Chapter 2
How to Design a Be-7 Based Soil Distribution Study at the Field Scale:
A Step-by-Step Approach

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2.1 Key Sample Sets and Associated Data

A ⁷Be-based soil redistribution budget is based on several key datasets (Table 2.1) which have strict rules on collection locations and timings, depending on the time period of application. Overall, the methodological approach follows the principles of other FRN techniques (e.g. the ¹³⁷Cs approach) but with necessary differences linked to the short half-life of ⁷Be and its delivery dynamics. The difference in delivery dynamics also provides the added advantage of opportunity for assumptions underpinning the approach to be tested in field and by laboratory experimentation (Taylor et al. 2014). As summarized in Table 2.1, some datasets are mandatory to convert measurement of ⁷Be inventory into soil redistribution amounts. Other datasets are advised under some circumstances to assist with data interpretation and improve the quality of soil distribution estimates. Fundamental considerations for the collection of all these datasets are outlined in the following section.
Table 2.1  Samples, measurements and resulting datasets required to construct a $^7\text{Be}$-based soil redistribution budget at the hillslope scale

| Sampling location | Samples or measurements taken | Associated dataset | Method(s) | Priority status |
|-------------------|-------------------------------|--------------------|-----------|----------------|
| Reference site    | Reference soil cores          | $^7\text{Be}$ reference inventory for undisturbed soil condition | Short manual core tubes (ca. 30–50 mm) | Needed for all applications |
|                   | Sectioned soil core           | Depth profile of $^7\text{Be}$ and $h_0$ | Fine increment soil sampler (ca 2 mm) | Needed for all applications |
| Study site        | Study plot soil cores         | $^7\text{Be}$ inventory of eroding and depositing sites; particle size distribution | Short manual core tubes (ca. 30–50 mm) | Needed for all applications |
| Reference site    | Rainfall samples (time-integrated) | $^7\text{Be}$ activity concentration in rainfall | Large funnel and polypropylene container | Recommended for short-term event-based study; essential for extended time series model |
|                   | Rainfall record               | 15 min rainfall data for amount and intensity | Tipping bucket rain gauge | Recommended for short-term event-based study; essential for extended time series model |
| Reference site and study site | Soil infiltration capacity | Infiltration capacity | Minidisc infiltrometer or similar | Recommended for all applications |
| Study site        | Representative sample of mobilised and deposited soil | Particle size properties | Runoff and sediment traps; rainfall simulation | Recommended for all applications where particle size selectivity of erosion is likely to occur |
| Reference site and study site | Topographic survey | Digital Elevation Model (DEM) of study plot | GPS-based or traditional survey | Recommended for all applications |
2.2 Reference Site Selection and Sampling

As outlined in Chap. 1, $^{7}\text{Be}$ inventory data are used to construct an FRN budget for the hillslope, to evaluate relative differences to the reference inventory, and this budget is subsequently converted into a soil redistribution budget (described in detail in Chap. 4). Accurate and representative determination of the reference inventory, and associated uncertainty is therefore a fundamental requirement since estimates of soil redistribution pattern and amount relies on this key value.

Reference sites serve two purposes in $^{7}\text{Be}$ studies: (1) to determine a mean reference inventory (i.e. the areal activity of $^{7}\text{Be}$ (Bq m$^{-2}$) in the soil surface unaffected by erosion), and (2) to determine the depth distribution of $^{7}\text{Be}$ in the undisturbed soil prior to erosion, to derive $h_0$. The first requirement is based on collection of bulk soil cores, and the second on the collection of at least one sectioned core. Both need to be determined at a flat, stable location near the study plot, as for $^{137}\text{Cs}$ studies, but it is essential that the land-use history of the location for the depth profile is exactly the same as the study plot. This is important as the $h_0$ value determined must be representative of the eroding soil surface. In practice, the best location for both these measures is a flat area that has been cultivated at the same time and in the same manner as the study plot (Fig. 2.1).

Sample designs for bulk cores need to account for potential FRN spatial variability within the reference site (Sutherland 1996; Mabit et al. 2012; Kirchner 2013) and also deliver sufficient mass of soil for sample analysis (Chap. 3). However, sample numbers are often constrained in $^{7}\text{Be}$ tracing investigations owing to the short half-life.
and availability of sufficient gamma detection facilities. Considering this limitation, Taylor et al. (2013) recommend that all studies should state a reference inventory with suitable upper and lower limits (i.e. $\pm 2\sigma$) (Owens and Walling 1996) and this should be incorporated into subsequent soil redistribution estimates (Chap. 4). Spatial variability in inventory within a plot is most likely due to local redistribution of soil by rain splash and micro-topography and accumulation of rain-splashed particles in hollows. To capture such variability at any given reference site, it is recommended that each sample integrates several cores and then this process is replicated to provide a minimum of 10–15 spatially-integrated reference samples for analysis (Fig. 2.1). Bulk soil cores need to be taken to a consistent depth that is below the known depth penetration of $^{7}\text{Be}$ in the study soil. Depth penetration is typically 20–30 mm (Blake et al. 1999; Doering et al. 2006; Sepulveda et al. 2008; Wallbrink and Murray 1996). In this regard, we strongly advise undertaking a preliminary investigation for trial depth-profile dataset at the study area to ensure the complete profile is captured whilst avoiding dilution of the sample by overestimating the profile depth. This will allow the researcher (1) to establish the maximum depth penetration of $^{7}\text{Be}$ in the soil of the investigated area and (2) to use this depth to determine the maximum depth collection of the remaining bulk cores to be collected (e.g. 0–30 mm in the reference site). Any vegetation on the ground surface must be included in the sample as this will carry part of the recent $^{7}\text{Be}$ inventory (Iurian et al. 2015). When collecting spatially-integrated cores, it is important that the total sum of the core areas that comprise one sample is recorded and that the depth penetration of all cores is consistent at 1 mm precision.

When characterising the $^{7}\text{Be}$ depth profile, it is essential that section cores are sampled from a soil surface that has experienced the same cultivation practice as the study slope but in a location that has remained undisturbed by erosion or deposition processes. Variability due to rain splash, as noted above, can present challenges in selection of the appropriate position of the core. It is highly recommended that more than one section core is collected but this is often limited by gamma detector resource availability. An alternative is to collect 3 replicate section cores and combine the respective layers from each core into integrated samples to capture, but not to quantify, spatial variability within the flat, uneroded reference area. The recommended tool for standardized section core sample collection is the Fine Increment Soil Collector (FISC) (Mabit et al. 2014; Fig. 2.2) which is proven to collect high precision depth profile data suitable for supporting $^{7}\text{Be}$ inventory conversion (Ryken et al. 2016).

It is also common practice to establish a rainfall collection and monitoring station at the reference site to permit assessment of the dynamic of $^{7}\text{Be}$ delivery in relation to inventory development and its radioactive decay in the study area under investigation (Fig. 2.3). Sampling of reference cores through a time period also serves to benchmark and/or validate rainfall-based inventory assessment (Wallbrink and Murray 1994; Walling et al. 2009). The importance of this when applying the event scale PDM is to validate the stability of the reference site. With high resolution rainfall data and rainwater samples, we can use the modelled inventory as a benchmark for confidence in our choice of reference site. For this purpose, rainfall data need to be collected using a tipping bucket rain gauge (Fig. 2.4) that provides 15 or 30 min interval
rainfall intensity data. Alongside rainfall monitoring, bulk rainfall samples need to be collected at a minimum of monthly intervals but preferably at event-scale intervals (depending on rainfall regime) and analysed for $^7$Be concentration (Bq L$^{-1}$). Samples should be collected in pre-acidified polypropylene containers with an attached funnel for rainfall capture (Fig. 2.3) and $^7$Be extracted following protocols described by (Taylor et al. 2016); (see Appendix 2.1 for standard operating procedure).

A time series of the relative inventory at a study site (e.g. Fig. 2.3) can then be calculated as follows, where for each daily time step:

$$A(t) = A(t-1) \cdot e^{\lambda} + F(t)$$

(2.1)

where $A(t-1)$ is the $^7$Be inventory of the previous day (Bq m$^{-2}$), $\lambda$ is the radioactive decay constant (daily time step) and $F(t)$ is the fallout contribution of the current day.

It is common practice to determine the start point either through collection of a suite of reference inventory cores (Walling et al. 2009) or to assume zero due to tillage of the soil surface and dilution of the $^7$Be signal within the soil profile. Table 2.2 shows a spreadsheet coding example to create a cumulative inventory dataset.
2.3 Sample Design Options for Soil Redistribution

The $^7$Be approach is most suited to erosion studies performed on bare soil surfaces (no vegetation) or with little vegetation cover. The method is limited to quantification of erosion by rain splash, sheet wash and shallow rill development since once rill incision goes beyond the depth of the $^7$Be depth profile, eroded soil is exported in the absence of the tracer signal. The selection of study site is very much dependent on the
Table 2.2  Coding for Microsoft Excel spreadsheet to calculate cumulative inventory from rainfall data and rainwater $^7$Be activity concentration data

| Cell number (assuming first row is column headings NB there is only one entry on row 2—see below) | Code | Explanation |
|---|---|---|
| A3 | n/a | Date and time step of rainfall data |
| B3 | n/a | Rainfall input for time step (mm) |
| C3 | =B3 * 1000/1000 | Rainfall expressed as volume per unit area (L m$^{-2}$) |
| D3 | n/a | Rainfall $^7$Be activity concentration (Bq L$^{-1}$) |
| E3 | D3 * C3 | $^7$Be areal activity deposition for time step (Bq m$^{-2}$) |
| F2 | n/a | Inventory at start of monitoring (generally zero if plot is cultivated at beginning) |
| F3 | =E3 + (F2 * EXP(-$I$1)) | Plot inventory (Bq m$^{-2}$) at timestep where cell I1 contains the decay constant for the appropriate time step. The $^7$Be deposition received (cell E3) is added to the decay corrected inventory from the previous day |

research question but, in any case, a basic pilot study will serve useful in determining the presence of a sufficient $^7$Be inventory in the region to make the approach viable and, as described above, to evaluate the typical depth penetration of $^7$Be to inform bulk core sample depth.

The $^7$Be approach may be applied at different spatial scales depending upon the questions being asked by land managers and the constraints imposed by the key assumptions discussed in Chap. 1. In this context, there are three main ways to design a soil core sampling strategy within the study hillslope: (1) sampling along transects from upper to lower slope (Schuller et al. 2006); (2) high resolution grid sampling (Walling et al. 1999; Blake et al. 1999); (3) spatially-integrated sampling within defined geomorphic landscape units (Wallbrink et al. 2002; Blake et al. 2009).

At the field scale, the single transect (Fig. 2.1) or a multi-transect sampling is the most straightforward and cost-effective approach in terms of field sample collection and laboratory processing work effort. Transects can, however, be limited in terms of spatial representativeness depending on local topography and research questions to be addressed. A high-resolution regular grid approach is effective for evaluation of spatial variability and will provide more representative information on soil export and
sediment delivery ratio from a larger study area than transects. However, this approach is highly limited by the analytical demand of a large number of samples, which is hampered further by the short half-life of $^{7}\text{Be}$. The geomorphic landscape unit approach offers a compromise between the limited spatial representativeness of the transect approach and the analytical demands of the grid approach. However, it should be pointed out that multiple reference sites may be required in some geomorphic landscapes.

### 2.4 Sampling for Particle Size Selectivity Correction

Particle size selectivity during soil erosion processes is well-known (Bernard et al. 1992) and users of soil loss assessment or measurement approaches need to make a decision on the relevance of this specific process to their own study site. Taylor et al. (2014) describe how particle size selectively of soil erosion processes can be accounted for in the $^{7}\text{Be}$ conversion model. Application of this method requires specific samples to be collected during or after the erosion event being studied.

Particle size correction requires representative samples of (1) uneroded soil, (2) mobilised soil and (3) deposited soil to be collected (Fig. 2.5). The first can simply be represented by the bulk cores collected for depth profile determination (i.e. in a non-eroding but cultivated site). The third requirement above can be represented by the samples collected to determine inventory in areas of sediment accumulation. The second, the characterisation of mobilised soil, requires more careful planning since after an erosion event, such material has either left the study site or been, in part, deposited at the foot slope. Taylor et al. (2014) propose that such material can be collected with Gerlach troughs installed in the study site or simple equivalent sediment trap systems. Alternatively, to avoid the need to install equipment prior to the event, a rainfall simulator could be used to mobilise material from a representative area, and the material captured for analysis. This needs to be done under rainfall conditions similar to the erosive event.

All samples collected need to be analysed for particle size distribution (Chap. 4).

### 2.5 Summary: Designing a Basic Small Scale $^{7}\text{Be}$ Pilot Study Sampling Programme at the Plot Scale

The procedures described in this chapter can be practised and developed within the context of a simple pilot study framework designed to test the viability of using $^{7}\text{Be}$ as a tracer in any given landscape. A step-by-step approach is detailed below:

**Step 1**: Having located your study site and secured permission from the landowners for its investigation, collect 3 topsoil samples (20 mm depth) after significant rainfall (e.g. >sufficient rainfall to develop a measurable inventory for the study area over an
extended time period) and analyse them for $^7$Be content to confirm if significant and measurable inventory of this radioisotope is present in the study area;

**Step 2**: Collect a trial section core to evaluate the depth penetration of $^7$Be in the study soil;

**Step 3**: Select the reference site in the study area and, if possible, the study plot location (prior to soil erosion taking place). Set up a rain gauge and, if required, rain sampling equipment. Note the timing of the last cultivation and, if this was some time prior to current time within which rainfall had occurred, collect a set of reference cores to establish the baseline ($t = 0$) inventory. Note this will be zero by default if plot study begins immediately after cultivation and mixing of existing $^7$Be inventory into the soil profile;

**Step 4**: After erosion has taken place within a target study plot (a) collect 10–15 spatially-integrated bulk reference cores from the non-eroding reference site to the depth of maximum $^7$Be penetration (e.g. 20–30 mm) following the information provided by the test core (in step 2), (b) collect up to 3 section cores from a flat, non-eroding area that has experienced the same cultivation practice as the study plot using the FISC and either analyse cores separately or combine layers to create a spatially integrated depth profile depending on analytical resource, (c) collect spatially-integrated cores along three transects within the study plot (Fig. 2.1) with 5–15 samples per transect depending on your analytical resource;

**Step 5**: Undertake necessary sampling for particle size correction if desired;

**Step 6**: Bring all recovered soil samples to laboratory (i) for preparation prior to gamma spectrometry (Chap. 3) measurements and, when necessary, (ii) for performing particle size distribution analysis by laser granulometry.

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![Fig. 2.5 Schematic diagram of sampling protocol for including particle size selectivity in $^7$Be soil erosion study (uneroded soil = s; mobilised soil = m; deposited soil = d)](image)
Glossary

Reference Inventory Radioactivity per unit area (Bq m\(^{-2}\)), also termed areal activity, at a stable (non-eroding) field site in close proximity to the eroding study site.

Bulk soil core A soil core taken to a specific depth wherein the material recovered within the corer represents one sample.

Section core A soil core that is initially kept intact within the soil corer and then extruded in small (ca 2 mm) increments to permit sections to be subsampled layer by layer.

Spatially–integrated sampling A process through which one sample collected for analysis comprises several smaller samples taken over a wider area to capture local variability e.g. due to micro-topography or variable vegetation cover. Can be used in routine core sampling but also extended to underpin the landscape-unit sampling approach to \(^{7}\)Be budgeting (see text for details).

Particle size selectivity The process by which erosion processes preferentially remove fine-grained soil particles due to greater critical shear stress required for mobilisation of coarser particles.

Appendix 2.1: Protocol for Extraction of \(^{7}\)Be from Rainwater

According to Taylor et al. (2016), prior to deployment of rainfall collectors, 10 mL HCl (2.5 M) is added to each bottle to prevent adsorption of \(^{7}\)Be to vessel walls during the sampling period. Due care must be taken when handling acid in accordance with your institution's Health and Safety code. Collectors may be exposed for periods of between 3 and 35 days depending on the frequency and magnitude of rainfall. Generally, samples comprise fallout from a number of events across the sample period and are therefore, referred to as integrated samples. At the point of sampling, funnels should be rinsed with a known volume of HCl (1 M) and the bottles replaced with acid-cleaned bottles.

Each sample should be checked to ensure pH is < 2 and then filtered to remove any coarse debris (e.g. using Whatman grade number 41 filter papers). \(^{7}\)Be can then be pre-concentrated from solution by co-precipitation with MnO\(_2\) following the method detailed by Short et al. (2007).

1 mL of 0.2 M KMnO\(_4\) is added per litre of rainwater sample and the pH adjusted to 8–10 using concentrated NH\(_4\)OH.
Once at the desired pH, 1 mL of 0.3 M MnCl₂ is added to the sample whilst stirring. MnO₂ precipitate is then allowed to settle for 24 h prior to removal by vacuum filtration using 0.45 μm cellulose nitrate filter paper.

Filter paper is then air dried, fixed with cellophane and sealed in a suitable container prior to analysis by gamma spectrometry. For each rainwater sample, duplicate 1 L subsamples should ideally be treated and the precipitate combined for filtration. Where rainfall samples are of low volume, a single 1 L sample may be treated. Samples should be considered to provide a representative sub-sample of rainfall for the period.

Repeatability can be tested by analysing triplicate subsamples separately and Relative Standard Deviation (RSD) between triplicates determined. This should typically be <10% (Taylor et al. 2016).

⁷Be recovery from solution using the coprecipitation method was tested by Taylor et al. (2016) by reprecipitating the filtrate from 3 samples. In each case, the ⁷Be activity in the filtrate was below Minimum Detectable Activity (MDA). MDA values for these samples were <10% of the total activity, suggesting that ⁷Be recovery using the above method is >90%, in agreement with Short et al. (2007).

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