Understanding the impact of water management on people for investment in sustainable infrastructure in the UK

- 1 Adam James Cambridge** BSc, MSc, MCIWEM, C.WEM, CSci, CEnv
Principal Consultant, Atkins, Oxford, UK
(corresponding author: adam.cambridge@atkinsglobal.com)
- 2 Andy Gill** BSc, MSc, MCIWEM, C.WEM, CSci, CEnv
Principal Consultant, Atkins, Oxford, UK
- 3 Monica Barker** MEarthSc, MSc, MCIWEM, C.WEM, CEnv
Environmental Scientist, Atkins, Epsom, UK

- 4 Max Tant** BSc, MSc
Flood Risk Manager, Kent County Council, Maidstone, UK
- 5 Carolann Simmonds** MSc, MCIWEM, C.WEM, CEnv
Principal Economist, Atkins, Epsom, UK
- 6 Nathan Watt** BA
Intelligent Mobility Consultant, Atkins, London, UK

This study explored whether digital footprinting through the use of mobile data could be used to improve the understanding of water and environmental events on people, to enhance the evidence base for investment in sustainable infrastructure. The study focused on Margate, UK, where an integrated stakeholder surface water management plan was being developed to support the town's regeneration and urban growth aspirations. The objectives were to assess (a) the usefulness of mobile data in infrastructure studies and (b) the impacts of a recent water pollution and beach closure event on visitor footfall to and from Margate. It was found that digital footprinting techniques provided substantial new insight into human dynamics (spatially, temporally, and demographically) with visitor footfall to and from Margate strongly driven by weather, predominately from the local area and over 65 years of age, but with 16% of visitors from London. With further work (longer time periods, further population data, and statistical analysis) digital footprinting techniques could give Margate's regeneration strategy an area to focus on in diversifying its economy and reliance on tourism, as well as moreover, a basis for future infrastructure appraisal and evaluation in the UK (potentially in real time). The development of the latter will pose many of the real privacy challenges that previous study has highlighted and is likely to be pursued due to the current financial climate needing to deliver better services for lower cost.

1. Introduction

Funding for flood and coastal erosion risk management projects in England has generally been in decline since the 2010 spending review (Ciwem, 2015), which was born out of the global financial crisis that happened in 2007–2008 and a subsequent change of government in the UK (HM Treasury, 2010). This backdrop of pressurised economic conditions has led to reforms in the water and environment sector, such as the Water Services Regulation Authority (Ofwat) introducing 'outcome-based regulation' rather than 'output-based regulation' with the aim of delivering savings (Ofwat, 2013), which in turn has been supported by legislation that places a greater emphasis on collaborative delivery to achieve this (Defra, 2012). Reforms in water and environmental management have extended into research and development activities, given that this underpins delivery, with the intent of developing unified methods and approaches that provide benefits to all as part of potential future delivery (EA, 2014) because of the scale and depth of the global financial crisis.

One area of water and environmental management that has been researched and developed alongside the relatively recent political and economic changes has been the preference to use sustainable urban drainage systems (Suds), a type of green infrastructure (GI), in the UK. Suds aim to mimic natural hydrological processes to reduce hydraulic loadings on drainage systems, so that flood risk management is enhanced while concurrently providing a wide range of additional societal benefits, such as improvements to biodiversity, reduction in urban heat effect, better water quality and elevated mental and physical health for citizens (Ciria, 2015). However, even though the benefits of Suds, and more generally GI, are widely acknowledged as effective urban solutions by both the academia and industry (Ciria, 2015), the valuation procedures currently used for infrastructure projects do not easily support their implementation (Ciwem, 2015). In practice, this is typically due to (Ciria, 2013)

- the lack of data that support the more intangible benefits that GI provides

- the volume of data required to support the range of benefits that GI provides
- deficiencies in current appraisal techniques (e.g. siloed evaluation).

There is, however, a strong drive to overcome the current issues in justifying the implementation of GI because these approaches are central in making places more liveable for citizens (Ciria, 2015), which is a priority of the government as evidenced in supporting the Liveable Cities Research programme (Liveable Cities, 2014) by way of the Engineering and Physical Sciences Research Council. To do this effectively, the water and environmental engineering sector needs to develop alternative techniques for evaluation and put citizens at the centre of the decision-making process (Ciria, 2013). Studies such as the pioneering triple-bottom line assessment undertaken for Philadelphia (Stratus Consulting, 2009) have demonstrated that alternative evaluation techniques can be used to determine the multiple benefits of a citywide GI approach, and this study focuses on the latter in putting citizens at the centre of decision-making.

Digital footprinting to put citizens at the heart of decision-making through improved understanding of human dynamics has been a rapidly developing area of academia and practice as society has continually adopted digital technologies, such as mobile phones. Digital footprinting in this context refers to electronic trails that can be used to understand human dynamics that can be both passive (interactions with an infrastructure) and active (from users themselves) (Girardin *et al.*, 2008). Previous studies have found that these techniques can be a powerful tool for urban planning, design and management (Ratti *et al.*, 2006) in demonstrating that

- the techniques can be used with some confidence due to human trajectories showing a high degree of spatial and temporal regularity (Gonzalez *et al.*, 2008)
- multiple data sets are required to gain a good and reliable understanding of human dynamics, but this is possible (Girardin *et al.*, 2008)
- the techniques can provide a framework for developing on-demand effective citizen services, potentially in real time (Ahas *et al.*, 2007).

Despite a previous study highlighting that the mentioned advantages are in direct conflict with important privacy concerns (Girardin *et al.*, 2009), which should be referred to for a fuller understanding, the opportunity for a given service provider to deliver savings in the ongoing pressurised global economic landscape is such that digital footprinting will more than likely be adopted. The previous study indicated that potential savings may revolve around digital footprinting superseding manual and/or personal surveys of tourists, as well as through the planning, design and management of events due to an improved understanding of human behaviours and thus effectiveness of delivery (Girardin *et al.*, 2009).

This study takes the above forward by exploring whether mobile data can be used to improve the preparation of sustainable

infrastructure investment cases by fusing data sets to put citizens, and citizen dynamics, at the centre of decision-making for infrastructure investment. Mobile data in the context of this study are passive, anonymised and aggregated mobile phone data that provide information on the demographics, origin, destination and type of a user (visitor or resident) for a given location.

This study explored through data fusion how weather affected human dynamics and if digital footprinting could be used as an evidence base to justify the implementation of Suds, and GI more generally, on the basis that these urban water management solutions will reduce the impact of weather (e.g. flood risk, water quality) on human dynamics. The study explored whether a link between weather, a recent water pollution and beach closure event, and human dynamics could be found because this could provide the basis of having Suds, which would reduce the hydraulic loadings on the drainage system in place. The study was undertaken in the coastal town of Margate, Kent, where an ongoing surface water management plan (SWMP) was being prepared and Suds were the preferred intervention.

The objectives of the study were to assess and explore

- the usefulness of mobile data in infrastructure studies, in terms of format, flexibility, accuracy and spatial resolution
- the impacts of a recent water pollution and beach closure event on visitor footfall to and from Margate during a recent pollution event.

2. The case study

2.1 The study area

Margate is located in Kent, UK, and has 17 listed beaches in the vicinity (The Beach Guide, 2017), of which approximately eight have been closed over the last 30 years due to poor water quality incidents (refer to Figure 1, which shows these eight beaches, in addition to Joss Bay). Margate is characterised by deprivation and a demographic that is transient (Thanet District Council, 2006). Other attractions in the town that bring visitors to Margate in addition to the beaches include the Turner Contemporary gallery, Dreamland pleasure park, the Shell Grotto, theatres, golf courses, museums and music festivals, among others (Visit Thanet, 2017).

Margate is targeting an ambitious regeneration strategy to abate the town's steady decline in tourism that many of the UK's seaside towns have experienced over the past 50 years (BBC, 2015). Hence, while there are a number of reasons a given person might visit Margate that may or may not include visiting the beaches, wet and cold weather could clearly discourage potential visitors, as well as local residents, and thus the effect on human dynamics that appropriate infrastructure could mitigate.

Margate is served by a predominately combined drainage system in which storm and foul flows are combined in one sewer, whereas modern drainage systems are typically designed to have

Figure 1. Map of the study area of Margate

one sewer for storm flows and one sewer for foul flows. When storm events exceed the capacity of the combined sewers, open channels that the sewers typically discharge into, and/or the capacity of the soil that contributes to the combined systems, flooding or water pollution due to combined sewer overflows (CSOs) can result.

2.2 Margate SWMP

The Margate SWMP is a multistakeholder project (Kent County Council, Southern Water, Thanet District Council and Environment Agency (EA)) being undertaken to manage surface water more effectively in the town. The preference of all stakeholders of the SWMP is to deliver GI in the form of Suds, which will redirect the amount of storm flows in the combined sewerage system to groundwater recharge or be used as a water resource (landscape watering and potentially water supply). It is anticipated that this will reduce the frequency of CSO spilling that can lead to coastal pollution, detrimental impacts on biodiversity and closure of the beaches, which are thought to impact the local economy negatively due to the town's historical dependency on tourism (BBC, 2015).

Faced with the challenges of climate change and an ambitious regeneration strategy involving new development, both of which contribute further foul loads to the existing sewerage system,

there is a risk that Margate's combined drainage system could become overwhelmed with additional flows. Margate therefore requires an SWMP to ensure that future drainage provision for the town is managed in a sustainable manner while allowing Margate to prosper through regeneration.

A full explanation of the project completed to date is beyond the scope of this paper, but the work has included integrated catchment flood and urban drainage modelling, engineering option development, multistakeholder engagement and economic appraisal.

The economic appraisal undertaken for the project has considered a broad range of impacts due to the financial pressures facing the water and environment sector, as previously discussed, which included flood damages, beach amenity, water quality, business disruption, traffic disruption and bathing waters. This, however, concluded that the engineering options prepared would deliver benefit-cost ratios (B_{CR}) ranging from the order of -0.1 to 1.4 to 3.2 , with the EA partnership funding calculator (EA, 2015a) indicating that the option with the highest B_{CR} value (3.2) still required 50% of the funding to come from a source other than the Flood Defence Grant in Aid fund to be financially viable. This demonstrates the importance of working together with a wide range of beneficiaries to capture the full value of a given scheme, the need to tailor current appraisal techniques carefully to suit

potential funding providers; moreover, this underlines the pressures that the water and environment sector currently faces in regard to available funding.

One potential source of funding is from Southern Water, who have agreed to outcome delivery incentives with Ofwat to increase the number of beaches with a rating of ‘excellent’ (Ofwat, 2014) as defined under the EU bathing water directive (EC, 2006). If undertaken in a coordinated and effective manner, this will reduce the potential for beach closures and thus increase the overall desirability of Margate as a place to live and to visit. This, however, requires citizens to be put at the centre of decision-making because clearly all water management authorities and companies are serving the same people; it is just that the appraisal processes are being undertaken independently.

2.3 Data collection

Some of the data sets that were used to undertake the Margate SWMP were used in combination with the mobile data obtained from the Atkins collaboration with EE. This included

- Hyrad rainfall data (KCC, 2015)
- Met Office weather data (rainfall, wind speed, air temperature, sunshine hours) (Met Office, 2015)
- Southend airport Metar temperature data (Gladstone, 2015)
- Thanet water quality monitoring data (Thanet District Council, 2015b).

The mobile data were obtained from EE as part of Atkins’s collaboration with the telecommunications company, with all data processing, analysis and provision undertaken in accordance with EE’s privacy policies and regulations. Visitors to Margate were

identified through the aggregated mobile data, with their origin, or ‘home location’, identified through a registered postcode (device registration at the district level). This can be inferred using a home location based on dwell time (the majority of time a device spends in a location) given that a registered postcode does not always correspond to a person’s home address, which is often the preference, but was not undertaken for the project.

It was assumed as part of the study that visitors to Margate were those with devices registered to postcodes outside of the study area (the postcodes excluded are shown in Figure 2 in white) with all dwell time in the area of interest of less than 30 min excluded to account for people passing through the area.

2.4 Beach closure event in Margate on 25 August 2015

There have been several beach closures in Margate due to poor water quality, which are likely to have affected visitor footfall and the town’s desirability to tourists. The Thanet District Council has confirmed the following recent beach pollution incidents and resulting beach closures (indicated by signed deployment records)

- 5–12 June 2012
- 14–15 April 2014
- 22–24 May 2014
- 29–30 July 2014
- 16–17 October 2014
- 25 August 2015.

The most recent beach closure was of St Mildred’s Bay in Westgate (see Figure 1) on 25 August, with signs being deployed at 9.30 a.m. The cause of poor water quality was an unscreened discharge by way of a local combined sewerage outfall, likely due

Figure 2. Number of visitors to Margate by home postcode over August 2015, based on mobile data. 1 mile = 1.61 km

to heavy rainfall on 24 August (refer to Figure 3) (Moore, 2015; Thanet District Council, 2015a). St Mildred's Bay was reopened at 4 p.m. on 25 August (Thanet District Council, 2015a), and it is likely that this heavy-rainfall event caused the poor weekly water quality readings for beaches around Margate (Walpole Bay, Fulsam Rock, Joss Bay and Broadstairs) on 27 August (see Table 1) (Thanet District Council, 2015b). Note that St Mildred's Bay itself did not record a poor water quality reading, but this could be due to deficiencies with the frequency, or techniques, of water quality sampling.

Hyrad spatially varied rainfall data that were obtained as part of the Margate SWMP are provided in Figure 3. This presents the rainfall for the period either side of the August 2015 beach closure (24 and from 26 August). As can be seen, the storm event occurring on 24 August is likely to have been responsible for the poor water quality around Margate and the closure of the St Mildred's Bay.

Figure 4 shows daily minimum temperature, sunshine hours, rainfall and wind speed in August 2015 in Margate, along with long-term (1934–2014) daily average sunshine hours and rainfall. This shows that the period from 1 to 10 August was relatively typical of the long-term average and that the rainfall between 24 and 27 August was a relatively intense weather event.

2.5 Methodology

To identify a baseline footfall level in the Margate area and to assess the potential change in footfall due to the beach closure on

25 August, the mobile data were scaled to a population equivalent and used to define

- daily visitor numbers over 6 months (May–October 2015) for the Margate area, shown in Figure 5
- visitor data over August 2015 showing visitor origins and demographics (see Figures 6 and 7).

It would have been desirable to analyse footfall over multiple periods and locations to incorporate the events that occurred in 2012–2014, but this was beyond the scope of the study. The aim of the study was to assess whether a given method could be employed to identify impacts on visitor footfall on the 25 August closure by identifying similar periods of time where a beach closure did not occur, so that footfall dynamics could be compared and further developed if insightful. The following periods were assessed

- 18 August, Tuesday – a surrogate day with relatively similar weather conditions (see Figure 4)
- weekdays (Monday–Thursday) over August
- weekdays during school holidays (25 July–2 September inclusive).

Based on Met Office weather data acquired for the study, 18 and 25 August, Tuesdays, were both relatively cool, rainy summer days, with minimum air temperatures of up to 14 and 13°C and around 7 and 6 mm of rainfall, respectively (see Figure 4). The 18th of August, Tuesday, had 0 h of sunshine, whereas 25 August, Tuesday, had 4 h. Weather conditions on these two days are

Figure 3. Storm events from 1 June 2015 to 29 August 2015. Source: (KCC 2015)

Table 1. Thanet weekly water quality. Source: Thanet District Council (2015b)

Botany Bay, Broadstairs	<div><div></div><div></div></div>	6 Jun	<div><div></div><div></div></div>	14 Jun	<div><div></div><div></div></div>	19 Jun	<div><div></div><div></div></div>	29 Jun	<div><div></div><div></div></div>	6 Jul	<div><div></div><div></div></div>	13 Jul	<div><div></div><div></div></div>	20 Jul	<div><div></div><div></div></div>	29 Jul	<div><div></div><div></div></div>	5 Aug	<div><div></div><div></div></div>	11 Aug	<div><div></div><div></div></div>	18 Aug	<div><div></div><div></div></div>	27 Aug	<div><div></div><div></div></div>	2 Sep	<div><div></div><div></div></div>	9 Sep	<div><div></div><div></div></div>	14 Sep	<div><div></div><div></div></div>	18 Sep
Broadstairs, Stone Bay	<div><div></div><div></div></div>	5 Jun	<div><div></div><div></div></div>	14 Jun	<div><div></div><div></div></div>	19 Jun	<div><div></div><div></div></div>	29 Jun	<div><div></div><div></div></div>	6 Jul	<div><div></div><div></div></div>	13 Jul	<div><div></div><div></div></div>	20 Jul	<div><div></div><div></div></div>	29 Jul	<div><div></div><div></div></div>	5 Aug	<div><div></div><div></div></div>	11 Aug	<div><div></div><div></div></div>	18 Aug	<div><div></div><div></div></div>	27 Aug	<div><div></div><div></div></div>	2 Sep	<div><div></div><div></div></div>	9 Sep	<div><div></div><div></div></div>	14 Sep	<div><div></div><div></div></div>	18 Sep
Broadstairs, Viking Bay	<div><div></div><div></div></div>	5 Jun	<div><div></div><div></div></div>	14 Jun	<div><div></div><div></div></div>	19 Jun	<div><div></div><div></div></div>	29 Jun	<div><div></div><div></div></div>	6 Jul	<div><div></div><div></div></div>	13 Jul	<div><div></div><div></div></div>	20 Jul	<div><div></div><div></div></div>	29 Jul	<div><div></div><div></div></div>	5 Aug	<div><div></div><div></div></div>	11 Aug	<div><div></div><div></div></div>	18 Aug	<div><div></div><div></div></div>	27 Aug	<div><div></div><div></div></div>	2 Sep	<div><div></div><div></div></div>	9 Sep	<div><div></div><div></div></div>	14 Sep	<div><div></div><div></div></div>	18 Sep
Joss Bay, Broadstairs	<div><div></div><div></div></div>	5 Jun	<div><div></div><div></div></div>	14 Jun	<div><div></div><div></div></div>	19 Jun	<div><div></div><div></div></div>	29 Jun	<div><div></div><div></div></div>	6 Jul	<div><div></div><div></div></div>	13 Jul	<div><div></div><div></div></div>	20 Jul	<div><div></div><div></div></div>	29 Jul	<div><div></div><div></div></div>	5 Aug	<div><div></div><div></div></div>	11 Aug	<div><div></div><div></div></div>	18 Aug	<div><div></div><div></div></div>	27 Aug	<div><div></div><div></div></div>	2 Sep	<div><div></div><div></div></div>	9 Sep	<div><div></div><div></div></div>	14 Sep	<div><div></div><div></div></div>	18 Sep
Margate, Fulsam Rock	<div><div></div><div></div></div>	5 Jun	<div><div></div><div></div></div>	14 Jun	<div><div></div><div></div></div>	19 Jun	<div><div></div><div></div></div>	29 Jun	<div><div></div><div></div></div>	6 Jul	<div><div></div><div></div></div>	13 Jul	<div><div></div><div></div></div>	20 Jul	<div><div></div><div></div></div>	29 Jul	<div><div></div><div></div></div>	5 Aug	<div><div></div><div></div></div>	11 Aug	<div><div></div><div></div></div>	18 Aug	<div><div></div><div></div></div>	27 Aug	<div><div></div><div></div></div>	2 Sep	<div><div></div><div></div></div>	9 Sep	<div><div></div><div></div></div>	14 Sep	<div><div></div><div></div></div>	18 Sep
Margate, The Bay	<div><div></div><div></div></div>	6 Jun	<div><div></div><div></div></div>	14 Jun	<div><div></div><div></div></div>	19 Jun	<div><div></div><div></div></div>	29 Jun	<div><div></div><div></div></div>	6 Jul	<div><div></div><div></div></div>	13 Jul	<div><div></div><div></div></div>	20 Jul	<div><div></div><div></div></div>	29 Jul	<div><div></div><div></div></div>	5 Aug	<div><div></div><div></div></div>	11 Aug	<div><div></div><div></div></div>	18 Aug	<div><div></div><div></div></div>	27 Aug	<div><div></div><div></div></div>	2 Sep	<div><div></div><div></div></div>	9 Sep	<div><div></div><div></div></div>	14 Sep	<div><div></div><div></div></div>	18 Sep
Minnis Bay, Birchington	<div><div></div><div></div></div>	5 Jun	<div><div></div><div></div></div>	14 Jun	<div><div></div><div></div></div>	19 Jun	<div><div></div><div></div></div>	29 Jun	<div><div></div><div></div></div>	6 Jul	<div><div></div><div></div></div>	13 Jul	<div><div></div><div></div></div>	20 Jul	<div><div></div><div></div></div>	29 Jul	<div><div></div><div></div></div>	5 Aug	<div><div></div><div></div></div>	11 Aug	<div><div></div><div></div></div>	18 Aug	<div><div></div><div></div></div>	27 Aug	<div><div></div><div></div></div>	2 Sep	<div><div></div><div></div></div>	9 Sep	<div><div></div><div></div></div>	15 Sep	<div><div></div><div></div></div>	25 Sep
Ramsgate Sands	<div><div></div><div></div></div>	5 Jun	<div><div></div><div></div></div>	14 Jun	<div><div></div><div></div></div>	19 Jun	<div><div></div><div></div></div>	29 Jun	<div><div></div><div></div></div>	6 Jul	<div><div></div><div></div></div>	13 Jul	<div><div></div><div></div></div>	20 Jul	<div><div></div><div></div></div>	29 Jul	<div><div></div><div></div></div>	5 Aug	<div><div></div><div></div></div>	11 Aug	<div><div></div><div></div></div>	18 Aug	<div><div></div><div></div></div>	27 Aug	<div><div></div><div></div></div>	2 Sep	<div><div></div><div></div></div>	9 Sep	<div><div></div><div></div></div>	14 Sep	<div><div></div><div></div></div>	18 Sep
Ramsgate Western Undercliffe	<div><div></div><div></div></div>	5 Jun	<div><div></div><div></div></div>	14 Jun	<div><div></div><div></div></div>	19 Jun	<div><div></div><div></div></div>	29 Jun	<div><div></div><div></div></div>	6 Jul	<div><div></div><div></div></div>	13 Jul	<div><div></div><div></div></div>	20 Jul	<div><div></div><div></div></div>	29 Jul	<div><div></div><div></div></div>	5 Aug	<div><div></div><div></div></div>	11 Aug	<div><div></div><div></div></div>	18 Aug	<div><div></div><div></div></div>	27 Aug	<div><div></div><div></div></div>	2 Sep	<div><div></div><div></div></div>	9 Sep	<div><div></div><div></div></div>	14 Sep	<div><div></div><div></div></div>	18 Sep
St Mildred's Bay, Westgate	<div><div></div><div></div></div>	5 Jun	<div><div></div><div></div></div>	14 Jun	<div><div></div><div></div></div>	19 Jun	<div><div></div><div></div></div>	29 Jun	<div><div></div><div></div></div>	6 Jul	<div><div></div><div></div></div>	13 Jul	<div><div></div><div></div></div>	20 Jul	<div><div></div><div></div></div>	29 Jul	<div><div></div><div></div></div>	5 Aug	<div><div></div><div></div></div>	11 Aug	<div><div></div><div></div></div>	18 Aug	<div><div></div><div></div></div>	27 Aug	<div><div></div><div></div></div>	2 Sep	<div><div></div><div></div></div>	9 Sep	<div><div></div><div></div></div>	15 Sep	<div><div></div><div></div></div>	25 Sep
Walpole Bay, Margate	<div><div></div><div></div></div>	5 Jun	<div><div></div><div></div></div>	14 Jun	<div><div></div><div></div></div>	19 Jun	<div><div></div><div></div></div>	29 Jun	<div><div></div><div></div></div>	6 Jul	<div><div></div><div></div></div>	13 Jul	<div><div></div><div></div></div>	20 Jul	<div><div></div><div></div></div>	29 Jul	<div><div></div><div></div></div>	5 Aug	<div><div></div><div></div></div>	11 Aug	<div><div></div><div></div></div>	18 Aug	<div><div></div><div></div></div>	27 Aug	<div><div></div><div></div></div>	2 Sep	<div><div></div><div></div></div>	9 Sep	<div><div></div><div></div></div>	14 Sep	<div><div></div><div></div></div>	18 Sep
West Bay, Westgate	<div><div></div><div></div></div>	5 Jun	<div><div></div><div></div></div>	14 Jun	<div><div></div><div></div></div>	19 Jun	<div><div></div><div></div></div>	29 Jun	<div><div></div><div></div></div>	6 Jul	<div><div></div><div></div></div>	13 Jul	<div><div></div><div></div></div>	20 Jul	<div><div></div><div></div></div>	29 Jul	<div><div></div><div></div></div>	5 Aug	<div><div></div><div></div></div>	11 Aug	<div><div></div><div></div></div>	18 Aug	<div><div></div><div></div></div>	27 Aug	<div><div></div><div></div></div>	2 Sep	<div><div></div><div></div></div>	9 Sep	<div><div></div><div></div></div>	15 Sep	<div><div></div><div></div></div>	25 Sep
Westbrook Bay, Margate	<div><div></div><div></div></div>	6 Jun	<div><div></div><div></div></div>	14 Jun	<div><div></div><div></div></div>	19 Jun	<div><div></div><div></div></div>	29 Jun	<div><div></div><div></div></div>	6 Jul	<div><div></div><div></div></div>	13 Jul	<div><div></div><div></div></div>	20 Jul	<div><div></div><div></div></div>	29 Jul	<div><div></div><div></div></div>	5 Aug	<div><div></div><div></div></div>	11 Aug	<div><div></div><div></div></div>	18 Aug	<div><div></div><div></div></div>	27 Aug	<div><div></div><div></div></div>	2 Sep	<div><div></div><div></div></div>	9 Sep	<div><div></div><div></div></div>	15 Sep	<div><div></div><div></div></div>	25 Sep

weekly sample reading does not indicate unacceptable water quality;

weekly sample reading indicates unacceptable water quality

, weekly sample reading does not indicate unacceptable water quality; , weekly sample reading indicates unacceptable water quality

Figure 4. Margate weather (rainfall, wind speed, sunshine, temperature) in August 2015. Source: Met Office (2015)

Figure 5. Number of daily visitors to Margate based on mobile data and maximum temperature: May–October 2015. Source of weather data: Southend airport Metar data (Gladstone, 2015)

Figure 6. Number of visitors to Margate by age over August 2015, based on mobile data

therefore considered to have been relatively consistent and similar visitor numbers would be expected.

Visitor demographic and catchment data over August 2015 were then used to understand where visitors to Margate typically come from and to explore if weather significantly impacted human dynamics.

2.6 Results and discussion

Figure 5 provides an overview of daily footfall to Margate between May and October 2015. This figure shows that there is a base footfall

of around 20 000 visitors throughout this time period, with increases towards and at weekends and peak numbers over August. Mean daily weekday visitor numbers over May–October were 27 800 (27 700 excluding the May and August bank holidays), while mean weekend numbers were 33 300. It is interesting to note that weekday totals are relatively constant over the period shown, with increases during August and due to the second May bank holiday (25 May 2015).

The results and discussion for three key areas of analysis are outlined under the respective headings in the following sections.

Figure 7. Proportion of visitors to Margate by region over August 2015, based on mobile data

2.6.1 Impact of weather

Figures 4 and 5 indicate that the combination of rainfall and maximum temperature is likely to have an impact on visitor numbers over the summer months. For example, 1 July, Wednesday, saw peak weekday visitor numbers outside of August and bank holidays. This appears to be linked to the high maximum temperature of around 30°C and minimal rainfall on this date.

The last weekend in July (25 and 26), in contrast, saw a drop in visitor numbers compared to other weekends from mid-June to the end of August and coincides with heavy rainfall on 24 July, Friday (Figure 3), and additional rainfall over the weekend, as well as relatively low maximum temperatures of around 18°C.

The first two weekends in August were warm and dry, with higher temperatures on the two Sundays compared to the Saturdays. This may account for the slightly higher Sunday visitor numbers compared to those for Saturday, a reversal of the pattern shown in June and July, when maximum temperatures on Sundays were generally slightly lower than those on Saturdays.

From October onwards, weather appears to play a weaker role in visitor numbers, with an overall decline in temperatures accompanied by relatively constant numbers of visitors (refer to Figure 5).

There is therefore a link between weather and human dynamics within the data sets considered, but there are other factors occurring that need to be considered for accurate decision-making (e.g. bank holidays). The authors' hypothesis on the link between daily weather and visitor footfall in Margate could be tested in other areas of the UK where coastal recreation plays a strong role in the local economy by using the same approach – for example, coastal areas in the south-west of England, as well as other settings where relevant. It would also be useful to extend this analysis further through the use of statistical models to assess the impact of these parameters and enable predictions (e.g. on the impact of weather events on footfall in the future), but this was beyond the scope of the study.

2.6.2 Spatial dynamics and demographics

Figure 6 presents the breakdown of visitors in August by age. The results show that the largest proportion of visitors were aged 65 and over, while people aged 18–24 were least likely to visit Margate over this period. Although based on Figure 6 there appears to be a relatively small proportion of 55- to 64-year-olds compared to some of the other age groups, this age group is slightly overrepresented compared to the proportion in the UK adult population based on Office for National Statistics data. Those aged 18–34 are also slightly underrepresented, while those visitors aged between 35 and 64 are slightly overrepresented. This indicates that Margate is currently most attractive to visitors aged 35 and over.

Figures 2 and 7 provide information on where visitors came from for the whole of August in 2015. This provides extremely useful insight into how far people are willing to travel to access Margate,

for either work or leisure. While this indicates that the highest proportion was from the nearby area, there was also a significant proportion from London (16%), which could be an area for the regeneration strategy of Margate to focus on in combination with the demographic insights. Visitors from the East Midlands, North East, North West, Scotland, South, Wales, West Midlands and Yorkshire and Humber regions comprised only 8% of total visitors over the period analysed, which is unsurprising given the travel distances involved.

Clearly the type of information that is gained from the previous analysis could be useful in tailoring tourism campaigns, stakeholder engagement and the management of facilities in the Thanet area, as well as evaluating the impact of any interventions or events like other studies have done (Girardin *et al.*, 2008).

2.6.3 Impact of beach closure event on visitor dynamics

One of the primary aims of the study was to explore whether the closure of St Mildred's Bay on 25 August, Tuesday, affected footfall numbers on this date. The approach used was to analyse a variety of different time periods to estimate what the expected visitor numbers would have been had the beach not been closed.

Table 2 shows the results from this analysis. It shows that visitor numbers were lower on 25 August (30 180) than the August weekday (Monday–Thursday) mean (32 932) and median (32 040). However, the number of visitors on the selected surrogate day (18 August) was very similar (30 260) to that on 25 August, despite the fact that there was no beach closure. The difference in visitor numbers between these two dates is within the standard error and standard deviation of mean weekday visitors in August.

This suggests that the beach closure event may not have been of sufficient duration and spatial extent to have had an impact on visitor numbers. It occurred on a relatively cool and rainy day and therefore bathing and spending time on the particular beach affected may not have been the primary motive for the majority of visitors to Margate. In addition, the sign was deployed only at 9.30 a.m., so there is unlikely to have been sufficient notice to visitors to deter many of those travelling to Margate on 25 August.

Furthermore, upon finding the beach closed, those who had intended to visit St Mildred's Bay could have travelled to a different beach in and around Margate, or a nearby area (e.g. Ramsgate) instead. These visitors would still have been recorded in the footfall numbers, as they are likely to have had a dwell time in the area of interest (see Figure 1) of greater than 30 min. Visitors who had changed their plans and travelled elsewhere upon finding the beach closed may have incurred additional travel costs, but this is uncertain based on the mobile data alone.

It may be that due to the spatial resolution of data used for the study, it would not be possible to discern changes in footfall on a beach scale, and this is something to note for further research.

Table 2. Visitor number analysis

Number of visitors on beach closure day (St Mildred's Bay, 25 August, Tuesday)	30 180
Number of visitors on surrogate day (18 August, Tuesday)	30 260
Difference	−80
% Change	−0.26%
Mean number of weekday (Monday–Thursday) visitors in August	32 932
Standard deviation of mean weekday visitors in August	3046
Standard error of mean weekday visitors in August	786
Median number of weekday (Monday–Thursday) visitors in August	32 040
Mean weekend and bank holiday visitors in August	43 175

What is clear from the mentioned findings, however, is that mobile data can very likely be used as a surrogate for surveys and counters, providing a basis for quantifying the economic impact of water and environmental events in preparing a case to invest in sustainable infrastructure. It may, however, need to be paired with further population data sets, longer time periods and statistical analysis to improve confidence in the work undertaken and any conclusions that are drawn.

3. Conclusions

This analysis represents the first time that mobile data have been used to understand visitor footfall and demographics in Margate with respect to urban water management and infrastructure planning. The study provided an improved level of insight compared to previously used visitor counts and surveys, enabling spatial, temporal and demographic analysis that would have been prohibitively expensive using more traditional approaches, as has been found in other studies (Girardin *et al.*, 2009).

The study provided an understanding of baseline visitor numbers to Margate over the course of 6 months and how visitor footfall changed due to weather, specific water and environmental events and other factors (e.g. school holidays). In undertaking the study, it was also, however, highlighted that while mobile data are an excellent data resource for impact studies, their accuracy is dependent on the density of mobile coverage and in most cases will need to be supplemented with additional data sets to improve confidence in analytical work, which is also what other studies have found (Ratti *et al.*, 2006).

Although the study could not confidently link associated changes in visitor footfall on 25 August 2015, when there was a beach closure due to weather and poor water quality around Margate, it is likely to be due to the limited time period considered and data sets used. There is, however, significant potential to use digital footprinting to improve the understanding of water and environmental events on people and therefore be used as an evidence base for enhancing investment cases in sustainable infrastructure. It is clear that there are numerous potential applications of the data, such as the targeting of tourism

campaigns, stakeholder engagement and real-time management, that will pose many of the real privacy challenges, which a previous study identified (Ratti *et al.*, 2006), due to the current financial climate, needing to deliver better services for lower cost.

For Margate, it was found that visitor footfall in Margate was likely to be driven strongly by weather, which underlines the importance of diversifying the local economy's dependency on tourism as part of the regeneration strategy. The study indicates that while the greatest proportion of visitors to Margate are from the local area and over 65 years of age, 16% of the visitors to Margate are from London, giving the regeneration strategy an area to focus on in diversifying its economy and reliance on tourism.

4. Further work

The findings from this study suggest future research work should be targeted at

- enhancing the robustness of the approach with further case studies and/or further consideration of the techniques employed in this study (including the use of statistical models and differing spatial resolutions)
- understanding the societal impacts of using citizens as sensors, as well as the benefits and appropriate methods for tailoring tourism campaigns and stakeholder engagement
- how such systems can be implemented so that they are connected, secure and reliable
- how a real-time dynamic monitoring, assessment and infrastructure planning system could be used alongside emerging digital approaches (e.g. Building Information Modelling) to ensure societal considerations are at the core of decisions
- how such systems can be used in place of current techniques used for economic appraisal, what impact this could have on decisions and how such techniques would operate in a real-time assessment environment.

Acknowledgements

The authors would like to thank Max Tant and Bronwyn Buntine of Kent County Council, as well as Mike Tomlinson of Southern Water and Mike Humber of Thanet District Council, for permission to publish this paper. The authors would also like to acknowledge the contributions from Hilary Carter, Gillian Iversen, Zoe Shute and Jon Swan, who supported the undertaking of this study.

REFERENCES

- Ahas R, Aasa A, Silm S and Tiru M (2007) Mobile positioning data in tourism studies and monitoring: case study in Tartu, Estonia. In *Information and Communication Technologies in Tourism 2007* (Sigala M, Mich L and Murphy J (eds)). Springer, Vienna, Austria, pp. 119–128, http://dx.doi.org/10.1007/978-3-211-69566-1_12.
- BBC (British Broadcasting Corporation) (2015) *Britain's Seaside Ruins*. BBC, London, UK. See <http://www.bbc.com/culture/story/20150609-britains-seaside-ruins> (accessed 21/06/2017).
- Ciria (Construction Industry Research and Information Association) (2013) *Demonstrating the Multiple Benefits of SuDS – a Business Case (Phase 2): Draft Literature Review*. Ciria, London, UK.

- Ciria (2015) *The SUDS Manual*. Ciria, London, UK.
- Ciwem (Chartered Institution of Water and Environmental Management) (2015) *Breaking the Bank? Funding for Flood and Coastal Erosion Risk Management in England*. Ciwem, London, UK.
- Defra (Department for Environment, Food and Rural Affairs) (2012) *Partnership Funding and Collaborative Delivery of Local Flood Risk Management: a Practical Resource for LLFAs (FD2643)*. Defra, London, UK.
- EA (Environment Agency) (2014) *Collaborative Research Priorities for the Environment Agency*. EA, Bristol, UK.
- EA (2015a) *FCRM Partnership Funding Calculator*. EA, Bristol, UK. See <https://www.gov.uk/government/publications/fcrm-partnership-funding-calculator> (accessed 16/05/2017).
- EC (European Community) (2006) Directive 2006/7/EC of the European Parliament and of the Council of 15 February 2006 concerning the management of bathing water quality and repealing Directive 76/160/EEC. *Official Journal of the European Communities*, vol. L64/37.
- Girardin F, Calabrese F, Dal Fiore F, Ratti C and Blat J (2008) Digital footprinting: uncovering tourists with user generated content. *IEEE Pervasive Computing* 7(4): 36–43, <http://dx.doi.org/10.1109/MPRV.2008.71>.
- Girardin F, Vaccari A, Gerber A, Biderman A and Ratti C (2009) Towards estimating the presence of visitors from the aggregate mobile phone network activity they generate. *International Conference on Computers in Urban Planning and Urban Management, Hong Kong, China*.
- Gladstone P (2015) <http://weather.gladstonefamily.net/cgi-bin/wxobservations.pl?site=EGMC&days=1000> (accessed 02/04/2016).
- Gonzalez M, Hidalgo C and Barabasi A (2008) Understanding individual human mobility patterns. *Nature* 453(7196): 779–782, <http://dx.doi.org/10.1038/nature06958>.
- HM Treasury (Her Majesty's Treasury) (2010) *Spending Review 2010 – CM7942*. The Stationery Office, London, UK.
- KCC (Kent County Council) (2015) *Hyrad Gridded Rainfall Data Export*. Centre for Ecology and Hydrology, Wallingford, UK.
- Liveable Cities (2014) <http://liveablecities.org.uk/> (accessed 16/05/2017).
- Met Office (2015) *Location Based Downtime Summaries – Margate, August 2015*. Met Office, Exeter, UK.
- Moore S (2015) *Safe to Swim Now!* Thanet Life, Kent, UK. See <http://birchington.blogspot.co.uk/2015/08/safe-to-swim-now.html> (accessed 21/06/2017).
- Ofwat (Water Services Regulation Authority) (2013) *Setting Price Controls for 2015–20 – Framework and Approach: a Consultation*. Ofwat, Birmingham, UK.
- Ofwat (2014) *Setting Price Controls for 2015–20: Final Price Control Determination Notice: Company Specific Appendix – Southern Water*. Ofwat, Birmingham, UK.
- Ratti C, Frenchman D, Pulselli R *et al.* (2006) Mobile landscapes: using location data from cell-phones for urban analysis. *Environment Planning B: Urban Analytics and City Science* 33(5): 727–748, <http://dx.doi.org/10.1068/b32047>.
- Stratus Consulting (2009) *A Triple Bottom Line Assessment of Traditional and Green Infrastructure Options for Controlling CSO Events in Philadelphia's Watersheds*. City of Philadelphia Water Department, Philadelphia, PA, USA.
- Thanet District Council (2006) *Thanet District Adopted Local Plan 2006*. Thanet District Council, Margate, UK. See <http://thanet.devplan.org.uk/document.aspx?document=15&display=contents> (accessed 21/06/2017).
- Thanet District Council (2015a) *Beach Pollution Incidents and Sign Deployment*. Thanet District Council, Margate, UK.
- Thanet District Council (2015b) *Bathing Water Sites in Thanet*. Thanet District Council, Margate, UK. See <http://thanet.gov.uk/your-services/beaches-and-coastline/bathing-water-quality/2015-water-quality-results/> (accessed 02/11/2015).
- The Beach Guide (2017) *Beaches in Margate, Kent*. The Beach Guide, UK. See <https://www.thebeachguide.co.uk/south-east-england/kent/margate-town> (accessed 21/06/2017).
- Visit Thanet (2017) *Margate*. Visit Thanet, Thanet District Council, Margate, UK. See <http://www.visitthanet.co.uk/destinations/margate/10537?microSiteId=210> (accessed 21/06/2017).

How can you contribute?

To discuss this paper, please email up to 500 words to the editor at journals@ice.org.uk. Your contribution will be forwarded to the author(s) for a reply and, if considered appropriate by the editorial board, it will be published as discussion in a future issue of the journal.

Proceedings journals rely entirely on contributions from the civil engineering profession (and allied disciplines). Information about how to email your paper online is available at www.icevirtuallibrary.com/page/authors, where you will also find detailed author guidelines.