

Pollutant advective spreading in beach sand exposed to high-energy tides



Okuroghoboye D. Itugha^a, Daoyi Chen^{b,*}, Yakun Guo^c

^a Faculty of Engineering and Technology, Civil & Environmental Engineering Department, Federal University Otuoke, 400 University Boulevard, Otuoke, PMB 126, Bayelsa State, Nigeria

^b Ocean Science and Technology Division, Graduate School at Shenzhen, Tsinghua University, Shenzhen, 518055, PR China

^c School of Engineering, University of Bradford, BD7 1DP, UK

ARTICLE INFO

Article history:

Received 26 October 2015

Received in revised form

2 July 2016

Accepted 11 August 2016

Available online 13 August 2016

Keywords:

Coastal foreshore

Dye migration

River Mersey Estuary (RME)

Interstitial hydraulics

Groundwater table

ABSTRACT

This paper presents field measurements in which dye solute was injected into coastal sand to investigate contaminant advection in intertidal beach sand. The measurements show the pathways of a contaminated plume in the unsaturated zone during both the flood and ebb tides. A prescribed amount of dye tracer solution was directly injected through the topsoil, with average porosity 0.3521 ± 0.01 , at pre-determined locations of the River Mersey's outer estuarial beach during ebb-tide. The injected dye was monitored, sampled and photographed over several tidal cycles. The distinctive features of the plume (full two dimensional cross-sections), sediments and water-table depth were sampled in-situ, close to the injection point (differing from previous contaminant monitoring tests in aquifers). The advective movement is attributed to tidal impact which is different from contaminant transport in aquifers. The experimental results show that plumes have significantly large spatial variability, diverging upwards and converging downwards, with a conical geometric shape which is different from the usual spherical/elliptical shape reported in literature. The mean vertical motion of the plume reaches three times the top-width within ten tidal cycles, exceeding the narrow bottom-width by a factor of order 2. The observed transport features of the plume within the beach sand have significant relevance to saltwater intrusion, surface water and groundwater quality. The field observations are unique and can serve as a valuable benchmark database for relevant numerical studies.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

Most contaminated beach sediments near industrial cities in Europe show relatively high concentrations of heavy metals and persistent organic pollutants (POPs) even though many years have passed since they were firstly polluted. This seems to be the case with estuaries whose watercourses pass through urban and highly industrialized areas, even after the surface water has been treated. This poses threats to the ecosystem and biodiversity due to releases associated to toxic sewage, and to remediation efforts often neglecting the river bed.

In the United Kingdom a number of estuaries, such as the Thames, the Mersey, and the Humber, have had well documented

accumulation of untreated domestic and industrial sewage. One special case is the River Mersey Estuary (RME, in north-west England), which is connected to Liverpool Bay at the Outer Estuary (see Fig. 1). It directly exchanges tidal input and output with the Irish Sea through Liverpool Bay, where the sands vary from medium to fine. The catchment area of the RME is densely populated and highly industrialized, and the RME is described as one of the most polluted water ways in Europe with flow rates promoting high turbidities (Turner et al., 1996; King et al., 2004; Jones, 2006). It has been reported that a large concentration of contaminants still persists in extensive RME and Liverpool Bay intertidal beach sediments. For example, concentrations of Mercury (Hg), caused by use of Castner-Kellner processes, remain as high as 2 mg/kg at discharge outlets linked to chemical plants in the Widnes–Runcorn areas of RME (Fox et al., 1999; Vane et al., 2007). [Mercury is associated with organic matter and is toxic to marine invertebrates with potential effects on humans through ingestion of fish and shellfish]. However, the toxicity levels in the sediments tend to decrease in

* Corresponding author.

E-mail addresses: itughaod@fuotuoake.edu.ng (O.D. Itugha), chen.daoyi@sz.tsinghua.edu.cn (D. Chen), y.guo16@bradford.ac.uk (Y. Guo).

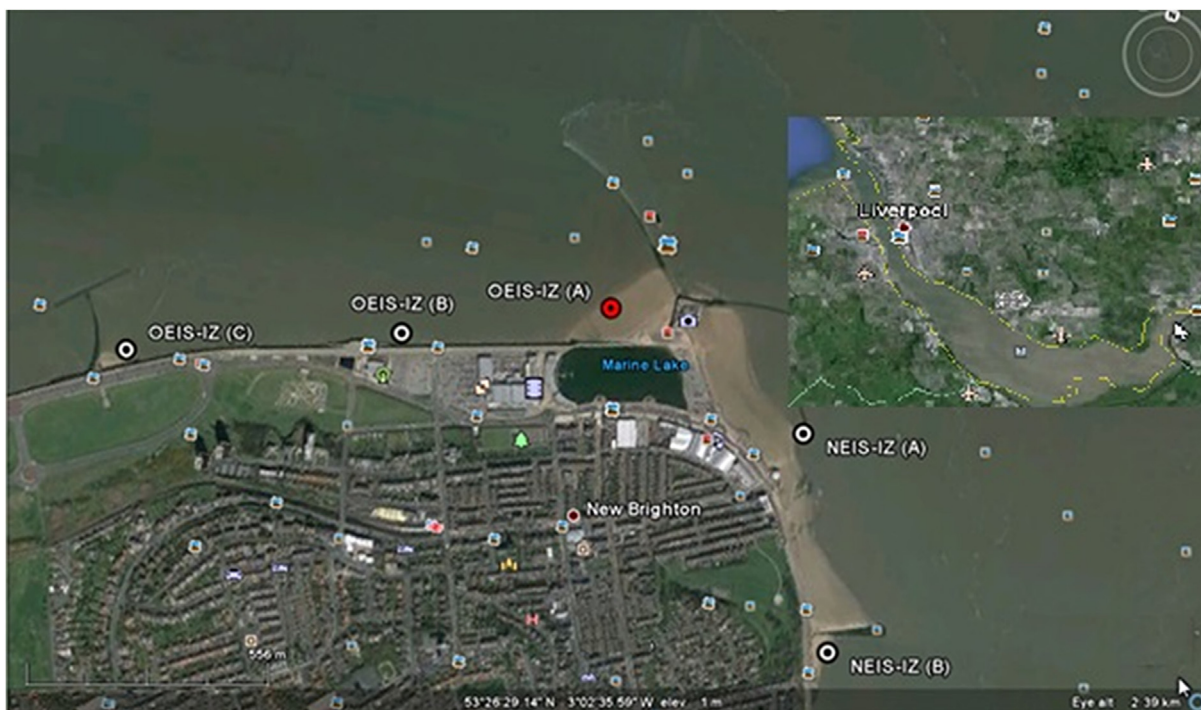


Fig. 1. Area map with markers showing the injection zones and Marine Lake at the sheltered boundary of the outer RME with overview map (at the right shows the RME).

the Liverpool Bay regions away from the discharge outlets (Rogers, 2002). Burt et al. (1992) reported the upper and lowest mean levels of Hg in the sediments as 1.2 and 0.01 mg/kg (in 40% silt), respectively. POPs, polyaromatic hydrocarbon (PAHs) and polychlorinated bipheniles (PCBs), in the sediments of RME, its tributaries and Manchester Ship Canal, may have originated from oil refineries, sewage, paper and chemical works, dockyards, power stations and shipping activities (Jones, 2006). King et al. (2004) found that PAH levels in the sediments were much more concentrated at depths of 0.5–0.53 m. PCB concentration in the RME is believed to be higher than that in the Thames and the Humber estuaries. Recent observations by Vane et al., 2007 show no declining trends of PCBs but implied that the Outer Estuary areas are 30 times less contaminated than the Inner Estuary. To our best knowledge, no clear relationship between contaminant movement and tidally mediated fluxes in beach sediments has been reported so far. However, Rogers et al. (1992) suggested that the presence of these substances deep in the RME sediments may have been due to tidally induced diffusive mixing. Organic matter content between sandy (low organic content) and marsh sediments can also strongly affect PAH concentration distribution (King et al., 2004). Huang et al. (2002) identified that hydrophobic organic contaminants (HOCs) can readily mix in benthic organic sediment (BOS) environments. They identified the importance of understanding and quantifying varied HOC properties for the prediction of transport and eventual fate in aquatic environments.

The vadose zone (intermediary between seawater and groundwater) of the RME intertidal beach is affected by very complex hydrological processes from high-energy semidiurnal tides. The beach water table rises and falls with the sea level. So water-borne sewage or sewage discharged from urban, coastal recreational and industrial activities can enter and be retained or redistributed (Diaw et al., 2001). Martino et al. (2002) suggested that trace-metals accumulated in beach sediments could be released by kinetic (advective) re-suspension processes and desorbed to the overlying watercourse. Accurate field studies/measurements are

limited due to the complex hydrological environment as the parameters controlling convective activity in-situ become more difficult to quantify (Wexler, 1992; Zhang et al., 2002; Precht and Huettel, 2004). As a result, there is presently poor understanding of the movement and spreading of anthropogenic substances (such as land-applied chemicals), spills and leaks that eventually enter beach sediments and consequently the freshwater domain (Mao et al., 2006). This may partly explain that considerably more research is conducted on contaminant transport in coastal groundwater (GW) aquifers than on transport in beach sediments (Lanyon et al., 1982; Diaw et al., 2001; Mao et al., 2006; Denham and Vangelas, 2008). More studies on groundwater behavior in sandy beaches, with relationships between tide and water-table, can be found in Baird and Horn (1996); Turner and Nielsen (1997); Kalbus et al. (2006); and Berkowitz et al. (2008).

Pressure fluctuations can have a significant impact on interstitial oxygenation processes, thus on fates of contaminants and in some cases on aquatic life (McLachlan, 1989; Precht and Huettel, 2004). Water movement is routed via complex pores and varies with depth and degree of compaction. The properties of the sand (porosity ϕ , grain size and grading) and the dye (density ρ , and dynamic viscosity μ) are therefore important to determine the role of hydraulic conductivity (Fetter, 1999). This is because the local unsaturated hydraulic conductivity depends on the degree of soil-water content and/or pressure head (Mohanty et al., 1994; Gupta et al., 1993). Typical porosity for medium to fine sand ranges from 26% to 53% (Domenico and Schwartz, 1997). Barnes (1995) estimated the hydraulic conductivity values of sand and sand-gravel mixtures to vary significantly from 0.036m/hr to 36m/hr respectively. Fox et al. (1999) showed that the sediment cores of the RME (e.g., Widnes – Runcorn areas) are made up of 2–5% sand with size distribution of 63–2000 μm , 70–75% silt (2–63 μm), and 25–27% clay (<2 μm).

The use of conservative tracers to simulate contaminant movement in the field is a known robust technique. However, Robbins (1989), Callaghan and Codd (1998) and Precht and Huettel

Download English Version:

<https://daneshyari.com/en/article/4539127>

Download Persian Version:

<https://daneshyari.com/article/4539127>

[Daneshyari.com](https://daneshyari.com)