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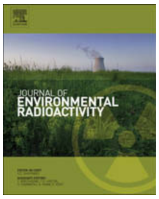

# Beryllium-7 atmospheric deposition and sediment inventories in the Neponset River estuary, Massachusetts, USA

Jun Zhu, Curtis R. Olsen*

*Department of Environmental, Earth and Ocean Sciences, University of Massachusetts Boston, 100 Morrissey Boulevard, Boston, MA 02125-3393, USA*

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ABSTRACT

Measured monthly atmospheric depositional fluxes of cosmogenically produced $^{7}$Be ranged from 1 to 67 mBq/cm$^{2}$ in Boston, Massachusetts between September 2000 and August 2007. These fluxes exhibited seasonality and supported a decay-corrected $^{7}$Be atmospheric depositional running inventory that ranged from 36 to 144 mBq/cm$^{2}$. Annual $^{7}$Be deposition exhibited an increasing trend that may reflect a general decrease in solar activity and a general increase in precipitation over the 7-year sampling period. To investigate short-term sediment dynamics and accumulation patterns in the Neponset River estuary, we collected six sediment cores in July 2006 and measured $^{7}$Be sediment inventories ranging from 48 to 546 mBq/cm$^{2}$ Comparisons of these sediment inventories with the $^{7}$Be running inventory from atmospheric deposition (101 mBq/cm$^{2}$) at the time of core collection indicated a large degree of spatial heterogeneity in sediment accumulation patterns and its potential use as a tool for assessing the impacts of environmental restoration activities in estuarine environments.

## 1. Introduction

Cosmogenic $^{7}$Be (53.3 days half-life) is produced primarily in the stratosphere via cosmic-ray spallation of nitrogen and oxygen. The amount of $^{7}$Be that reaches the Earth's surface is a function of its production rate in the atmosphere, the extent of stratosphere–troposphere air exchange, tropospheric circulation patterns, and its efficiency of removal via wet and dry deposition (Doering and Akber, 2008; Feely et al., 1989; Heikkila et al., 2008). Once deposited, $^{7}$Be rapidly adsorbs to above ground vegetation and soils in terrestrial systems and onto suspended particles in river-estuarine systems (Olsen et al., 1986). Due to its continuous production in the atmosphere, its relatively short half-life, and its ease of measurement by gamma spectrometry, $^{7}$Be has proven to be a useful tool for tracing and quantifying environmental processes, such as atmospheric mixing (Graham et al., 2003; Junge, 1963; Viezee and Singh, 1980), sediment erosion/accretion in watersheds (Casey et al., 1986; Olsen et al., 1985), and sediment accumulation, mixing and resuspension in estuarine and coastal environments (Dibb and Rice, 1989; Feng et al., 1999; Matisoff et al., 2005; Olsen et al., 1981; Osaki et al., 1997; Palinkas et al., 2005).

In this study, we report a long-term (7-year) record of monthly $^{7}$Be atmospheric depositional fluxes to the Boston metropolitan area and discuss the atmospheric processes associated with its seasonal and annual variations. In addition, we used this dataset to examine the relationship between the running inventory of $^{7}$Be atmospheric deposition (standing crop) and the $^{7}$Be sediment inventories measured in six cores collected in the urbanized Neponset River estuary.

The Neponset River drains a 340-km$^{2}$ watershed within the highly urbanized Boston area and supports an extensive salt marsh near its mouth into Dorchester Bay, Boston Harbor. Riverine discharge to the estuary is controlled by Baker Dam, located 7 km upstream from the estuarine mouth. As part of the *Neponset River Fish Passage and Habitat Restoration Project*, the Commonwealth of Massachusetts is considering the removal of this Dam to restore anadromous fish passage and spawning (U.S. Army Corps of Engineers, N.E.D., 2002). Previous studies have shown that dam removal significantly affects the geomorphological features and sedimentological processes of river-estuarine systems (Lorang and Aggett, 2005; Pizzuto, 2002) and may cause local ecological changes (Shuman, 1995).

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* Corresponding author. Tel.: +1 617 287 7433; fax: +1 617 287 7474.
*E-mail address:* curtis.olsen@umb.edu (C.R. Olsen).

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The objectives of this study were to use $^7$Be as a tracer to examine short-term sediment dynamics and accumulation patterns in the Neponset River estuary, and to document its potential use as a new and novel tool for determining how estuarine and sedimentary processes may change in association with human activities, such as urbanization, environmental restoration, or dam removal.

## 2. Study area

The Neponset River Watershed is located in southeastern Massachusetts, USA, which includes parts of 14 cities and towns. The Neponset River estuary extends from its mouth in Boston Harbor to Baker Dam (Fig. 1). The dam was originally built in 1639 to provide power for a factory and is considered one of the first dams in the United States (Breault et al., 2004). River discharge from the dam varies from 0.6 to 3.1 m$^3$/s depending on the season, as gauged by the U.S. Geological Survey (Breault, 2002). The tidal range within the estuary is about 3 m. A large fraction of the water in the estuary is exchanged on each tide and about 29% of the intertidal surface area is non-vegetated (Gardner et al., 2005). This combination of physical and geomorphologic features contributes to the short-time scale for water transport and mixing (Gardner et al., 2005), and supports the use of a short-term and particle-reactive tracer ($^7$Be) for examining sediment resuspension, mixing and accumulation within the estuary.

## 3. Methodology

Beryllium-7 was measured in monthly precipitation samples collected in 5-gallon polyethylene buckets on the roof of the Science Building at University of Massachusetts Boston from September 2000 to August 2007 (Fig. 1). The bucket was placed 1 m above the roof surface and a bulk precipitation sample was collected at the end of each month. The amount of precipitation was measured at the Boston Logan International Airport Weather Observation Station, about 6 km away from the precipitation collection site.

After collection, the sample was acidified using 1 N HCl and evaporated to ~90 ml using a hot plate. It was then adjusted to pH ~6 by adding 25% $NH_4OH$, and sealed in a plastic-lined aluminum can. Each monthly precipitation sample was analyzed for $^7$Be (477.6 KeV gamma peak) by gamma spectroscopy using an ultra low-background, high-resolution Canberra Broad Energy Germanium planar detector equipped with Canberra Genie 2000 MCA microprocessor. Each sample was counted for 24–36 h and the counting error was expressed as 1$\sigma$.

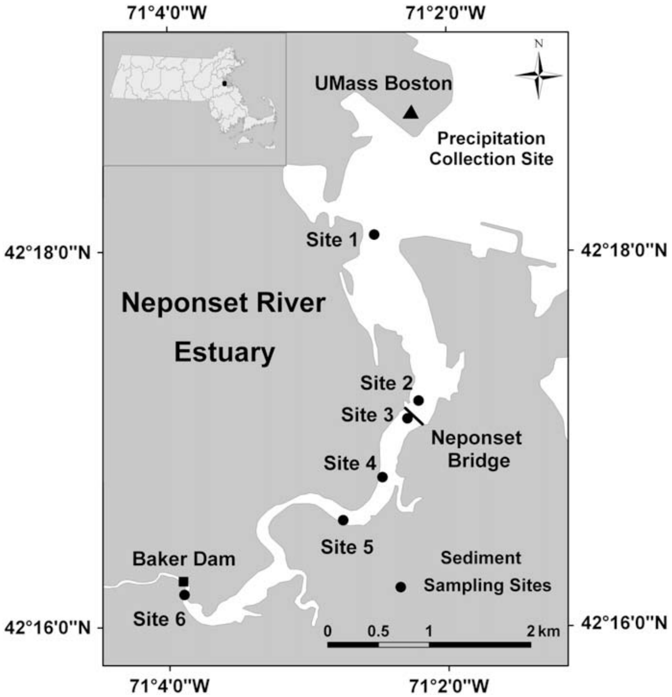

**Fig. 1.** Map illustrating the Neponset River estuary from its mouth to Baker Dam and the collection sites for the six sediment cores and precipitation samples.

The $^7$Be activity for each monthly sample was decay-corrected to the midpoint of the sampling period. The annual $^7$Be flux was determined by summing the monthly atmospheric depositional fluxes from January to December. These monthly fluxes were also used to determine a running inventory of $^7$Be atmospheric deposition (standing crop) by consecutively decay-correcting the previous month's standing crop and adding this residual amount to the total $^7$Be atmospheric deposition flux of the current month.

To investigate local short-term sediment dynamics and accumulation patterns, we collected six sediment cores from the mouth of the Neponset River estuary to Baker Dam (Fig. 1) on July 14, 2006 and compared the measured $^7$Be sediment inventories to the $^7$Be atmospheric depositional running inventory expected at the time of sediment core collection. The cores were sectioned at 1 cm intervals, and each section was oven-dried at 50 °C, homogenized, sealed in a plastic-lined aluminum can and analyzed by gamma spectrometry (as described above). The measured $^7$Be activity for each section was summed to calculate the total $^7$Be sediment inventory (mBq/cm$^2$) at each sampling site.

## 4. Results

The monthly $^7$Be atmospheric deposition flux ranged from 1 to 67 mBq/cm$^2$ (Table 1), with a 7-year average monthly flux of 21.6 ± 0.3 mBq/cm$^2$. The calculated $^7$Be atmospheric depositional running inventory ranged from 36 to 144 mBq/cm$^2$ (Table 1), with an average of 65 ± 2 mBq/cm$^2$. The atmospheric deposition fluxes of $^7$Be were positively correlated with the total amounts of precipitation (Fig. 2a) and exhibited seasonality (Fig. 2b). The atmospheric deposition fluxes of $^7$Be averaged 153 mBq/cm$^2$/month during the spring and summer months (March–August) and averaged 107 mBq/cm$^2$/month during the fall to winter months (September–February). The abnormally high atmospheric deposition flux of $^7$Be during October 2005 (Table 1) was associated with the large amount of precipitation that occurred during that month.

The $^7$Be sediment inventories and depths of $^7$Be penetration in each of the six estuarine sediment cores are reported in Table 2. The $^7$Be sediment inventories ranged from 48 ± 7 mBq/cm$^2$ at Site 2 to as high as 546 ± 54 mBq/cm$^2$ at Site 3 (Fig. 1 and Table 2). At the time of sediment core collection, the expected running inventory of $^7$Be atmospheric deposition was 101 ± 3 mBq/cm$^2$, which is highlighted in Table 1. Site 2 was the only sampling location where the total measured $^7$Be sediment inventory was less than the expected $^7$Be inventory supported by its atmospheric deposition (Table 2). The penetration depths of $^7$Be in the sediment ranged from 3 cm at Site 2 to as deep as 9 cm at Site 3 (Table 2).

## 5. Discussion

### 5.1. *Seasonal and annual variations in the atmospheric deposition of $^7$Be*

Previous studies examining the production of $^7$Be in the atmosphere have shown that ~90% is produced in the stratosphere in association with cosmic-ray spallation of nitrogen (Kaste et al., 2002). Mid-latitude folding of the tropopause in spring has also been shown to enhance stratospheric–tropospheric exchange of $^7$Be and increase $^7$Be concentrations in the troposphere (Burchfield et al., 1983; Doering and Akber, 2008; Feely et al., 1989; Heikkila et al., 2008; Noyce et al., 1971). In addition, high-tapping thundershowers in the spring and summer months, can enhance stratospheric–tropospheric exchange and the washout of $^7$Be via precipitation (Burchfield et al., 1983). As a result, deposition of $^7$Be from the atmosphere is often higher during spring and summer months (Azahra et al., 2003; Cooper et al., 2002; Feely et al., 1989; Gonzalez-Gomez et al., 2006; Kulan, 2006; Yamamoto et al., 2006), and this is also indicated by our results (Table 1 and Fig. 2b). Over

**Table 1**
Monthly summaries of total precipitation, $^7$Be atmospheric depositional flux, and the calculated $^7$Be atmospheric depositional running inventory for Boston from September 2000 to August 2007.

| Month[a] | Total Precipitation (cm) | Monthly $^7$Be Flux (mBq/cm$^2$) | Running $^7$Be Inventory[c] (mBq/cm$^2$) |
|---|---|---|---|
| Sep-00 | 7.3 | 19.5 ± 0.3 | 19.5 ± 0.3 |
| Oct-00 | 7.3 | 13.0 ± 0.2 | 25.9 ± 0.3 |
| Nov-00 | 11.5 | 11.8 ± 0.2 | 29.2 ± 0.4 |
| Dec-00 | 11.9 | 19.4 ± 0.3 | 39.3 ± 0.4 |
| Jan-01 | 4.0 | 6.5 ± 0.1 | 32.8 ± 0.5 |
| Feb-01 | 3.5 | 6.5 ± 0.1 | 28.8 ± 0.5 |
| Mar-01 | 19.2 | 11.1 ± 0.2 | 30.6 ± 0.5 |
| Apr-01 | 2.2 | 10.8 ± 0.1 | 31.3 ± 0.5 |
| May-01 | 3.1 | 7.2 ± 0.1 | 28.4 ± 0.5 |
| Jun-01 | 12.7 | 42.8 ± 0.6 | 61.9 ± 0.8 |
| Jul-01 | 5.4 | 20.8 ± 0.3 | 62.4 ± 0.8 |
| Aug-01 | 10.5 | 41.4 ± 0.6 | 82.3 ± 1.0 |
| Sep-01 | 5.8 | 23.8 ± 0.3 | 79.1 ± 1.1 |
| Oct-01 | 2.5 | 5.4 ± 0.1 | 59.9 ± 1.1 |
| Nov-01 | 1.9 | 9.0 ± 0.1 | 48.7 ± 1.1 |
| Dec-01 | 7.2 | 12.8 ± 0.2 | 45.1 ± 1.1 |
| Jan-02 | 8.0 | 26.8 ± 0.4 | 57.3 ± 1.1 |
| Feb-02 | 4.6 | 9.8 ± 0.1 | 49.1 ± 1.2 |
| Mar-02 | 8.9 | 47.6 ± 0.7 | 81.0 ± 1.3 |
| Apr-02 | 6.6 | 10.9 ± 0.1 | 65.4 ± 1.3 |
| May-02 | 11.4 | 19.4 ± 0.3 | 63.6 ± 1.3 |
| Jun-02 | 12.1 | 25.3 ± 0.3 | 68.0 ± 1.4 |
| Jul-02 | 3.6 | 14.5 ± 0.2 | 59.9 ± 1.4 |
| Aug-02 | 5.4 | 17.4 ± 0.2 | 57.1 ± 1.4 |
| Sep-02 | 8.6 | 10.6 ± 0.1 | 49.0 ± 1.4 |
| Oct-02 | 8.8 | 24.9 ± 0.3 | 58.1 ± 1.5 |
| Nov-02 | 12.8 | 26.7 ± 0.4 | 65.5 ± 1.5 |
| Dec-02 | 13.5 | 13.0 ± 0.2 | 56.8 ± 1.5 |
| Jan-03 | 4.6 | 5.9 ± 0.1 | 44.1 ± 1.5 |
| Feb-03 | 10.7 | 9.7 ± 0.1 | 39.9 ± 1.5 |
| Mar-03 | 10.2 | 15.4 ± 0.2 | 42.5 ± 1.5 |
| Apr-03 | 10.2 | 21.8 ± 0.3 | 50.4 ± 1.6 |
| May-03 | 10.5 | 36.6 ± 0.5 | 70.2 ± 1.6 |
| Jun-03 | 11.9 | 31.2 ± 0.4 | 78.4 ± 1.7 |
| Jul-03 | 5.4 | 12.4 ± 0.2 | 65.8 ± 1.7 |
| Aug-03 | 7.4 | 1.0 ± 0.01 | 44.6 ± 1.7 |
| Sep-03 | 6.7 | 12.2 ± 0.3 | 42.2 ± 1.7 |
| Oct-03 | 15.8 | 28.0 ± 0.6 | 56.8 ± 1.8 |
| Nov-03 | 6.7 | 29.8 ± 0.7 | 67.7 ± 1.9 |
| Dec-03 | 12.9 | 15.2 ± 0.3 | 61.0 ± 2.0 |
| Jan-04 | 2.57 | 9.2 ± 0.2 | 49.7 ± 2.0 |
| Feb-04 | 3.7 | 2.6 ± 0.03 | 35.8 ± 2.0 |
| Mar-04 | 8.6 | 48.5 ± 0.8 | 72.3 ± 2.1 |
| Apr-04 | 24.3 | 45.3 ± 0.8 | 94.2 ± 2.3 |
| May-04 | 7.8 | 29.2 ± 0.5 | 94.1 ± 2.3 |
| Jun-04 | 5.0 | 20.4 ± 0.3 | 83.7 ± 2.3 |
| Jul-04 | 9.8 | 26.5 ± 0.4 | 82.7 ± 2.4 |
| Aug-04 | 11.1 | 15.3 ± 0.3 | 70.5 ± 2.4 |
| Sep-04 | 18.9 | 32.3 ± 0.5 | 80.0 ± 2.5 |
| Oct-04 | 4.8 | 15.2 ± 0.3 | 69.0 ± 2.5 |
| Nov-04 | 7.4 | 20.9 ± 0.4 | 67.3 ± 2.5 |
| Dec-04 | 9.3 | 19.3 ± 0.3 | 63.9 ± 2.5 |
| Jan-05 | 11.3 | 10.3 ± 0.2 | 51.4 ± 2.5 |
| Feb-05 | 6.9 | 11.6 ± 0.2 | 46.3 ± 2.5 |
| Mar-05 | 9.9 | 25.6 ± 0.4 | 57.5 ± 2.6 |
| Apr-05 | 8.1 | 31.1 ± 0.5 | 70.0 ± 2.6 |
| May-05 | 10.1 | 21.2 ± 0.4 | 69.5 ± 2.6 |
| Jun-05 | 3.7 | 12.0 ± 0.2 | 59.7 ± 2.6 |
| Jul-05 | 8.6 | 33.1 ± 0.6 | 73.4 ± 2.7 |
| Aug-05 | 7.3 | 16.7 ± 0.3 | 64.5 ± 2.7 |
| Sep-05 | 4.5 | 16.1 ± 0.2 | 58.0 ± 2.7 |
| Oct-05 | 23.9 | 53.8 ± 0.9 | 93.0 ± 2.9 |
| Nov-05 | 9.4 | 29.9 ± 0.5 | 93.6 ± 2.9 |
| Dec-05 | 7.3 | 30.9 ± 0.5 | 91.0 ± 3.0 |
| Jan-06 | 11.6 | 30.2 ± 0.5 | 90.2 ± 3.0 |
| Feb-06 | 6.7 | 9.1 ± 0.1 | 73.4 ± 3.0 |
| Mar-06 | 1.4 | 7.3 ± 0.1 | 58.2 ± 3.0 |
| Apr-06 | 4.7 | 30.9 ± 0.5 | 70.3 ± 3.0 |
| May-06 | 31.7 | 66.0 ± 1.1 | 113 ± 3 |
| Jun-06 | 25.6 | 67.3 ± 1.1 | 144 ± 3 |
| **Jul-06**[d] | **9.1** | **4.0 ± 0.1** | **101 ± 3** |
| Aug-06 | 8.1 | 31.7 ± 0.5 | 98.9 ± 3.5 |
| Sep-06 | 4.4 | 24.0 ± 0.4 | 90.0 ± 3.5 |
| Oct-06 | 11.4 | 16.6 ± 0.3 | 75.9 ± 3.5 |
| Nov-06[b] | 14.7 | 24.9 ± 0.4 | 76.6 ± 3.5 |
| Dec-06[b] | 19.5 | 24.9 ± 0.4 | 78.8 ± 3.5 |
| Jan-07 | 6.5 | 24.3 ± 0.4 | 76.2 ± 3.5 |
| Feb-07 | 5.6 | 2.7 ± 0.1 | 59.5 ± 3.5 |
| Mar-07 | 11.0 | 26.9 ± 0.4 | 67.7 ± 3.6 |
| Apr-07 | 17.0 | 48.2 ± 0.8 | 93.7 ± 3.6 |
| May-07 | 9.4 | 12.5 ± 0.2 | 75.5 ± 3.6 |
| Jun-07 | 5.4 | 16.3 ± 0.3 | 66.4 ± 3.6 |
| Jul-07 | 13.4 | 30.2 ± 0.5 | 74.8 ± 3.6 |
| Aug-07 | 1.7 | 5.7 ± 0.1 | 56.3 ± 3.6 |

[a] The monthly fluxes have been decay-corrected to the midpoint of the sampling period.

[b] The precipitation samples for Nov-06 and Dec-06 were accidentally combined. As a result, the $^7$Be atmospheric depositional fluxes for both months were averaged.

[c] The $^7$Be atmospheric depositional running inventory (standing crop) was determined by consecutively decay-correcting the previous month's standing crop and adding this residual amount to the total $^7$Be atmospheric depositional flux of current month. As a result, the inventory data for the first few months underestimate the standing crop by not including $^7$Be activity from months prior to the start of sampling period.

[d] The running inventory of $^7$Be atmospheric deposition at the time of sediment core collection is highlighted.

the 7-year sample collection period, the atmospheric deposition flux of $^7$Be during the 6 months of spring and summer (March–August) was about 1.5 times greater than during the 6 months of fall and winter (September–February).

As illustrated in Fig. 3, there is an increasing trend in the atmospheric deposition flux of $^7$Be on an annual basis ($R^2 = 0.867$, $p < 0.01$) over this 6-year period. This trend probably reflects the general increase in annual precipitation (Table 1 and Fig. 3), but may also reflect the general decrease in solar activity that has occurred over the past 6 years (Woods and Lean, 2007). Previous work by Lal and Peters (1967) has shown that the production rate of $^7$Be in the stratosphere is directly related to the cosmic-ray flux, and that increases in solar activity deflect cosmic-rays from our solar system. As a result, during periods of decreased solar activity, there is actually an increase in the cosmic-ray flux to the Earth's atmosphere causing an increase in the production of $^7$Be (Azahra et al., 2003; Papastefanou and Ioannidou, 2004). Measurements of total solar irradiance (TSI) indicate that solar activity has been decreasing since 2002 (data from the Jet Propulsion Laboratory, JPL, of the California Institute of Technology and Columbia University at http://www.acrim.com). Based on the annual $^7$Be atmospheric deposition fluxes (calculated from Table 1) and from the above referenced measurements of TSI, it appears that the annual $^7$Be atmospheric deposition fluxes are moderately correlated with decreasing solar activity ($R^2 = 0.717$, $p < 0.05$). The correlation between the annual $^7$Be atmospheric deposition flux and the annual precipitation (Table 1) is also moderately significant ($R^2 = 0.738$, $p < 0.05$) over the past 6 years. These results indicate that the increasing trend in the annual $^7$Be atmospheric deposition flux (Fig. 3) reflects the decreasing trend in solar activity and increase in precipitation.

### 5.2. *$^7$Be as a tracer for examining sediment dynamics and accumulation patterns*

Once deposited to the Earth's surface, $^7$Be rapidly adsorbs to above ground vegetation and soils in terrestrial systems and onto suspended particles in freshwater and estuarine environments,

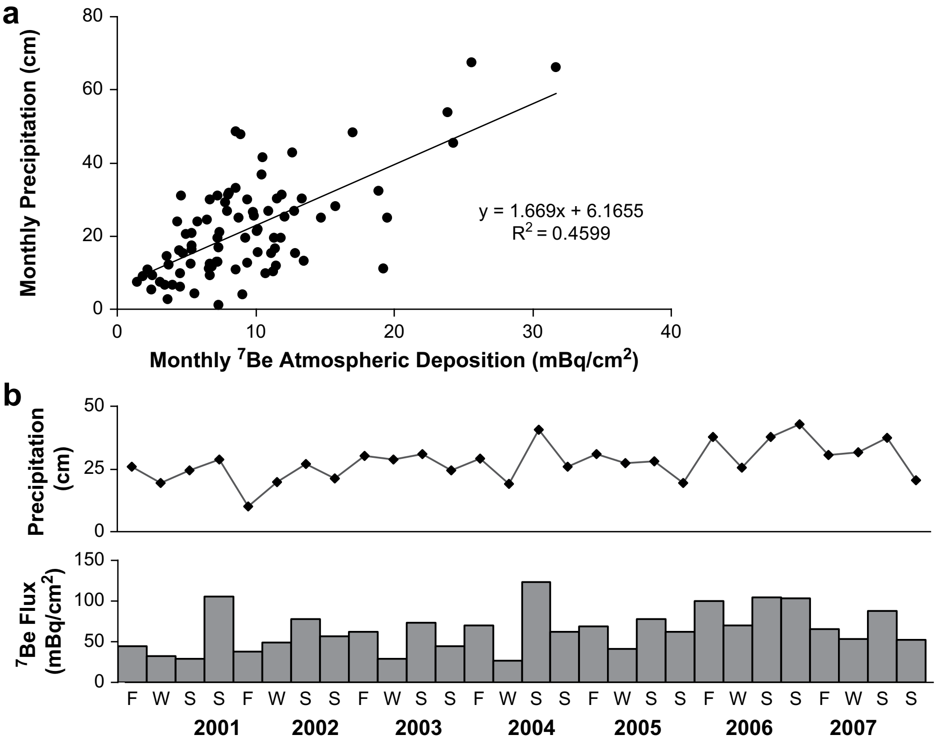

**Fig. 2.** (a) A scatter plot illustrating a linear correlation between the total monthly precipitation and the total monthly $^7$Be atmospheric deposition. (b) An illustration indicating the correlation between the precipitation (cm) and the corresponding atmospheric deposition fluxes of $^7$Be (mBq/cm$^2$) from September 2000 to August 2007 using 3-month integrals: F – Fall (September–November); W – Winter (December–February); S – Spring (March–May); and S – Summer (June–August). This graph starts with Fall 2000 (September through November).

with a particle-to-water distribution coefficient ($K_d$) ~$10^5$ l/kg (Olsen et al., 1986; You et al., 1989). In watersheds and freshwater aquatic systems, $^7$Be inventories have been used to quantify soil erosion rates, sediment source functions and sediment resuspension (Matisoff et al., 2005; Olsen et al., 1989). In estuarine environments, Olsen et al. (1993) have shown that the highest $^7$Be sediment inventories occur in areas that are experiencing rapid fine-particle accumulation in response to a sediment surface that is temporarily out of equilibrium with its current physical regime. These "non-equilibrium" areas of rapid sediment accumulation can occur naturally in estuarine turbidity zones and deltaic environments (Olsen et al., 1986; Zhu, 2003). They can also occur anthropogenically in dredged channels or around piers, slips, bridges, dams and other structures associated with urban/harbor development and environmental restoration activities (Smith, 2007).

As illustrated in Fig. 4 and Table 2, the depths of $^7$Be penetration in sediments and the corresponding $^7$Be sediment inventories are quite variable within the Neponset River estuary. This probably

**Table 2**
Beryllium-7 inventories (mBq/cm$^2$) for each 1-cm depth increment, its sediment penetration depth, and its total sediment inventory in each of the six cores collected in the Neponset River estuary on July 14, 2006.

| Depth (cm) | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 |
|---|---|---|---|---|---|---|
| | $^7$Be Inventory[a] (mBq/cm$^2$) | $^7$Be Inventory (mBq/cm$^2$) | $^7$Be Inventory (mBq/cm$^2$) | $^7$Be Inventory (mBq/cm$^2$) | $^7$Be Inventory (mBq/cm$^2$) | $^7$Be Inventory (mBq/cm$^2$) |
| 0–1 | 92 ± 4 | 32 ± 4 | 68 ± 4 | 84 ± 5 | 25 ± 4 | 60 ± 4 |
| 1–2 | 45 ± 6 | 13 ± 1 | 64 ± 4 | 134 ± 6 | 25 ± 3 | 33 ± 5 |
| 2–3 | 13 ± 4 | 3 ± 2 | 73 ± 6 | 94 ± 5 | 34 ± 6 | 22 ± 3 |
| 3–4 | 11 ± 4 | | 99 ± 6 | 44 ± 5 | 31 ± 6 | 16 ± 3 |
| 4–5 | | | 87 ± 6 | 8 ± 3 | 43 ± 8 | 10 ± 4 |
| 5–6 | | | 90 ± 9 | | 27 ± 7 | 24 ± 8 |
| 6–7 | | | 35 ± 6 | | 37 ± 6 | 4 ± 3 |
| 7–8 | | | 18 ± 5 | | 14 ± 8 | |
| 8–9 | | | 12 ± 8 | | | |
| Total[b] Inventory | 161 ± 18 | 48 ± 7 | 546 ± 54 | 364 ± 24 | 236 ± 48 | 169 ± 30 |
| Expected Inventory[c] | 101 ± 3 | 101 ± 3 | 101 ± 3 | 101 ± 3 | 101 ± 3 | 101 ± 3 |
| Difference[d] | +60 | −53 | +445 | +263 | +135 | +68 |

[a] The $^7$Be sediment inventory (mBq/cm$^2$) retained in each 1-cm depth increment.
[b] The total $^7$Be sediment inventory is the sum of the incremental $^7$Be inventories within each sediment core.
[c] The $^7$Be atmospheric depositional running inventory expected at the time of sediment core collection (July 2006, Table 1).
[d] The differences between $^7$Be sediment total inventory and expected atmospheric depositional running inventory are listed for each sediment core. Positive values (+) indicate sediment accumulation and negative values (−) indicate sediment erosion, resuspension and redeposition in areas undergoing accumulation.

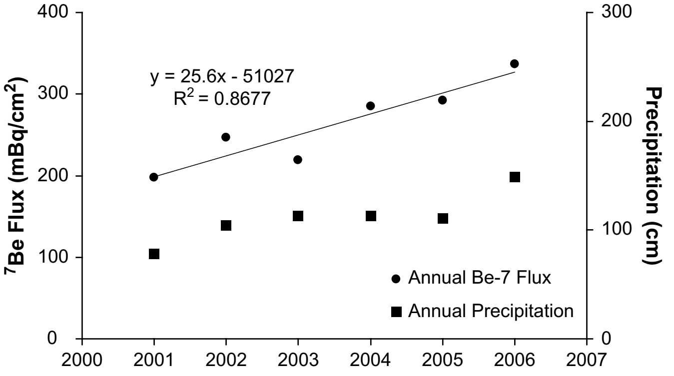

**Fig. 3.** A plot of annual $^{7}$Be atmospheric deposition fluxes and annual precipitation from 2001 to 2006. The increase in the annual fluxes of $^{7}$Be to the Earth's surface may reflect the increasing production rate of $^{7}$Be via cosmic-rays and the increasing amount of annual precipitation.

indicates a high degree of spatial heterogeneity in sediment accumulation rates and patterns, but may also reflect sediment mixing by organisms or sediment resuspension/erosion. Comparisons of the $^{7}$Be sediment inventories with the running inventory of $^{7}$Be atmospheric deposition (101 mBq/cm$^{2}$) at the time of core collection, indicate relatively rapid sediment accumulation at Sites 1, 3, 4, 5, and 6 between the Baker Dam and the estuary mouth (Fig. 1). The sub-surface peaks in $^{7}$Be sediment inventory at Sites 3, 4 and 5 may reflect $^{7}$Be deposition and sediment accumulation associated with specific rain-storm events. Recent studies have shown that sediment deposition and accumulation may be enhanced in areas upstream of bridges as river flow is hindered by bridge structures (Bruns et al., 2006; Wellman et al., 2000; Westerman, 2007). This is supported by the extremely large $^{7}$Be sediment inventory (546 mBq/cm$^{2}$) measured at Site 3 (Figs. 1 and 4). At Site 2, the depth of $^{7}$Be penetration was limited to the top 3 cm and its total sediment inventory (48 mBq/cm$^{2}$) was about half of what would be expected from the running inventory (101 mBq/cm$^{2}$) at the time of core collection. This probably indicates a slower rate of net sediment accumulation at this site, but may also reflect some sediment resuspension and erosion, followed by redeposition in adjacent estuarine areas.

The $^{7}$Be sediment inventories at Site 1 (161 mBq/cm$^{2}$) and Site 6 (169 mBq/cm$^{2}$) are similar. The depth of $^{7}$Be penetration (4 cm) at Site 1, however, is about half as much as the depth of $^{7}$Be penetration (7 cm) at Site 6. This may indicate that the rate of sediment accumulation at Site 1 is about half of that at Site 6. The vertical profile of $^{7}$Be in the sediments at Site 1 appears to reflect what would be expected from radioactive decay with continuous sediment deposition without mixing. The vertical profile of $^{7}$Be in the sediments at Site 6, however, exhibits a sub-surface peak at the 5–6 cm depth interval (Table 2 and Fig. 4). Although this sub-surface peak may reflect a redistribution of surface sediment to a deeper depth by organisms, it more likely represents the larger error associated with the $^{7}$Be counting statistics.

We plan to revisit these sampling sites and compare measured short-term changes in the $^{7}$Be sediment profiles and inventories during times of differing seasonal and hydrological conditions. We expect that this will allow us to quantify changes in sediment accumulation patterns in association with short-term natural processes and provide a baseline that can be used to assess changes

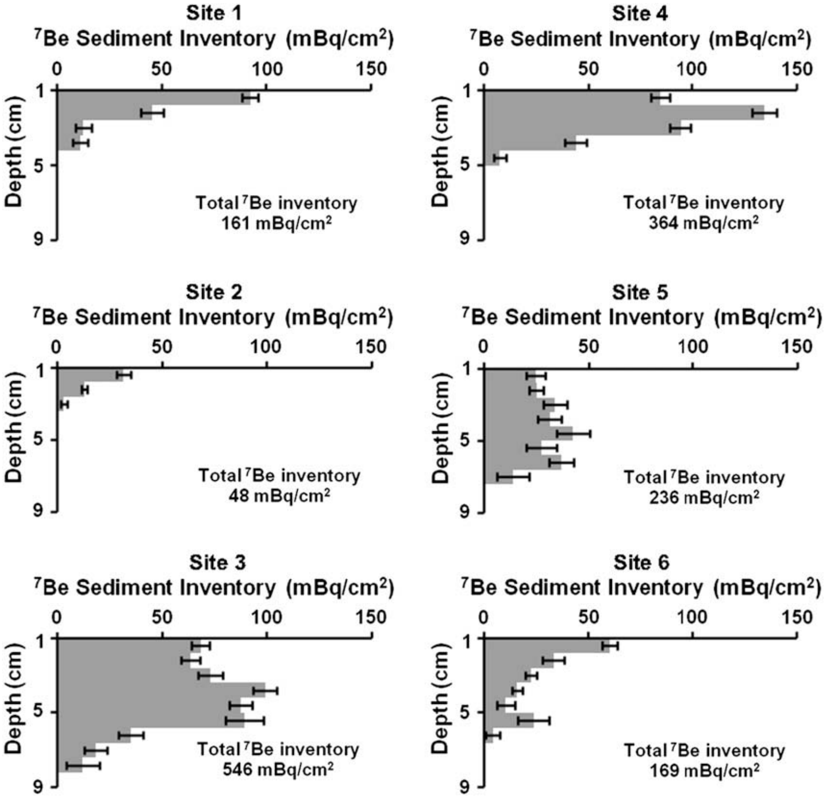

**Fig. 4.** Plots of the $^{7}$Be sediment inventory versus sediment depth for the six cores collected in the Neponset River estuary. A comparison of the measured $^{7}$Be sediment inventories in these cores with the running inventory of $^{7}$Be atmospheric deposition expected at the time of core collection (101 ± 3 mBq/cm$^{2}$) serves as a useful tool for examining particle dynamics and identifying areas of sediment accumulation, resuspension, or erosion in estuarine environments.

in sediment dynamics in response to future urban development or estuarine restoration activities.

## 6. Conclusions

Monthly $^7$Be atmospheric deposition fluxes to the Boston area measured over a 7-year time period exhibit seasonality in association with precipitation events and stratospheric–tropospheric exchange. There is also an overall increasing trend in the annual $^7$Be atmospheric deposition flux from September 2000 to August 2007. This increasing trend may reflect the decrease in solar activity since 2002, as well as the increase in total annual precipitation over the study period. Variations in the depths of $^7$Be penetration and $^7$Be inventories in sediment cores collected in the Neponset River estuary indicate a high degree of spatial heterogeneity in sediment accumulation patterns. These results suggest that $^7$Be can serve as a useful tool for quantifying short-term changes in sediment dynamics (associated with both natural and anthropogenic processes) and assessing the impacts of urban development and environmental restoration activities in estuarine systems.

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