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Identifying heavy metal levels in historical flood water deposits using sediment cores

Anna Lintern [a, 1], Paul J. Leahy [b], Henk Heijnis [c], Atun Zawadzki [c], Patricia Gadd [c], Geraldine Jacobsen [c], Ana Deletic [a, d], David T. Mccarthy [a, d, *]

[a] Department of Civil Engineering, Monash University, Clayton, 3800, Victoria, Australia
[b] EPA Victoria, Applied Sciences Group, Ernest Jones Drive, Macleod, Victoria, 3085, Australia
[c] Australian Nuclear Science and Technology Organisation, New Illawarra Road, Lucas Heights, New South Wales 2234, Australia
[d] Environmental and Public Health Microbiology Laboratory (EPHM Lab), Monash University, Clayton, 3800, Australia

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ABSTRACT

When designing mitigation and restoration strategies for aquatic systems affected by heavy metal contamination, we must first understand the sources of these pollutants. In this study, we introduce a methodology that identifies the heavy metal levels in floodplain lake sediments deposited by one source; fluvial floods. This is done by comparing sediment core heavy metal profiles (i.e., historical pollution trends) to physical and chemical properties of sediments in these cores (i.e., historical flooding trends). This methodology is applied to Willsmere and Bolin Billabongs, two urban floodplain lakes (billabongs) of the Yarra River (South-East Australia). Both billabongs are periodically inundated by flooding of the Yarra River and one billabong (Willsmere Billabong) is connected to an urban stormwater drainage network. 1–2-m long sediment cores (containing sediment deposits up to 500 years old) were taken from the billabongs and analysed for heavy metal concentrations (arsenic, chromium, copper, lead, nickel, zinc). In cores from both billabongs, arsenic concentrations are high in the flood-borne sediments. In Bolin Billabong, absolute metal levels are similar in flood and non-flood deposits. In Willsmere Billabong, absolute copper, lead and zinc levels were generally lower in fluvial flood-borne sediments in the core compared to non-fluvial sediments. This suggests that heavy metal concentrations in Bolin Billabong sediments are relatively similar regardless of whether or not fluvial flooding is occurring. However for Willsmere Billabong, heavy metal concentrations are high when overland runoff, direct urban stormwater discharges or atmospheric deposition is occurring. As such, reducing the heavy metal concentrations in these transport pathways will be of great importance when trying to reduce heavy metal concentrations in Willsmere Billabong sediments. This study presents a proof-of-concept that can be applied to other polluted aquatic systems, to understand the importance of river floods in the contamination of the bed sediments of aquatic systems. As a cost effective and less time consuming alternative to extensive field monitoring, our proposed method can be used to identify the key sources of pollution and therefore support the development of effective management strategies.

1. Introduction

Heavy metal contamination of aquatic environments is a growing problem (Kivaisi, 2001). Due to the threat to human health and species biodiversity, there is a critical need for strategies that can prevent and remediate heavy metal pollution in these aquatic environments. Development of successful strategies requires the accurate identification of pollutant sources (ANZECC/ARMCANZ, 2000). For example, in the case of floodplain lakes, it is important to identify whether pollutants are entering these lakes through the local catchment (i.e., by local surface runoff or atmospheric deposition) or via overbank flooding of the main river channel.

Understanding long-term pollution trends is invaluable for

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[*] Corresponding author. Environmental and Public Health Microbiology Laboratory (EPHM Lab), Monash University, Clayton, 3800, Australia.

E-mail addresses: a.lintern@unimelb.edu.au (A. Lintern), David.McCarthy@monash.edu (D.T. Mccarthy).

[1] Now at: Department of Infrastructure Engineering, University of Melbourne, Parkville 3010, Victoria, Australia.

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identifying pollution sources and for developing successful mitigation strategies (Saunders and Taffs, 2009). A time series of metal deposition in aquatic environments that spans 50–100 years can be used to identify when water and sediment quality changes occurred, and thereby infer the main causes of these fluctuations. Despite the importance of understanding long-term heavy metal contamination trends, water quality data spanning many decades is not available for most aquatic systems (Alexander et al., 1998). Ongoing field monitoring could be used to build these datasets but this is a costly and time consuming undertaking.

This paucity in data could be overcome by using sediment cores from the beds of aquatic environments. Indeed, previous works have reconstructed historical pollution records using dated sediment cores (Christensen and Arora, 2007; Lo and Fung, 1992; Okumura et al., 2004). In addition, such palaeolimnological methods enable the identification of baseline heavy metal levels in aquatic systems (Wiklund et al., 2014). By identifying both the historical pollution and the historical hydrologic trends using sediment cores, we can better understand the transport pathways of pollutants. For example, by identifying the contaminant levels in discrete fluvial flood deposits in a floodplain lake sediment core, we can better understand how fluvial floods contribute to the contamination of the aquatic system. This understanding will enable us to focus our mitigation efforts. It will also allow us to identify the quality of flood-deposited sediments and thereby prepare appropriate risk management strategies.

To our knowledge, only a handful of studies (Bábek et al., 2011; Chen et al., 2015; Daessle et al., 2009; Ferrand et al., 2012; MacDonald et al., 2016; Nguyen et al., 2009; Thevenon et al., 2013; Wiklund et al., 2014) have identified the pollutant levels in historical flood deposits in floodplains. Chen et al. (2015), Ferrand et al. (2012) and Thevenon et al. (2013) investigate the overall relationship between hydrologic change and pollution levels, rather than identifying pollution levels in discrete flood deposits. Bábek et al. (2011), Nguyen et al. (2009) and Daessle et al. (2009) identified discrete flood deposits in floodplain lake sediments and identified the pollutant levels in these deposits. However, their findings are somewhat uncertain as the occurrence of these flood layers in the cores were not validated using observed flow data. As such, there is a need to refine this methodology to demonstrate that it can be used to identify the heavy metal levels in historical flood deposits.

In a previous work (Lintern et al., 2016b), we developed and validated a methodology for reconstructing historical hydrologic trends of rivers using sediment cores from floodplain lakes. Historical hydrologic trends, and in particular, flood-deposited sediments in sediment cores were identified using several indicators including: the presence of visually identifiable laminations, the presence and amount of magnetic minerals and organic matter, sediments with large particle size, and the elemental composition through the sediment cores. Two urban floodplain lakes (billabongs), Willsmere and Bolin Billabong, in the Yarra River catchment in South-East Australia were used as case studies, and the historical hydrological trends and historical flood records reconstructed for these two billabongs were validated using measured flow data (from 1891 to 2013) and anecdotal records of flood events.

The main aim of this current study is to identify the concentration of heavy metals within fluvial flood deposits in the sediment cores from Willsmere and Bolin Billabongs, previously identified in Lintern et al. (2016b). Willsmere and Bolin Billabongs are located in the metropolitan region of Melbourne, and as such may be experiencing elevated levels of urban heavy metal pollutants such as copper, lead and zinc. The analysis presented here builds on our previous investigations of historical heavy metal deposition in these two billabongs (Lintern et al., 2016a, 2015). This study will (i) provide an insight into the heavy metal concentrations within overbank flood-borne sediment deposits, and (ii) further our understanding about the relative importance of fluvial flooding on the heavy metal contamination of the bed sediments of these two billabongs. In this study, we use sediment concentrations as a measure of pollution or contamination extent in the sediments, which is in line with the current sediment quality guidelines used in Australia (ANZECC/ARMCANZ, 2000). We envisage that the methodology used in this study could be applied to other aquatic environments when designing site-specific water quality management programs.

2. Materials and methods

2.1. Study site and its hydrology

The Yarra River catchment (Victoria, Australia) is approximately 4000 km^2 in area and contains both urban and non-urban (agricultural and forested) areas (Fig. 1). Two billabongs of this river, Bolin Billabong and Willsmere Billabong, are the focus of this study. Both are relatively small systems, with bank-full areas of 3.4 ha for Bolin Billabong, and 1.9 ha for Willsmere Billabong (Leahy, 2007). They receive water from their local catchments (15 ha for both billabongs) by overland runoff and from the greater Yarra River catchment through overbank flows of the Yarra River (Leahy, 2007). Minor flood levels at Bolin Billabong and Willsmere Billabong are approximately 6 m and 3 m Australian Height Datum (AHD) (Vic SES, 2013; 2012). Willsmere Billabong also receives urban stormwater from a nearby residential area (1.8 ha) through a drain that was installed in the 1940s (David Barclay, City of Boroondara, personal communication, 2nd April 2013). A stormwater treatment wetland was built in 2006, approximately 500 m^2 in surface area, between the residential catchment and Willsmere Billabong, which treats this urban stormwater (Fig. 1). Bolin Billabong is not directly connected to the urban drainage network.

Hydrological data are available for the Yarra River since 1891, with the longest operational stream gauge (the Warrandyte stream gauge) located approximately 15 km upstream of Bolin Billabong (Fig. 1). Average daily flow and river level data have been collected at the Warrandyte stream gauge from 1891 to 1933, 1959 to 1969 and 1974 to 2001. In addition, average daily flow and average daily river level data are available at stream gauges adjacent to Willsmere Billabong (Chandler Highway stream gauge) and Bolin Billabong (Banksia St stream gauge) between 1975 and 2012. Over 80% of the daily measurements are classified as being of reliable quality. Previously in Lintern et al. (2016b), power functions (Grayson et al., 1996) that relate the flows at the Warrandyte stream gauge to the flows at the Chandler Highway and Banksia St stream gauges were used to model the average daily flows prior to 1975 at the Chandler Highway and Banksia St stream gauges. Non-systematic records of flood events (e.g., from historical newspapers) are also available for the Yarra River in the 19th and 20th centuries. A summary of the recorded major Yarra River floods since 1835 was obtained from Lacey (2004).

Both the measured average daily flow rates and river level data at the three stream gauges along the Yarra River, and the records of major flooding events from Lacey (2004) indicate that the flooding frequency of the Yarra River had decreased through the 20th century. The largest flood recorded occurred in 1863 and 1934 (100 year Average Recurrence Interval floods with peak flows of over 1000 m^3/s). Although these billabongs historically received water once a year from the Yarra River on average, since the mid-20th century, inundation frequencies have reduced to once every 3–4 years (Sinclair Knight Merz, 2005).