mBq/cm^2, estimated for 1996). Adapted from UNSCEAR, 1969 [8].

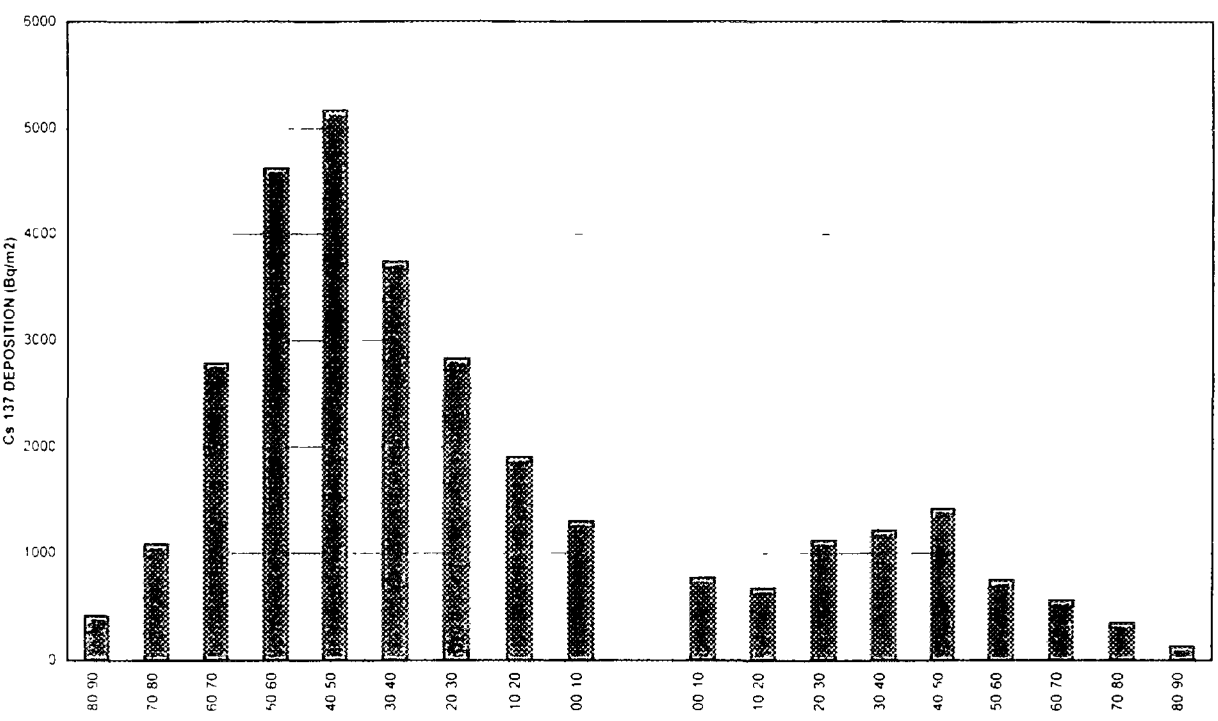

FIG. 2. Distribution of ^{137}Cs deposition by latitude bands.

However, as these two countries contributed with less than 10% to the total ^{137}Cs introduced into the atmosphere, these changes should not be very significant. On another hand, the Chernobyl accident produced important changes of the ^{137}Cs distribution pattern in some European countries. This fact is not reflected in Figure 1.

The distribution of ^{137}Cs deposition in the globe, by latitude bands, is presented in Figure 2. It has been elaborated with ^{90}Sr data presented in [4]. No further deposition has occurred since publication of the data. It can be seen that between the peaks in each hemisphere, the minimum deposition data are not in the equator but between 10° and 20° in the southern hemisphere.

5. CONCLUSIONS

The global ^{137}Cs deposition data were used to identify regions or countries, especially in the southern hemisphere, where the ^{137}Cs input would be appropriate for soil erosion studies. As such, regions in the southernmost parts of Africa (South Africa, Namibia and Botswana) and South America (south of Brazil, Uruguay, Argentina, Paraguay and Chile) seem to be adequate.

The potential of the ^{137}Cs technique for areas located near the equator has also been a matter of study. The northern part of South America, Central and West Africa, and Southeast Asia, should have enough ^{137}Cs in the soil for soil erosion studies. Countries in Africa and America located between latitudes 0 and 30°S should be excluded, as the ^{137}Cs inputs may be very low.

It is expected that additonal data on ^{137}Cs inventories in soils will soon be provided and more reliable information on the global distribution of ^{137}Cs and its potential for the study of soil erosion and deposition in the southern hemisphere will be available.

REFERENCES

[1] FAW, R W , KENNETH SHULTIS, J , Radiological Assessment - Sources and Exposures, PTR Prentice-Hall Inc, New Jersey (1993) 218-221

[2] MACHTA, L , A Survey of Information on Meteorological Aspects of World-Wide Fallout In WMO, Technical Note No 43 Meteorological Factors Influencing the Transport and Removal of Radioactive Debris, Geneva (1961) 3-30

[3] UNITED NATIONS, United Nations Scientific Committee on the Effects of Atomic Radiation 1982 37th Session, Suppl No 45 (A/37/45) United Nations, New York (1982)

[4] UNITED NATIONS, United Nations Scientific Committee on the Effects of Atomic Radiation 1993 48th Session, Suppl No 46 (A/48/46) United Nations, New York (1993)

[5] EISENBUD, M , Environmental Radioactivity from Natural, Industrial and Military Sources, Academic Press Inc , New York (1987) 475 pp

[6] UNITED NATIONS, United Nations Scientific Committee on the Effects of Atomic Radiation 1977 32nd Session, Suppl No 40 (A32/40) United Nations, New York (1977)

[7] BLEEKER, W , The tropospheric circulation and its relation to the distribution of radioactive matter In WMO, Technical Note No 43 Meteorological Factors Influencing the Transport and Removal of Radioactive Debris, Geneva (1961) 65-84

[8] UNITED NATIONS, United Nations Scientific Committee on the Effects of Atomic Radiation 1969 24th Session, Suppl No 13 (A/7613) United Nations, New York (1969)

[9] PLAYFORD, K , LEWIS, G N J , CARPENTER, R C , Radioactive Fallout in Air and Rain Results to the End of 1989 Report AEA-EE-0227, DOE/HMIP/PR/91/042, Harwell Laboratories, UK (1990) 21 pp

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