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Assumptions and challenges in the use of fallout beryllium-7 as a soil and sediment tracer in river basins

A. Taylor [a], W.H. Blake [a,*], H.G. Smith [b], L. Mabit [c], M.J. Keith-Roach [a,d]

[a] School of Geography, Earth and Environmental Sciences, Plymouth University, PL4 8AA, UK
[b] School of Environmental Sciences, University of Liverpool, L69 7ZT, UK
[c] Soil and Water Management and Crop Nutrition Laboratory, FAO/IAEA Agriculture & Biotechnology Laboratory, IAEA Laboratories Seibersdorf, Austria
[d] Kemakta Konsult, Stockholm, Sweden

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ABSTRACT

This contribution reviews research surrounding the assumptions that underpin the use of beryllium-7 (^{7}Be) as a soil and sediment tracer in river basins. As a cosmogenic radionuclide, the constant natural production of ^{7}Be and fallout via precipitation, coupled with its ability to bind to soil and sediment particles provides the basis for its application as a conservative soil and sediment tracer. Consequently, ^{7}Be has been extensively employed as a tracer across a range of spatial and temporal (event to seasonal) scales. The short half-life of ^{7}Be (53.3 days) lends itself to tracing sediment dynamics over short time periods, thus, providing complementary data to medium-term estimates derived from longer lived radionuclides such as caesium-137 (^{137}Cs). This short half-life could provide a major advantage when considering the potential for ^{7}Be to document recent effects of climate or land use change upon soil redistribution, with the latter having particular relevance for assessing the effectiveness of mitigating strategies within a catchment-wide approach to management. Although ^{7}Be has been widely applied as a tracer to date, application is still in its infancy and there remains a lack of knowledge in relation to the assumptions for its use as a tracer. Specifically, our findings suggest that there are crucial information gaps with regard to ^{7}Be application as an erosion tracer. Of key importance is the potential for fallout uniformity and rapid tracer sorption to be compromised under certain conditions. The assumption of irreversible sorption is likely to hold for common hillslope conditions but literature identifies the potential for tracer mobility with changing environmental parameters in the wider catchment. Further research is required to determine the likelihood of ^{7}Be sorption being affected by conditions found at relevant field sites and the impact of this upon tracer applications at the catchment-scale.

Contents

1. Introduction

Knowledge of sediment sources and the dynamics of sediment redistribution within catchment systems is required to inform management solutions, particularly with regard to addressing Diffuse Water Pollution from Agriculture (DWPA). The off-site impacts associated with soil

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* Corresponding author at: School of Geography, Earth and Environmental Sciences, Portland Square, Plymouth PL4 8AA, UK. Tel.: +44 1752 585459.
E-mail address: wblake@plymouth.ac.uk (W.H. Blake).

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erosion are well documented (Anderson et al., 2002; Camargo and Alonso, 2006; Weijters et al., 2009) and as a result of climate change and global warming, water erosion is expected to increase in many areas across the globe during the 21st century (EEA, 2002; Pruski and Nearing, 2002). Current concerns for sustainable use and management of global soil and water resources (Lal, 2011) generate an urgent need for obtaining reliable quantitative data on the extent and actual rates of soil erosion and sedimentation in water bodies, involving multidisciplinary approaches and tools (Toy et al., 2002; Boardman and Poesen, 2006; CEC, 2006; Marchetti et al., 2012).

Traditional monitoring and modelling techniques for soil erosion/sedimentation have a number of important limitations in terms of validation, data acquisition and involved costs (Loughran, 1989; Toy et al., 2002). The quest for alternative techniques of soil erosion assessment, both to complement existing methods and to meet new requirements, has directed attention to the use of fallout radionuclide tracers (FRN) which have the potential to enable retrospective estimates of soil redistribution from fewer site visits (Walling, 2006). Moreover, the sampling techniques involve minimal disturbance to the study site and are, therefore, unlikely to affect erosion processes (Mabit et al., 2008). The most commonly applied FRN tracers are caesium-137 (^{137}Cs), excess lead-210 (^{210}Pb$_{ex}$) and beryllium-7 (^{7}Be) with assumptions underpinning the former being the subject of continuing debate (Mabit et al., 2013; Parsons and Foster, 2013).

^{7}Be ($t_{1/2} = 53.3$ days) is a cosmogenic radionuclide produced in the stratosphere and troposphere as a result of cosmic ray spallation of nitrogen and oxygen (Brost et al., 1991). Following its formation, ^{7}Be is scavenged by submicron aerosol particles and removed from the troposphere primarily by precipitation with dry deposition accounting for around 10% of total fallout to the Earth's surface (Wallbrink and Murray, 1994; Ioannidou and Papastefanou, 2006; Doering and Akber, 2008a). High partition coefficients highlighted in river systems (e.g. Hawley et al., 1986) have underpinned the use of ^{7}Be as a sediment tracer to date. Owing to its half-life, ^{7}Be has been applied to estimate soil redistribution over short timescales, thus, complementing medium-term estimates derived from the longer lived anthropogenic ^{137}Cs ($t_{1/2} =$ 30.2 years) and geogenic ^{210}Pb$_{ex}$ ($t_{1/2} = 22.3$ years). This is likely to be of particular relevance when assessing the effects of land use change or variation in future climatic patterns on soil erosion and sediment transfer to water bodies. ^{7}Be also provides the benefit of constant, natural production, a key advantage given the finite nature of ^{137}Cs inventories without continuing atmospheric fallout.

Applications of ^{7}Be as a tracer are extensive (Table 1) and to date include studies of: hillslope soil erosion (e.g. Blake et al., 1999; Walling et al., 1999; Schuller et al., 2006, 2010; Sepulveda et al., 2008), erosion processes (e.g. Wallbrink and Murray, 1993; Whiting et al., 2001; Liu et al., 2011), channel sediment dynamics (e.g. Fitzgerald et al., 2001; Blake et al., 2002; Salant et al., 2007), floodplain accretion (Blake et al., 2002), estuarine and marine shelf deposition (e.g. Sommerfield et al., 1999; Woodruff et al., 2001; Cooper et al., 2002; Giffin and Corbett, 2003; Corbett et al., 2004; Schmidt et al., 2007; Rose and Kuehl, 2010; Kolker et al., 2012), sediment source fingerprinting (e.g. Burch et al., 1988; Feng et al., 1999; Noakes and Jutte, 2006; Du et al., 2010; Huisman and Karthikeyan, 2012; Wilson et al., 2012), sediment-contaminant dynamics (e.g. Steinmann et al., 1999; Roos and Valeur, 2006; Saari et al., 2010) and sediment transport distance and residence time (e.g. Bonniwell et al., 1999; Ciffroy et al., 2003; Matisoff et al., 2005; Evrard et al., 2010).

The use of ^{7}Be as a tracer in river catchments (i.e. studies of hillslope erosion rates and processes, deposition rates, source fingerprinting and residence time) is based upon a set of assumptions, which have varying degrees of importance and impact depending on the scale of study, location (e.g. hillslope or catchment) and research application. For the subject of hillslope soil erosion, which has received most attention to date, the

Table 1
Examples of the application of ^{7}Be as a sediment tracer in river basins.

Application	Authors	Location	Landscape unit
Sediment budget (forest wildfire)	Wallbrink et al. (2005); Blake et al. (2009)	NSW, Australia	Small catchment (<1 km^2)
Sediment/contaminant dynamics	Clifton et al. (1995)	SW UK	Estuary
Sediment/contaminant dynamics	Huang et al. (2011)	S China	Estuary
Sediment/contaminant dynamics	Saari et al. (2010)	SW France	Estuary
Sediment/contaminant dynamics	Steinmann et al. (1999)	Switzerland/Italy	Lake
Sediment deposition	Blake et al. (2002)	SW UK	Floodplain
Sediment deposition	Neubauer et al. (2002)	VA, USA	Tidal marsh (~4 km^2)
Sediment deposition	Woodruff et al. (2001)	NY, USA	Estuary
Sediment deposition/resuspension	Fitzgerald et al. (2001)	WI, USA	River units
Sediment residence time	Ciffroy et al. (2003)	NW France	Estuary
Sediment residence time	Evrard et al. (2010)	Central Mexico	Sub catchments (3–12 km^2)
Sediment residence time	Fisher et al. (2010)	ME, USA	River (9 km reach)
Sediment residence time	Gartner et al. (2012)	VT & NH, USA	River units
Sediment residence time	Le Cloarec et al. (2007)	N France	Nested catchments (7–65,700 km^2)
Sediment residence time	Wieland et al. (1991)	NE Switzerland	Lake
Sediment residence time/transport distance	Bonniwell et al. (1999)	ID, USA	River (~20 km reach)
Sediment residence time/transport distance	Dominik et al. (1987, 1989)	SW Switzerland	Catchment/lake
Sediment residence time/transport distance	Matisoff et al. (2002, 2005)	OH; AL; OR, USA	River channel and wetland
Sediment residence time/transport distance	Salant et al. (2007)	VT, USA	River units
Sediment source fingerprinting	Evrard et al. (2011)	SE France	Catchment (907 km^2)
Sediment source fingerprinting	Huisman and Karthikeyan (2012)	WI, USA	Catchment (12.4 km^2)
Sediment source fingerprinting	Wilson et al. (2012)	IA, USA	Sub-catchment (26 km^2)
Sediment source/transport distance	Whiting et al. (2005)	MT, USA	River (>400 km reach)
Soil erosion processes	Burch et al. (1988); Wallbrink and Murray (1993)	NSW, Australia	Hillslope to channel
Soil erosion processes	Liu et al. (2011)	W China	Hillslope plots
Soil erosion processes	Walling and Woodward (1992)	SW UK	Hillslope to channel
Soil erosion processes	Whiting et al. (2001)	IA, USA	Hillslope
Soil erosion processes	Yang et al. (2006)	W China	Hillslope plot
Soil redistribution (agriculture)	Benmansour et al. (2011)	W Morocco	Hillslope plot
Soil redistribution (agriculture)	Blake et al. (1999); Walling et al. (1999)	SW UK	Hillslope
Soil redistribution (agriculture)	Wilson et al. (2003)	IA, USA	Hillslope plot
Soil redistribution (agriculture and burning)	Sepulveda et al. (2008)	Central Chile	Hillslope
Soil redistribution (logging)	Schuller et al. (2006)	Central Chile	Hillslope plot
Soil redistribution (logging)	Schuller et al. (2010)	Central Chile	Hillslope plots
Suspended sediment dynamics	Feng et al. (1999)	NY, USA	Estuary