



LJMU Research Online

Percival, S, Gaterell, M and Teeuw, R

Urban neighbourhood flood vulnerability and risk assessments at different diurnal levels

<http://researchonline.ljmu.ac.uk/id/eprint/10569/>

Article

Citation (please note it is advisable to refer to the publisher's version if you intend to cite from this work)

Percival, S, Gaterell, M and Teeuw, R (2018) Urban neighbourhood flood vulnerability and risk assessments at different diurnal levels. Journal of Flood Risk Management. ISSN 1753-318X

LJMU has developed **LJMU Research Online** for users to access the research output of the University more effectively. Copyright © and Moral Rights for the papers on this site are retained by the individual authors and/or other copyright owners. Users may download and/or print one copy of any article(s) in LJMU Research Online to facilitate their private study or for non-commercial research. You may not engage in further distribution of the material or use it for any profit-making activities or any commercial gain.

The version presented here may differ from the published version or from the version of the record. Please see the repository URL above for details on accessing the published version and note that access may require a subscription.

For more information please contact researchonline@ljmu.ac.uk

<http://researchonline.ljmu.ac.uk/>

1 **Urban Neighbourhood Flood Vulnerability and Risk Assessments at Different Diurnal**
2 **Levels.**

3

4 Percival Sarah¹, Gaterell Mark¹ & Teeuw Richard²

5

6 ¹ School of Civil Engineering & Surveying, University of Portsmouth, UK

7 sarah.percival@port.ac.uk & mark.gaterell@port.ac.uk

8 ² Centre for Applied Geoscience, School of Earth and Environmental Sciences, University of

9 Portsmouth, UK. richard.teeuw@port.ac.uk

10

11

12

13

14

15

16

17

18

19

20

21

22

23

24

25

26

27

28

29

30

31

32

33

34

Abstract

Diurnal changes within communities can significantly alter the level of impacts during a flood, yet these essential daily variations are not currently catered for within flood risk assessments. This paper develops a flood vulnerability and risk model that captures crucial features of flood vulnerability; integrating physical and socio-economic vulnerability data, combined with a flood hazard analysis, to give overall flood risk at neighbourhood scale, at two different times of day, for floods of different magnitudes. The flood vulnerability and risk model, the resulting diurnal coastal flood vulnerability and risk indexes and corresponding maps for the ward of Hilsea, (Portsmouth, UK), presented within this paper, highlight three previously unidentified neighbourhoods in particular in the north-west of the Hilsea ward, that have the highest levels of risk during both time zones and for flood events of different magnitude. Critically, these neighbourhoods lie further inland and not directly on the Hilsea coastline, yet by analysing at this resolution (including diurnal impacts), substantial levels of underlying vulnerability were identified within these areas.

49

Keywords: integrated flood risk; mapping of hazard and risk; risk analysis; vulnerability

51

Introduction

Recent flood disasters in the UK (2007, 2013-2014 storm surges, 2015 and 2017) have reminded us of society's increasing vulnerability, as flooding has far-reaching, short and long-term consequences for those concerned, including death, damage, and disruption. The Committee on Climate Change (2016) stated that future flood research needs to focus and prioritise efforts on the understanding of potential impacts to communities, businesses and infrastructure. Current levels of flood risk management in the UK are considered insufficient (Committee on Climate Change 2016), and in the context of sustainability, new and proactive approaches for the management of flood hazards are needed, that engage with a much wider set of tools and knowledge (Wilkinson *et al.* 2015; Bracken *et al.* 2016).

Currently 5.2 million people in England and Wales are deemed to be at risk of flooding (National Flood Forum 2016). Yet within those at-risk areas, people and places will suffer differently according to their degrees of vulnerability (Birkmann *et al.* 2013), i.e. the physical and socio-economic characteristics or wider deprivation in those areas (Maantay and Maroko 2009; Wilson *et al.* 2014). Understanding and identifying vulnerability at the right scale prior to undertaking new flood management approaches is vital in order to establish potential impacts within communities. While risk and vulnerability can be seen as

69 continuous, impacts are a materialisation ('this is happening now'/ 'real event') of these
70 underlying conditions (Renn 1992; Adam and Van Loon 2000; Beck 2000; Cardona *et al.*
71 2012; Birkmann *et al.* 2013).

72 While vulnerability analyses have evolved significantly, there is still no consensus
73 within the risk science community about vulnerability or its factors. Therefore, development
74 of a theoretical framework to structure the analysis is essential. Research presented in this
75 paper, based on a case study of Portsmouth, UK, aims to assess and map coastal flood risk
76 (CoFR) for urban communities at neighbourhood scale, for floods of different magnitudes,
77 diurnally. In the methodology presented, the original risk, hazard and vulnerability
78 relationship (Wisner *et al.* 2004; Cancado *et al.* 2008) has been developed to further analyse
79 vulnerability, by combining three components (physical vulnerability, socio-economic
80 vulnerability and resilience) into one measurement (Equation 1). The resulting tool captures
81 the most relevant features of diurnal flood vulnerability (both pre and post impact), assisting
82 our understanding of the reality of vulnerability at the level of detail necessary to truly deliver
83 effective local solutions and embed resilience.

84 Equation 1

$$85 \quad \text{Risk} = \text{Hazard} \times \text{Vulnerability (Physical Vulnerability + Socio-economic Vulnerability +}$$
$$86 \quad \quad \quad \text{Resilience)}$$

87

88 Within this research hazard refers to the possible future occurrence of natural events
89 that could have serious adverse effects on vulnerable elements (Birkmann 2006; Ramieri *et al.*
90 *et al.* 2011; Cardona *et al.* 2012; IPCC 2014). The concept of risk combines the probability of
91 hazard occurrence with the likely impacts or consequences that are associated with that event
92 (vulnerability) (Ramieri *et al.* 2011; IPCC 2014). Vulnerability therefore relates to the
93 predisposition, lack of capacities, exposure, susceptibilities, weaknesses, or fragilities that
94 would favor the adverse effects from hazardous events (Birkmann 2006; Cutter 2006;
95 UNISDR 2009; Kaźmierczak and Cavan 2011; Menoni *et al.* 2012) i.e. vulnerability is more
96 dynamic than traditional approaches suggest (Birkmann *et al.* 2013). It encompasses a broad
97 range of factors including socio-economic characteristics of the population and the physical
98 characteristics of the built environment, as well as a community's ability to cope and recover
99 from a flood and the associated impacts (resilience). The combination of these factors can
100 increase the significance of potential impacts for those at risk (England and Knox 2015). Any
101 risk assessment should therefore incorporate the interaction between the nature of the hazard

102 and the inherent characteristics of the area/community at risk (Green, Parker and Tunstall
103 2000; Cancado *et al.* 2008).

104 A fundamental problem with current flood risk forecasting and the implementation of
105 comprehensive safety/management measures has been the lack of detailed information
106 regarding diurnal and seasonal variations (Bush and Cerveny 2013). The time of day when
107 the flood occurs is a variable that can seriously affect degrees of flood vulnerability and the
108 levels of flood impact i.e. turning an event into a disaster. On average, more people are killed
109 by flooding than by any other single severe weather hazard including tornados and
110 hurricanes, and most of these deaths have occurred at night (NOAA 2015). Generally people
111 are unaware of disasters occurring at night as most are sleeping. People become aware of the
112 situation perhaps 'too late', when it has become very dangerous, increasing risk to life. It is
113 therefore best to evacuate the inundating/inundated area immediately and go to shelter on
114 safer or higher ground (Miltner 2017; Earth Networks 2017). However, leaving any flooded
115 area can be fraught with dangers that are both immediate and continue when water levels
116 have stopped rising (Miltner 2017; Earth Networks 2017). Six inches of swiftly moving water
117 can knock most people off of their feet (NOAA 2015; Miltner 2017) and driving must be
118 done with extreme caution (Public Health England 2015). Loss of vehicle control can onset
119 very quickly, especially when water levels build. Vehicles can hydroplane, stall or even come
120 to a complete standstill, trapping those inside and sweeping them away, possibly leading to
121 drowning (Public Health England 2015; NOAA 2015; Earth Networks 2017). It is also ill-
122 advised to either drive or walk through standing water with poor visibility (Public Health
123 England 2015). Depths of floodwater are not always obvious and roads/pathways can be
124 seriously compromised or blocked due to heavy invisible debris (NOAA 2015). Floodwater
125 can also hide downed power lines or sharp debris/objects, and can be heavily contaminated
126 with either sewage or other hazardous substances, all leading to possible increases in risk of
127 harm, general infection or diarrheal/sickness diseases (Public health England 2015; NOAA
128 2015; Earth Networks 2017; Miltner 2017). All of these dangers highlight that contact with
129 either moving or standing floodwater should be minimised.

130 Floods at night time present a real danger as darkness can lead to disorientation and
131 inability to observe any flood dangers present i.e. deep water, contaminated flood water,
132 flooded drains, missing manhole covers, dangerous submerged large/sharp objects, or fast
133 moving objects (Newry, Mourne and Down District Council 2016; NOAA 2015; Public
134 Health England 2016). Thus flood forecasting and warning systems are vital for safe
135 evacuation practices. Yet despite our flood forecasting and warning systems and carefully

136 managed search and rescue teams, these systems are not perfect and problems still arise,
137 resulting in tragedies or being caught in very dangerous situations, particularly at night e.g.
138 9th January 2018 California, USA floods, 2013/14 UK storm surges and recently 22nd April
139 2018 Southampton, UK flash floods. In the UK as a result of the 1953 North Sea storm surge
140 (which occurred mainly during the night) that resulted in 307 deaths in England, 19 in
141 Scotland and 1800 in the Netherlands; the Storm Tides Warning Service was established by
142 the Met Office to accurately forecast development and movement of storm surges up to two-
143 five days ahead (Met Office 2014). The flood alert and warning service was established more
144 recently and is freely available to the English public, sending an alert/warning anywhere
145 between 2 hours and 2 days prior to the flood (Environment Agency 2014; 2018). However,
146 this warning service is not available in all areas, requires prior sign up via governmental
147 links, and the alert and warning codes provide little detail unless further investigation is
148 made, firmly placing the responsibility with the homeowner (BBC 2007; Environment
149 Agency 2014; 2018). Furthermore these services have led to unnecessary residential
150 evacuations (Yarmouth 2007 and 2017) i.e. no flood transpired, leading to mistrust in the
151 warnings. Unfortunately though, the greatest issue is that residents can refuse to leave their
152 homes. In January 2017 in Great Yarmouth, UK, 60% of residents chose not to leave their
153 dwellings, despite door-to-door severe flood warnings issued to around 6000 properties (BBC
154 2017; Norfolk Constabulary 2017). Additionally, in areas of the UK such as Portsmouth,
155 where risk is very high but severe or catastrophic coastal flooding events have either never
156 occurred or not for some time, there is a high probability of limited individual flood
157 preparation and severe impacts, due to lack of knowledge or even complacency. Potentially
158 leading to further problems and risk to emergency service personnel when rescue is required.

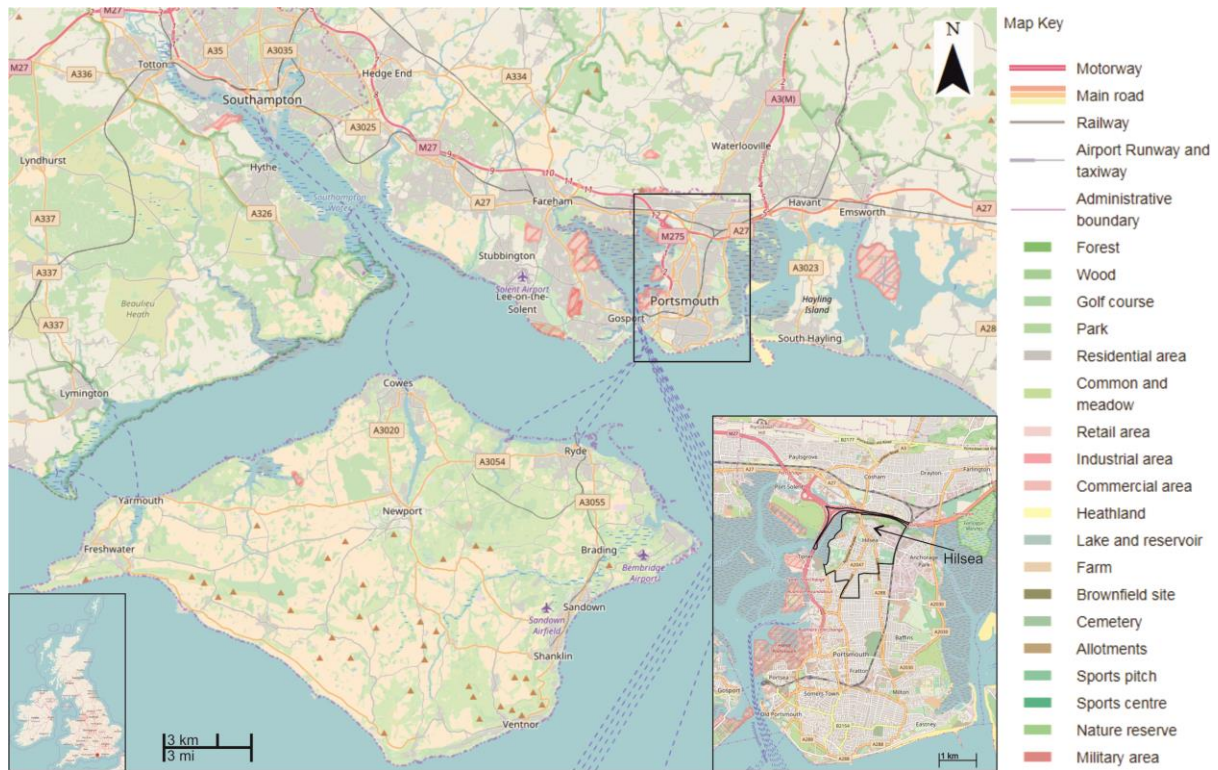
159 Meteorological events cannot be changed, but the severity of impacts arising from a
160 flood event as a result of weather extremes, can be mitigated. As floods at different times of
161 day can result in different levels of impact, it is key to pinpoint neighbourhoods where these
162 perils may arise in order to improve our evacuation and mitigation strategies and target where
163 our resources are needed. To better spotlight these at risk areas, the remainder of this paper
164 discusses how we can understand diurnal variations in flood risk and presents a methodology
165 that analyses it at the appropriate scale, establishing its local context. This research uniquely
166 assesses and pinpoints diurnal flood risk, providing a significant advance on existing
167 approaches to considering the impact of flooding to communities when undertaking flood
168 risk management. Finally, the implications, uncertainties and opportunities to improve this
169 methodology are discussed.

170
171
172
173
174
175
176
177
178
179
180
181
182
183
184
185
186
187
188
189
190
191
192
193

Methodology

Study Area – Portsmouth, UK

The study area chosen to pilot this methodology was the island city of Portsmouth, UK (Figure 1). Flood risk issues confronting Portsmouth reflect many of those being faced by other UK communities and indeed globally. The city and unitary authority of Portsmouth covers a total area of 40 km² split between the mainland and Portsea Island, with the primary source of flood risk from the sea (Atkins 2007; Portsmouth City Council 2011a, b, c; Wadey *et al.* 2012). Physically, Portsmouth's topography ranges from sea level to approx. 125 m above Ordnance datum (mAOD), however on the island and most of the mainland very few areas are higher than 10 mAOD (Atkins, 2011). Portsmouth is a densely populated (just over 197,000) and urbanised city, the majority of which reside on Portsea Island (Figure 1) (Environment Agency, 2010). This city is extensively developed (over 87%) with future plans for an additional 14,700 homes to be built before 2026 (Environment Agency, 2010). Furthermore, 47% of the city land area is designated within Environment Agency (EA) Flood Zones 2 and 3, with 0.1% and 0.5% chance of flooding, respectively (Atkins 2007, 2011). Coastal floods of this magnitude would inundate densely populated, expensive, and socially deprived neighbourhoods in Portsmouth (more than 15,000 properties), causing devastation and difficult evacuation. With these mounting pressures on flood risk management practices, successful flood risk identification and communication is vital in Portsmouth to reduce flood risk levels. Within Portsmouth, the ward of Hilsea was chosen to present this methodology for this paper (Figure 1), as Portsmouth City Council (2011a) has identified this area to be critical, due to potentially high risk to life from inundation and high capital costs for flood defences.



194

195 Figure 1. Location map of Hilsea and Portsmouth. Inset boxes shows the location of Hilsea
 196 within Portsmouth and Portsmouth within the UK. Map data © OpenStreetMap

197

198 Coastal Flood Vulnerability Factors

199 Pinpointing attributes of vulnerability and the ability to measure them in terms of data is a
 200 challenging task. Nevertheless, a number of datasets are available for the UK that can be used
 201 to represent different aspects and internal characteristics of geographical areas when
 202 considering coastal flooding. However, when incorporating many different data sources into
 203 one model, a standardisation of the data, to ensure uniformity in scales and units is required
 204 (Cutter *et al.* 2003; Tapsell *et al.* 2010; Menoni *et al.* 2012). An index approach was therefore
 205 adopted for this study, as indexing is one of the most simplistic systems and commonly used
 206 when assessing flood vulnerability (e.g. Chang *et al.* 2004; Connor and Hiroki 2005; Sullivan
 207 and Meigh 2005; Lindley *et al.* 2011; Balica *et al.* 2012) to natural and climate induced
 208 processes and hazards (erosion, flooding, sea-level rise etc.) (Ramieri *et al.* 2011). This
 209 approach enabled all the different vulnerability factors to be combined into their respective
 210 Coastal Flood Vulnerability components (physical vulnerability, socio-economic
 211 vulnerability and resilience), within one framework.

212 The final hazard and vulnerability indices were created and combined in equation 1,
 213 to create a Coastal Flood Risk index. Resulting in a simple numerical basis for ranking

214 neighbourhoods in terms of their potential for impact and change, diurnally. These results are
215 also displayed on maps to highlight specific regions assisting the identification of factors that
216 might contribute to the vulnerability of those areas. To achieve this the first methodological
217 step included the identification of key factors to represent the significant driving processes
218 influencing coastal flood vulnerability. The second step involved the quantification of those
219 key factors.

220 Vulnerability is composed of interacting elements where different processes or
221 individual interactions increase or decrease it. For better understanding of this paper the
222 different vulnerability components are further discussed, including the factors that compose
223 each component. All the factors presented in this paper have been deduced through
224 theoretical research (Cutter *et al.* 2003; Kaźmierczak and Cavan 2011; Lindley *et al.* 2011;
225 Birkmann *et al.* 2013) where links have been derived from a theoretical framework, with
226 proxies chosen based on those links (Balica *et al.* 2012; Damm 2010) i.e. all factors are
227 chosen from a coastal flooding perspective. The factors used were screened for their
228 suitability, definition (or theoretical structure) and their data availability. Figure 2 presents
229 the vulnerability data variables included in the final flood risk model, the vulnerability factors
230 they populate and the vulnerability component to which they are associated.

231

232 **Physical Vulnerability**

233 In recent years, natural hazards in metropolitan areas, such as floods, have shown that
234 environment-compatible urbanisation has not occurred (Başaran-Uysal *et al.* 2014).
235 Residential areas with an inadequate physical environment suffer the most in natural disasters
236 (White *et al.* 2004; Wamsler 2006). Therefore in order to mitigate against hazards such as
237 flooding, the degree of physical vulnerability in urbanised areas needs to be established
238 (Başaran-Uysal *et al.* 2014). This is defined by the essential physical characteristics of the
239 urban environment and the population density within the exposed area, i.e. the predisposition
240 of a community that can either exacerbate or reduce the hazard's impact (Birkmann 2006;
241 Kaźmierczak and Cavan 2011; Lindley *et al.* 2011; Menoni *et al.* 2012; Birkmann *et al.*
242 2013; Climate Just 2015), including buildings, roads, power stations, critical infrastructure,
243 land, ecosystems, individuals, households etc. (Kaźmierczak and Cavan 2011; Cardona *et al.*
244 2012; Menoni *et al.* 2012). Topography is not included here as this is already considered (via
245 a Digital Terrain Model (DTM)) within the Flood Zone 2 (1 in 1000 year event) and 3 (1 in
246 200 year event) data that populate the hazard analysis. A set of physical vulnerability factors
247 (Figure 2) were created to guide data selection and manipulation, resulting in a physical

248 vulnerability analysis in the form of a Coastal Flood Physical Vulnerability Index (CoFPVI);
249 aided by remote sensing, image processing and GIS software. The Coastal Flood Physical
250 Vulnerability (CoFPV) factors included *population density, green areas, essential buildings,*
251 *utilities, transport, dwellings, tenure, commercial and industrial areas* and *vulnerable*
252 *buildings day and night.*

253

254 **Socio-economic Vulnerability**

255 Social data have been identified as essential to vulnerability analyses (Gornitz 1991; Cutter *et*
256 *al.* 2003; Boruff *et al.* 2005). The risk of a disaster occurs in the interaction zone of the
257 human and the physical environment; yet socially created vulnerabilities are sometimes
258 ignored due to quantification. Within this paper socio-economic vulnerability is understood
259 as the social and economic elements susceptible within the system, influencing the
260 probabilities of being harmed at times of hazardous events (Cardona 2011; Carreno 2007;
261 Cardona *et al.* 2012). Socio-economic vulnerability focuses on demographic and socio-
262 economic factors that either increase or decrease levels of impact of flooding on communities
263 (Tierney *et al.* 2001; Heinz Carter 2002; Cutter *et al.* 2009). A set of socio-economic
264 vulnerability factors were created to guide data selection and manipulation, resulting in a
265 Coastal Flood Socio-economic Vulnerability Index (CoFSVI); aided by data variables from
266 the National UK Census (2011) database and estate agents via GIS software. The Coastal
267 Flood Socio-economic Vulnerability (CoFSV) factors (Figure 2) included *age, household*
268 *structure, illness or disability, proficiency in English, economic, providers of unpaid care,*
269 *occupation, communal establishment residents, and day or night population.*

270

271 **Resilience**

272 Resilience in communities is an important asset for buffering the effects of natural hazards
273 and promoting social reorganisation (Adger 2005). Communities with knowledgeable,
274 prepared and responsive institutions are more likely to prevent continuous flooding cycles
275 transitioning to long-term social disasters. Flood resilience can be seen as a
276 community/system's ability to either defy or alter itself so that flood damage is mitigated or
277 minimised. Within this article resilience refers to the existing capacity of linked systems to
278 absorb recurrent floods, so as to retain/adapt and mitigate/avoid harm, maintaining a
279 significant/acceptable amount of processes, functioning and structure (Adger 2005; Balica
280 2012). This includes limitations in hazard response i.e. access to and mobilisation of
281 resources, including pre-event risk reduction, in-time coping and post-event response

282 measures (Birkmann *et al.* 2013). The essential resilience characteristics were identified
283 through review, observation and evaluation. From this a set of Coastal Flood Resilience
284 (CoFRe) factors were created to guide data selection, resulting in a Coastal Flood Resilience
285 Index (CoFRe) aided by data from Ordnance Survey the National UK Census (2011)
286 database, via GIS and remote sensing techniques. The CoFRe factors (Figure 2) included
287 *socio-economic status, education, car ownership, and emergency facilities.*

288

289 **Diurnal Factors**

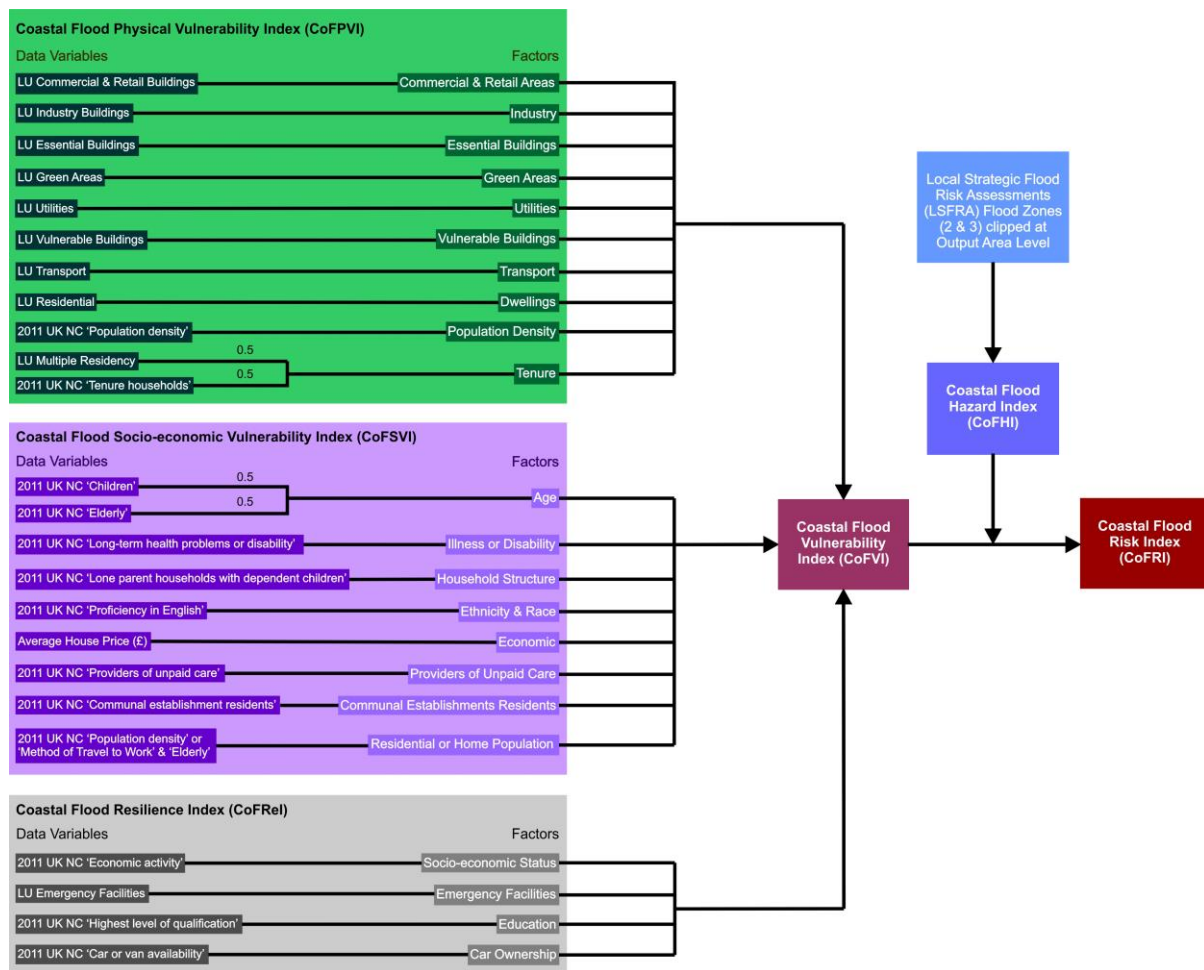
290 The repercussions of floods that occur at different times of day can vary significantly, yet
291 assessments of flood vulnerability and risk diurnally are not currently undertaken. The final
292 flood risk model (Figure 2) used to analyse diurnal flood vulnerability and risk for wards in
293 Portsmouth, UK, highlights the different flood vulnerability factors that can be used to assess
294 coastal flood risk from this new perspective. Taking into account how the areas in which we
295 reside change diurnally, and how everyday circumstances can affect levels of vulnerability
296 and ultimately levels of risk and impact, resulting in a more realistic understanding of why
297 and where vulnerability and risk levels alter in communities.

298 To achieve the day and night time analysis for Coastal Flood Vulnerability and Risk,
299 new parameters were created and applied to differentiate these time periods. The first diurnal
300 factors are *Vulnerable Buildings Day* and *Vulnerable Buildings Night*, within the physical
301 vulnerability analysis. Vulnerable buildings are identified by the Fire and Rescue Service
302 (2013) as buildings they would primarily seek out; due to the vulnerable nature of the
303 buildings and the residents/occupants of those buildings (Environment Agency per comms
304 2012; Hampshire Fire and Rescue per comms 2013). Examples include bungalows, schools,
305 nurseries, care homes, mobile homes, day care, chemical works/factories, hospitals, prisons,
306 children's homes, student halls of residence, social services homes, and hostels. Some of the
307 vulnerable buildings listed above classed as vulnerable during the day are not vulnerable
308 during the night and vice versa. The former is due to the building becoming empty at night
309 i.e. schools, day care, nurseries etc. The latter is due to the resident type residing/sleeping in
310 those buildings i.e. children's homes, social service homes, halls of residence etc. And
311 finally, some vulnerable buildings are always vulnerable, due to the nature of the building
312 (e.g. chemical works/factories), its activities (e.g. hospitals) or its residents (e.g. care homes).
313 The other established diurnal factors are simply described as *Day Population and Night*
314 *Population* within the socio-economic vulnerability component (there are no diurnal factors
315 within the resilience assessment). *Day Population* relates to the residents predominantly

316 present in their areas/homes during the day time. Large day populations increase vulnerability
317 (Cardona *et al.* 2012) as they are situated within the flood pathway, and higher numbers need
318 more assistance and evacuation. There are no datasets that tell us exactly how many people
319 stay at home during the day. However, there are figures that represent those (aged between 16
320 and 74 years) working mainly at or from home, and the retired. It is also highly probable that
321 the elderly (≥ 75 years) will be within their homes during the day as well. These datasets were
322 combined to give an indication of a day population figure. This factor could also contain very
323 young children (under 5 years), as it is likely they would be at home for the majority of the
324 day under some form of care (parent, grandparent, carer, nanny etc.). However, this is not
325 guaranteed due to childcare, nursery times, outings etc. During the holidays (not term time)
326 this factor could also apply to children between 4-16 years, again however there is no
327 guarantee they would be at home or close to the vicinity. People also tend to leave their
328 houses during the day for shopping, commuting or other leisure activities, and these
329 movements in population numbers are not considered here.

330 *Night Population* refers to the entire population residing in an area and should be at its
331 maximum as most residents will be in their homes in order to sleep. Floods at night are more
332 dangerous (Hampshire Fire and Rescue per comms 2013; NOAA 2015; Miltner 2017) and
333 can result in higher amounts of fatalities (Met Office 2014). Therefore, large night
334 populations increase vulnerability due to higher risk to life, larger numbers needing
335 evacuation, and higher amounts of resources required (Category 1 Responders i.e. Ministry of
336 Defence (MOD), emergency services, Environment Agency).

337



338

339 Figure 2. CoFRI and CoFVI model including data variables and vulnerability factors. NC:

340 UK 2011 National Census. LU: Land Use

341

342

Results

343 Figures 3 and 4, display coastal flood vulnerability and risk levels in Hilsea at neighbourhood

344 level (Output Area –the lowest geographical level UK National Census data are provided)

345 from the flood risk model (Figure 2) designed to assess and map how impacts at street level

346 vary diurnally, for floods of different magnitude. The results were produced where no

347 judgement was made on the relative importance of the different factors used i.e. equal

348 weights were applied to each factor (Briguglio 2004; Rygel *et al.* 2006; Lindley *et al.* 2011;349 Balica *et al.* 2013). Neighbourhoods within census wards from Portsmouth were used to test

350 this model (the ward of Hilsea is shown as an example) producing three detailed key indices:

351 a Coastal Flood Hazard Index (CoFHI), a Coastal Flood Vulnerability Index (CoFVI) and a

352 Coastal Flood Risk Index (CoFRI). The vulnerability and hazard indexes were combined

353 producing a subsequent analysis of risk for Portsmouth electoral wards, at neighbourhood

354 level. The vulnerability and risk indexes for Hilsea are displayed at 7 intervals between 0 and

355 1; slight, very low, low, moderate, high, very high and acute. The indexes assign a numerical
 356 value (0-1) to coastal flood vulnerability and risk, allowing for numerical comparisons of
 357 vulnerability and risk levels between neighbourhoods within Hilsea. In order to produce vital
 358 and improved targeting of vulnerable and at-risk areas, crucial to prioritising interventions to
 359 improve resilience, reduce vulnerability and enhance recovery.

360 To create a diurnal equally weighted Coastal Flood Vulnerability Index (CoFVI) for
 361 Hilsea involved the combination of the Day CoFPVI, Day CoFSVI and CoFREI or the Night
 362 CoFPVI, Night CoFSVI and CoFREI in equations 2 and 3 (based on Sullivan and Meigh's
 363 (2005) CVI equation and equation 1). A working example of the vulnerability index
 364 development can be seen in equation 4. This presents the CoFVI value (using equation 2 and
 365 corrected to two decimal points) for neighbourhood 23 (identified in bold in Table 1 and
 366 Figure 3) during the daytime.

367 Equation 2

$$368 \quad \text{Day CoFVI} = \frac{w_{cofpvid}CoFPVId + w_{cofsvd}CoFSVId + w_{cofri}CoFREI}{w_{cofpvid} + w_{cofsvd} + w_{cofri}}$$

369 Where *Day CoFVI* – Coastal Flood Vulnerability Index Day; *CoFPVId* – Coastal Flood
 370 Physical Vulnerability Index Day; *CoFSVId* – Coastal Flood Socio-economic Vulnerability
 371 Index Day; *CoFREI* – Coastal Flood Resilience Index; *w_{cofpvid}*, *w_{cofsvd}*, *w_{cofri}* –
 372 weights of vulnerability components.

373 Equation 3

$$374 \quad \text{Night CoFVI} = \frac{w_{cofpvin}CoFPVIn + w_{cofsvin}CoFSVIn + w_{cofri}CoFREI}{w_{cofpvin} + w_{cofsvin} + w_{cofri}}$$

375 Where *Night CoFVI* – Coastal Flood Vulnerability Index Night; *CoFPVIn* – Coastal Flood
 376 Physical Vulnerability Index Night; *CoFSVIn* – Coastal Flood Socio-economic Vulnerability
 377 Index Night; *CoFREI* – Coastal Flood Resilience Index; *w_{cofpvin}*, *w_{cofsvin}*, *w_{cofri}* –
 378 weights of vulnerability components.

379

380 Equation 4

381 Neighbourhood 23 Day CoFVI

$$382 \quad 0.6 = \frac{((0.33*0.57)+(0.33*0.42)+(0.33*0.81))}{(0.333+0.333+0.333)}$$

383

384 The vulnerability and hazard indexes were then combined producing a subsequent analysis of
 385 risk for Hilsea, diurnally, at neighbourhood level (Figure 4). This involved combining the
 386 *Day* and *Night* CoFVI results with the *Flood Zone 3 (FZ3)* and *Flood Zone 2 (FZ2)* CoFHI

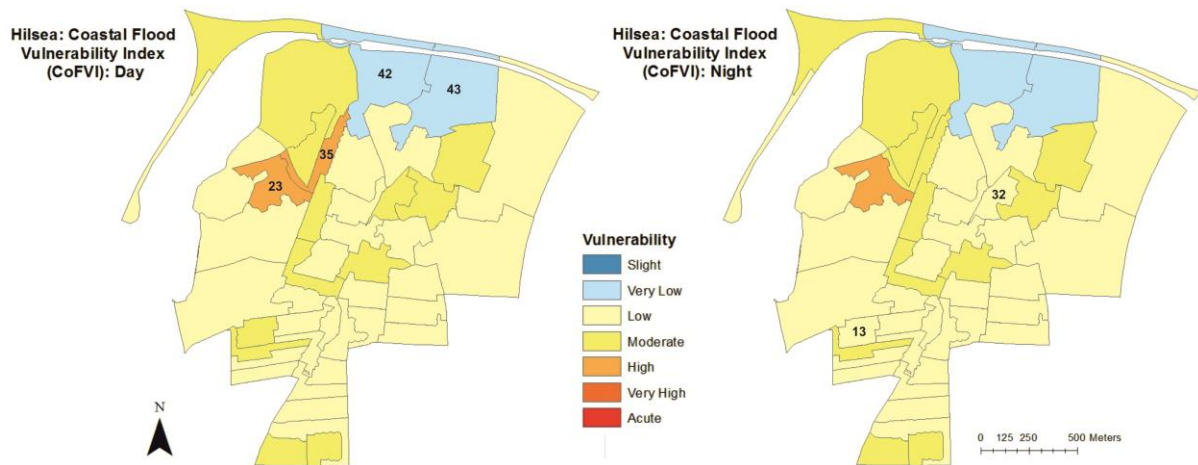
387 results of each neighbourhood in Hilsea in Equation 5. This resulted in four different CoFRI's
 388 for Hilsea – Day CoFRI (FZ3); Night CoFRI (FZ3); Day CoFRI (FZ2); and Night CoFRI
 389 (FZ2).

390 Equation 5

391
$$\text{Coastal Flood Risk (CoFRI)} = \text{CoFHI} * \text{CoFVI}$$

392 Where *CoFRI* – Coastal Flood Risk Index; *CoFHI* – Coastal Flood Hazard Index; *CoFVI* –
 393 Coastal Flood Vulnerability Index.

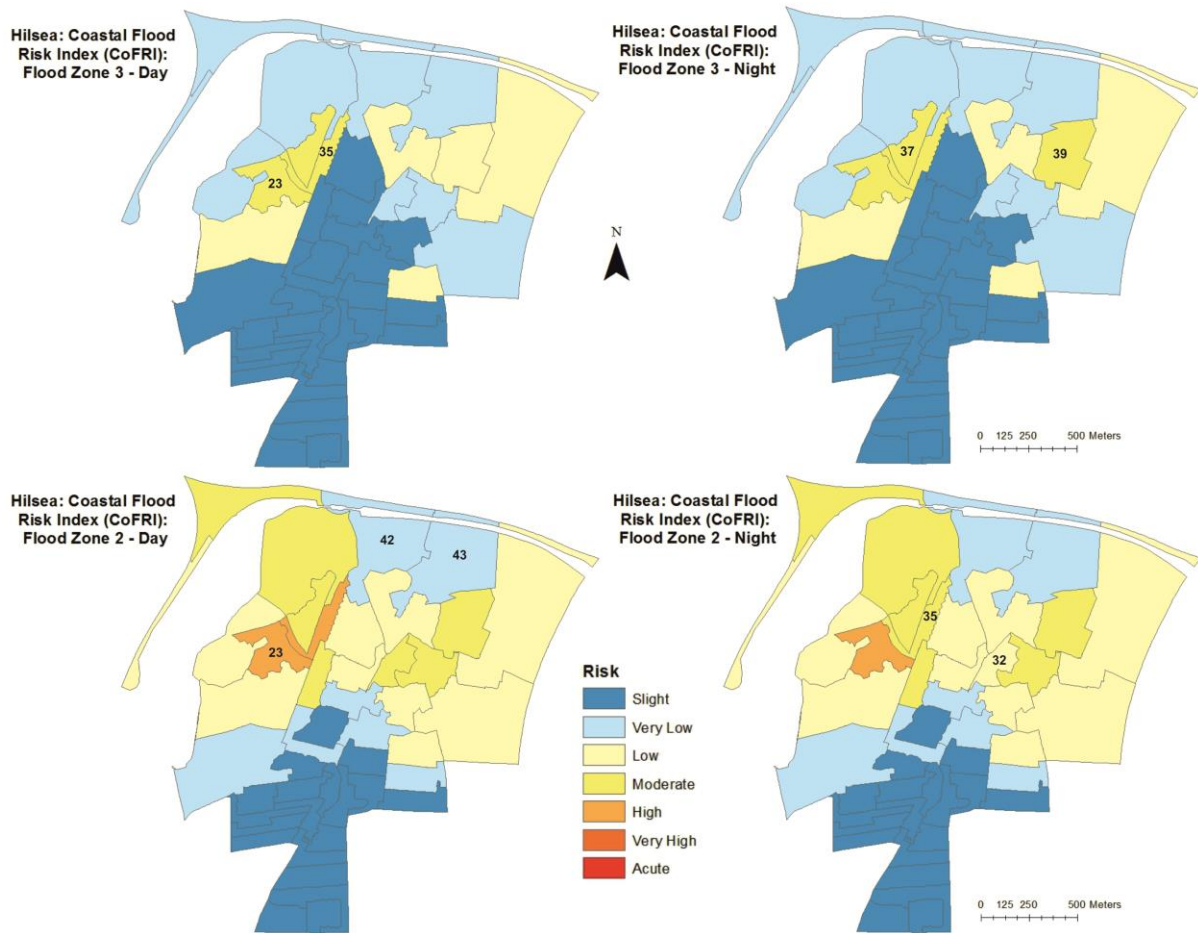
394



395

396 Figure 3. CoFVI for Hilsea ward at OA level - Day & Night. Numbers (Table 1) highlight
 397 certain neighbourhoods due to resulting vulnerability levels. ©Crown Copyright/database
 398 right supplied by Ordnance Survey and Contains National Statistics data © Crown copyright
 399 and database right [2017] (for ONS)

400



401

402 Figure 4. CoFRI for Hilsea ward at OA level – Flood Zone 3 and 2, Day & Night. Numbers

403 (Table 2) highlight certain neighbourhoods due to resulting risk levels. ©Crown

404 Copyright/database right supplied by Ordnance Survey and Contains National Statistics data

405 © Crown copyright and database right [2017] (for ONS)

406

407 All Coastal Flood Vulnerability and Risk results for the ward of Hilsea are presented
 408 in Tables 1 and 2, and Figures 3, and 4. Numbers highlighted in bold in Tables 1 and 2
 409 indicate neighbourhoods with notable vulnerability or risk levels (lowest or highest) and are
 410 also highlighted in Figures 3 and 4. Figure 3 and Table 1 show that during the day the
 411 majority of Hilsea’s neighbourhoods have low or moderate vulnerability. Two particular
 412 neighbourhoods (42 and 43) have very low vulnerability and are situated on the northern
 413 coastline of the ward. Neighbourhoods 23 and 35 have the highest vulnerability levels within
 414 Hilsea; these are situated adjacent to each other at the north-west end of the ward, close to the
 415 coastline. These levels are due to very low resilience, and moderate physical and socio-
 416 economic vulnerability. Neighbourhood 23 has the highest amount of children, lone parent
 417 households with dependent children, dwellings and renters. It has very high day population

418 numbers and many unemployed. It also has very few areas of green space, few main
419 accessible transport links, and no essential buildings. Neighbourhood 35 has very high
420 numbers of renters and multiple residency buildings, very little green spaces and hardly any
421 accessible transport links, high numbers of unemployed and the highest number of
422 households with no car availability in Hilsea.

423 The night analysis presents change for the Hilsea vulnerability results (Figure 3 and
424 Table 2). Neighbourhood 23 still has high vulnerability, whereas neighbourhood 35's levels
425 have lowered to moderate. The former neighbourhood (23) has the highest night population
426 within Hilsea, increasing the night vulnerability level, resulting in neighbourhood 23 having
427 the highest overall vulnerability level in Hilsea for both day and night time. Neighbourhood
428 35 compared to other neighbourhoods in the ward has a very low night population, hence
429 decreasing its overall vulnerability level. Neighbourhood 32 also decreases in vulnerability
430 from day to night time; this is due to a very low day population and a slight night population,
431 compared to other neighbourhoods within Hilsea. Whereas neighbourhood 13 has a moderate
432 day population but a low night population, again causing a drop in vulnerability levels.

433 For a Flood Zone 3 event during the day and night, the ward of Hilsea has three
434 neighbourhoods that are most at risk – 23, 35 and 37 (Figure 4). These three neighbourhoods
435 have higher levels of vulnerability for all three of the vulnerability component analyses
436 (CoFPV, CoFSV & CoFRE). This combined with the chance of acute inundation coverage,
437 resulted in moderate coastal flood risk. Neighbourhood 39 has moderate risk during the night
438 time due to diurnal population changes compared to other Hilsea neighbourhoods. The risk
439 levels for the centre and southern end of the ward are mostly slight, due to no flood water
440 coverage predicted in these areas. However, all neighbourhoods surrounded by the coastline
441 are at risk, yet that risk is very low. In fact the results show that neighbourhoods further
442 inland were the most at risk rather than those along the coastline. This is due to high levels of
443 underlying vulnerability combined with total flood water coverage.

444 For a Flood Zone 2 (1 in 1000 year) event, many neighbourhoods have substantial
445 risk levels (Figure 4), due to potential spread of inundation. Within Hilsea risk levels range
446 from slight to high, however the southern end has either slight or no risk, as the flood water
447 again would not travel this far. This part of Hilsea is certainly the safest with regard to coastal
448 flooding, which is advantageous as some of the neighbourhoods in this region had moderate
449 vulnerability levels. For a Flood Zone 2 event, many more neighbourhoods (twenty four)
450 have risk levels compared to a Flood Zone 3 event. This is due to more flood water

451 inundating areas, and spreading further into the ward, affecting more neighbourhoods in the
452 centre and further south.

453 Again the three neighbourhoods 23, 35 and 37 have the highest risk levels within
454 Hilsea during both time zones for a flood event of this magnitude. However, neighbourhood
455 35 has moderate risk during the night time, due to distinct changes in day and night time
456 populations. Although neighbourhoods 42 and 43 (situated on Hilsea's northern coastline)
457 would be expected to be of high risk due to their proximity to the water and predicted almost
458 full coverage by flood water (especially in 1 in 1000 year event), the risk levels are in fact
459 very low, due to the very low levels of underlying vulnerability including very low numbers
460 of children, elderly, sick, lone parents, non-English speakers, communal community
461 residents, households without cars, multiple residency buildings, renters, commercial and
462 industrial buildings.

463

464

Discussion

465 It is essential we assess and pinpoint flood risk in a way that provides as clear a picture as
466 possible of the reality of local areas in order to understand and assess risk for future flood risk
467 management activities. By understanding, evaluating and representing specific local contexts
468 (socio-economic, physical, and resilient) diurnally, that shape the local flood risk problem
469 within the flood risk management process (Maskrey *et al.* 2016), we can strive towards flood
470 risk management practices that are successful and embed resilience into the community. To
471 move towards this approach an appropriate vulnerability and risk analysis is needed, an
472 example of which has been established within the paper.

473 The flood vulnerability and risk model presented (Figure 2) combines key
474 components of vulnerability into one framework at the most efficacious level possible
475 (neighbourhood scale), as this represents a level in which principle dimensions of
476 vulnerability are founded and includes the 'physical', 'social', and 'resilient' composition of
477 an area, diurnally. The resulting maps allow us to understand flood risk communities in a
478 methodical and comprehensive way, identify potential fragilities and allow better targeting of
479 new interventions to improve resilience and reduce vulnerability in the long term. The
480 Coastal Flood Vulnerability and Risk analyses for Hilsea presented in this paper, provided
481 new knowledge and understanding of which particular Hilsea regions are vulnerable at
482 different times of day, and how this affects levels of risk. Critically it was in fact
483 neighbourhoods further inland (rather than those directly on the coast as one might expect)
484 that had the highest levels of flood risk in Hilsea, and this was due to the substantial levels of

485 underlying vulnerability in those areas. For instance neighbourhood 23 has the highest levels
486 of risk for both time zones, due to having acute or very high levels for the majority of its
487 vulnerability factors. Some neighbourhoods in Hilsea have one or two vulnerability factors
488 that are the highest in Hilsea, yet the remaining factors have either low or moderate
489 vulnerability levels, resulting in that neighbourhood having low or moderate levels of risk.
490 The results from this study highlight that only when many or the majority of a
491 neighbourhood's vulnerability factors have significantly high levels of vulnerability, will a
492 neighbourhood have a high level of risk. Additionally, if a factor also significantly shifts
493 from day to night time i.e. population, this can result in a neighbourhood with a key change
494 in risk level (neighbourhood 32 and 35). A critical point when planning emergency
495 management strategies for Hilsea i.e. where are populations concentrated within an area
496 during different times of the day. By analysing at this resolution, this methodology has
497 identified key vulnerable and at risk areas within Hilsea that have been undetected by other
498 assessments (notably the Local Strategic Flood Risk Assessment (Atkins 2007) and the UK
499 River and Coastal Flood Disadvantage Index (Climate Just 2015)) that have influence on
500 flood risk management decisions.

501 However, there are opportunities to further develop this methodology. Despite many
502 vulnerability indices being created over time as a quick and consistent method for
503 characterising relative vulnerability of different areas, the use of factors to represent reality in
504 order to assist our urban/community comparisons, diurnally, can be subjective. There are
505 many different definitions of vulnerability, and yet it is a concept that comprises a multitude
506 of processes and aspects, the understanding of which helps with our understanding of risk and
507 thus helps with our disaster risk reduction activities. Therefore, what one perceives as
508 vulnerability, another may not. It is recommended that indices used for any natural hazards
509 should be continuously developed as new knowledge is discovered or superior analytical
510 processes created, assuring the best results for that time.

511 In this particular study, some of the differences between vulnerability levels for the
512 Hilsea day and night analyses were very small (Tables 1 and 2), and these differences did not
513 always transpire visually in the vulnerability and risk maps (Figures 3 and 4). There is an
514 opportunity to further investigate this method to include other variables that clearly
515 distinguish the difference between a day and night flood event; further establishing a
516 distinction of vulnerability between the time zones. There is also an opportunity to develop
517 the resilience component, which had the fewest factors (including no diurnal ones) and
518 variables for analysis, due to its complexity. Three examples of factors that could be

519 considered for this component are; *flood insurance, flood awareness* and *building adaptation*
520 *measures*. Possessing flood insurance (i.e. Flood Re) would increase local resilience as
521 dwellers would have the documentation necessary to assist with their personal and financial
522 recovery from flood damage. Awareness and knowledge of floods would also improve
523 resilience as residents would be prepared. Building flood adaptation measures (e.g. wet-
524 proofing, dry proofing, raising floor levels, one way valves, specific building regulations etc.)
525 would again increase community resilience, and is well established in European coastal
526 communities that have high flood risk e.g. Dordrecht, Netherlands and Hafen City, Germany
527 (Goltermann *et al.* 2008).

528

529

Conclusion

530 Being flooded is traumatic, and floods at night are predominantly more dangerous than
531 during the day. Recent UK flood events have brought serious concerns about the
532 effectiveness of current flood risk management (Committee on Climate Change 2016) and
533 the levels of impacts to those that are most vulnerable. Added to this, is a general lack of
534 flood awareness and care in communities, plus expected increases in frequency and intensity
535 of future inundation events due to changing climatic conditions, further compounding the
536 urgent need to measure and map flood vulnerability, highlighting areas of high risk,
537 facilitating better mitigation and adaptation. To address this challenge, this paper has
538 presented a methodology that can capture the relevant features of flood vulnerability,
539 assisting our understanding of the reality of vulnerability (diurnally) at the level of detail
540 necessary to truly deliver effective solutions (locally). The flood vulnerability and risk model
541 presented has been tested on the city of Portsmouth, UK, with the results for one of
542 Portsmouth's electoral wards (Hilsea) shown as an example. The resulting indexes and maps
543 for Hilsea highlight areas with high levels of flood vulnerability and risk at different times of
544 day; leading to previously unidentified communities requiring attention before and during a
545 flood, thereby improving flood risk identification and future placement for flood risk
546 management practices, increasing overall flood resilience. The results presented emphasise
547 that in order to better support the development of future flood management policy and
548 planning, integrated assessments of climatic change in flood risk areas are required, including
549 the significant non-climatic aspects, such as time zones, physical (the land), socio-economic
550 and resilience indicators, in order to understand the possible degree of impact for a
551 community to this event. This model could be utilised by flood delegates (flood managers,
552 emergency planners, and Local Resilience Forum members) to assist with future flood

553 preparedness, effective flood risk management and communication, potentially and critically
 554 improving urban flood resilience in vulnerable communities.

555

556 **Acknowledgements**

557 We wish to thank Ordnance Survey for their assistance and Studentship Bursary that
 558 supported this research. Part of the research presented in this manuscript is based on a PhD
 559 thesis submitted to the University of Portsmouth:

560 https://researchportal.port.ac.uk/portal/files/5488234/spercival_thesis.pdf

561

562 **References**

- 563 • Adam, B. and Loon, J. van. (2000) *Repositioning risk; the challenge for social theory*.
 564 SAGE Publications, London.
- 565 • Adger, W.N. (2006) Vulnerability. *Global Environ Chang.*, 16 (3), 268–281.
 566 doi:10.1016/j.gloenvcha.2006.02.006.
- 567 • Atkins (2007). Strategic Flood Risk Assessment (SFRA) report *Partnership for*
 568 *Urban South Hampshire*.
- 569 • Atkins (2011). Flood risk overview. Guidance document: *Portsmouth City Council,*
 570 *Partnership for Urban South Hampshire*.
- 571 • Balica, S. (2012) Approaches of Understanding Developments of Vulnerability
 572 Indices for Natural Disasters. *J Environ Eng.*, 11 (5), 963-974.
- 573 • Balica, S.F. Wright, N.G. and Meulen, F. (2012) A Flood Vulnerability Index for
 574 Coastal Cities and its use in Assessing Climate Change Impacts. *Nat Hazards.*, 64 (1),
 575 73–105. doi:10.1007/s11069-012-0234-1.
- 576 • Balica, S.F. Popescu, I. Wright, N.G. and Beevers, L. (2013) Parametric and Physical
 577 Modelling Techniques for Flood Risk and Vulnerability Assessment: A Comparison.
 578 *Environ Model and Softw.*, 41, 84-92. doi: 10.1016/j.envsoft.2012.11.002.
- 579 • Başaran-Uysal, A. Sezen, F. Özden, S. and Karaca, Ö. (2014) Classification of
 580 Residential Areas According to Physical Vulnerability to Natural Hazards: A Case
 581 Study of Çanakkale, Turkey. *Disasters.*, 38 (1), 202–226. doi:10.1111/disa.12037.
- 582 • BBC. (2007) Thousands go home after tidal fear [online]. BBC.
 583 <http://news.bbc.co.uk/1/hi/england/7086280.stm> [accessed 24 April 2018]

- 584 • BBC. (2017) Storm surge: Severe flooding avoided in Essex, Suffolk and Norfolk
 585 [online]. BBC. <http://www.bbc.co.uk/news/uk-england-38619611> [accessed 24 April
 586 2018]
- 587 • Beck, U. (2000) *Risk society revisited: Theory, politics and research programmes*. In:
 588 *The Risk Society and Beyond*. SAGE Publications, London.
- 589 • Birkmann, J. (2006) *Measuring vulnerability to promote disaster-resilient societies:
 590 conceptual frameworks and definitions*. United Nations University Press, Tokyo.
- 591 • Birkmann, J. Cardona, O.D. Carreño, M.L. Barbat, A.H. Pelling, M. Schneiderbauer,
 592 S. Kienberger, S. Keiler, M. Alexander, D. Zeil, P. and Welle, T. (2013) Framing
 593 Vulnerability, Risk and Societal Responses: the MOVE Framework. *Nat Hazards*, 67
 594 (2), 193–211. doi:10.1007/s11069-013-0558-5.
- 595 • Boruff, B.J. Emrich, C. and Cutter, S.L. (2005) Erosion Hazard Vulnerability of US
 596 Coastal Counties. *J Coastal Res.*, 21 (5), 932–942.
- 597 • Bracken, L.J. Oughton, E.A. Donaldson, A. Cook, B. Forrester, J. Spray, C. Cinderby,
 598 S. Passmore, D. and Bissett, N. (2016) Flood Risk Management, an Approach to
 599 Managing Cross-border Hazards. *Nat Hazards*, 82 (2), 217-240. doi:
 600 10.1007/s11069-016-2284-2.
- 601 • Briguglio, L. and Kisanga, E.J. (2004) *Economic vulnerability and resilience:
 602 concepts and measurements*. Commonwealth Secretariat and the University of Malta.
- 603 • Building Futures (2009) Facing up to rising sea-levels: retreat? defend? attack? The
 604 future of our coastal and estuarine cities. [online] RIBA.
 605 [http://www.buildingfutures.org.uk/assets/downloads/Facing_Up_To_Rising_Sea_Lev
 606 els.pdf](http://www.buildingfutures.org.uk/assets/downloads/Facing_Up_To_Rising_Sea_Levels.pdf) [accessed 4 January 2016]
- 607 • Bush, C.E. and Cerveny, R.S. (2013) Diurnal and Seasonal Variations in Flash Floods
 608 across the Western United States. *J Ariz-Nev Acad Sci.*, 44 (2), 143-152.
- 609 • Cancado, V. Brasil, L. Nascimento, N. and Guerra, A. (2008) Flood risk assessment
 610 in an urban area: measuring hazard and vulnerability. *International Conference on
 611 Urban Drainage*, Edinburgh, Scotland, UK.
- 612 • Cardona, O.D (2011) *Disaster risk and vulnerability: concepts and measurement of
 613 human and environmental insecurity*. In: Brauch H. et al. (eds) *Coping with global
 614 environmental change, disasters and security*. Hexagon Series on Human and
 615 Environmental Security and Peace, vol 5. Springer, Berlin, Heidelberg

- 616 • Cardona, O.D. Aalst, M.K. van. Birkmann, J. Fordham, M. McGregor, G. Perez, R.
 617 Pulwarty, R.S. Schipper, E.L.F. and Sinh, B.T. (2012). Determinants of risk: exposure
 618 and vulnerability. In: *Managing the risks of extreme events and disasters to advance*
 619 *climate change adaptation. A special report of working groups I and II of the*
 620 *Intergovernmental Panel on Climate Change (IPCC) Cambridge University Press,*
 621 *Cambridge, UK, and New York, NY, USA.*
- 622 • Carreno, M.L. Cardona, O.D. and Barbat, A.H. 2007. Urban Seismic Risk Evaluation:
 623 a Holistic Approach. *Nat Hazards.*, 40 (1), 37–172.
- 624 • Chang, S.E. and Shinozuka, M. 2004. Measuring Improvements in the Disaster
 625 Resilience of Communities. *Earthq Spectra.*, 20 (3), 739–755.
- 626 • Climate Just. (2015) Welcome to Climate Just web tool [online]. Climate Just.
 627 <http://www.climatejust.org.uk/> [accessed 4 December 2017]
- 628 • Committee on Climate Change. (2016) UK climate change risk assessment 2017 –
 629 Synthesis report: priorities for the next five years [online].
 630 [https://www.theccc.org.uk/wp-content/uploads/2016/07/UK-CCRA-2017-Synthesis-](https://www.theccc.org.uk/wp-content/uploads/2016/07/UK-CCRA-2017-Synthesis-Report-Committee-on-Climate-Change.pdf)
 631 [Report-Committee-on-Climate-Change.pdf](https://www.theccc.org.uk/wp-content/uploads/2016/07/UK-CCRA-2017-Synthesis-Report-Committee-on-Climate-Change.pdf) [accessed 12 January 2018]
- 632 • Connor R. F. and Hiroki K. (2005) Development of a Method for Assessing Flood
 633 Vulnerability, *Water Sci Technol.*, 51 (5), 61–67.
- 634 • Cutter, S.L. Boruff, B.J. and Shirley, W.L. (2003) Social Vulnerability to
 635 Environmental Hazards. *Soc Sci Q.*, 84 (2), 242–261.
- 636 • Cutter, S.L. (2006) *Hazards vulnerability and environmental justice*. Taylor and
 637 Francis.
- 638 • Cutter, S.L. Emrich, C.T. Webb, J.J. and Morath, D. (2009) *Social vulnerability to*
 639 *climate variability hazards: A review of the literature. Final report to Oxfam*
 640 *America*. [online]. <http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.458.7614>
 641 [accessed 12 January 2018]
- 642 • Damm, M. (2010) Mapping socio-ecological vulnerability to flooding. PhD
 643 Dissertation
- 644 • DEFRA. and EA (2006). R&D outputs: Flood risks to people. Phase 2. FD2321/TR1
 645 The flood risks to people methodology *London: Department for Environment Food*
 646 *and Rural Affairs and the Environment Agency.*
- 647 • Earth Networks. (2017) Dangers of floods: Considerations for environmental health
 648 professionals [online]. Earth Networks.

- 649 [https://www.earthnetworks.com/blog/dangers-of-floods-for-environmental-health-](https://www.earthnetworks.com/blog/dangers-of-floods-for-environmental-health-professionals/)
 650 [professionals/](https://www.earthnetworks.com/blog/dangers-of-floods-for-environmental-health-professionals/) [accessed 22 January 2018]
- 651 • England K. and Knox K. (2015) Targeting flood investment and policy to minimise
 652 flood disadvantage [online]. Joseph Rowntree Foundation.
 653 [https://www.jrf.org.uk/report/targeting-flood-investment-and-policy-minimise-flood-](https://www.jrf.org.uk/report/targeting-flood-investment-and-policy-minimise-flood-disadvantage)
 654 [disadvantage](https://www.jrf.org.uk/report/targeting-flood-investment-and-policy-minimise-flood-disadvantage) [accessed 22 January 2018]
 - 655 • Environment Agency. (2010) Portsmouth Fact Sheet Report
 - 656 • Environment Agency. (2012) Conversations on vulnerable buildings
 - 657 • Environment Agency. (2014) Flood warnings – what they are and what to do [online].
 658 GOV UK. [https://www.gov.uk/government/publications/flood-warnings-what-they-](https://www.gov.uk/government/publications/flood-warnings-what-they-are-and-what-to-do)
 659 [are-and-what-to-do](https://www.gov.uk/government/publications/flood-warnings-what-they-are-and-what-to-do) [accessed 22 April 2018]
 - 660 • Environment Agency. (2018) How to plan ahead for flooding [online]. GOV UK.
 661 [https://flood-warning-information.service.gov.uk/plan-ahead-for-](https://flood-warning-information.service.gov.uk/plan-ahead-for-flooding?utm_source=warning&utm_medium=gov.uk&utm_campaign=prepare&utm_content=national-view)
 662 [flooding?utm_source=warning&utm_medium=gov.uk&utm_campaign=prepare&utm](https://flood-warning-information.service.gov.uk/plan-ahead-for-flooding?utm_source=warning&utm_medium=gov.uk&utm_campaign=prepare&utm_content=national-view)
 663 [_content=national-view](https://flood-warning-information.service.gov.uk/plan-ahead-for-flooding?utm_source=warning&utm_medium=gov.uk&utm_campaign=prepare&utm_content=national-view)
 - 664 • Goltermann, D. Ujeyl, G. and Pasche, E. (2008) Making coastal cities flood resilient
 665 in the era of climate change. *4th International Symposium on Flood Defence:
 666 Managing Flood Risk, Reliability and Vulnerability*. Toronto, Ontario, Canada.
 - 667 • Gornitz, V. (1991) Global Coastal Hazards from Future Sea Level Rise. *Palaeogeogr
 668 Palaeocl.*, 89 (4), 379–398.
 - 669 • Green, C.H. Parker, D.J. and Tunstall, S.M (2000) Assessment of flood control and
 670 management options *World Commission on Dams, Cape Town*.
 - 671 • Hadley, D. (2009) Land Use and the Coastal Zone. *Land Use Policy.*, 26 (1), S198–
 672 S203. doi:10.1016/j.landusepol.2009.09.014.
 - 673 • Hampshire Fire and Rescue. (2013) Written and telephone correspondence on
 674 vulnerable buildings
 - 675 • IPCC (2014). Summary for policymakers. In: *Climate change 2014: Impacts,
 676 adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of
 677 Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on
 678 Climate Change Cambridge University Press, Cambridge, United Kingdom and New
 679 York, NY, USA.*

- 680 • Kaźmierczak, A. and Cavan, G. (2011) Surface Water Flooding Risk to Urban
681 Communities: Analysis of Vulnerability, Hazard and Exposure. *Landsc Urban Plann.*,
682 103 (2), 185–197. doi:10.1016/j.landurbplan.2011.07.008.
- 683 • Lindley, S. O’Neill, J. Kandeh, J. Lawson, N. Christian, R. and O’Neil, M. (2011)
684 Climate change, justice and vulnerability [online]. Joseph Rowntree Foundation.
685 www.jrf.org.uk/publications/climate-change-justice-and-vulnerability [accessed 4
686 January 2016]
- 687 • Maantay, J. and Maroko, A. (2009) Mapping Urban Risk: Flood Hazards, Race, and
688 Environmental Justice in New York. *Appl Geogr.*, 29 (1), 111-124. doi:
689 10.1016/j.jageog.2008.08.002.
- 690 • Maskrey, S.A. Mount, N.J. Thorne, C.R. and Dryden, I. (2016) Participatory
691 Modelling for Stakeholder Involvement in the Development of Flood Risk
692 Management Intervention Options. *Environ Model Softw* 82, 275-294.
693 <http://doi.org/10.1016/j.envsoft.2016.04.027>
- 694 • Menoni, S. Molinari, D. Parker, D. Ballio, F. and Tapsell, S. (2012) Assessing
695 Multifaceted Vulnerability and Resilience in Order to Design Risk-mitigation
696 Strategies. *Nat Hazards.*, 64 (3), 2057–2082. doi: 10.1007/s11069-012-0134-4.
- 697 • Met Office. (2014) 1953 East coast flood - 60 years on [online].
698 <http://www.metoffice.gov.uk/news/in-depth/1953-east-coast-flood> [accessed 4
699 January 2016]
- 700 • Miltner, O. (2017) 5 dangers to be aware of after a flood strikes [online].
701 AccuWeather. [https://www.accuweather.com/en/weather-news/5-dangers-to-be-](https://www.accuweather.com/en/weather-news/5-dangers-to-be-aware-of-after-a-flood-strikes/70002092)
702 [aware-of-after-a-flood-strikes/70002092](https://www.accuweather.com/en/weather-news/5-dangers-to-be-aware-of-after-a-flood-strikes/70002092) [accessed 12 January 2018]
- 703 • National Flood Forum. (2016) At risk of flooding? [online]. National Flood Forum.
704 <http://www.nationalfloodforum.org.uk/at-risk-of-flooding-2/> [accessed 4 January
705 2018]
- 706 • Newry, Mourne and Down District Council. (2016) Flood safety advice [online].
707 http://www.newrymournedown.org/flood_safety_advice [accessed 12 January 2018]
- 708 • New Forest District Council. (NFDC) (2009) Cabinet 06/07/09 report a: North Solent
709 shoreline management plan. New Forest District Council [online].
710 <http://www.northsolentsmp.co.uk/9907> [accessed 1 October 2014]
- 711 • NOAA. (2015) Flash flood safety *National Oceanic and atmospheric Administration*
712 *and National Weather Service*.

- 713 • Norfolk Constabulary. (2017) Flood awareness event for locals in Yarmouth [online].
 714 Norfolk Constabulary. [https://www.norfolk.police.uk/news/latest-news/flood-](https://www.norfolk.police.uk/news/latest-news/flood-awareness-event-locals-yarmouth)
 715 [awareness-event-locals-yarmouth](https://www.norfolk.police.uk/news/latest-news/flood-awareness-event-locals-yarmouth) [accessed 24 April 2018]
- 716 • Portsmouth City Council. (2011a) Flood response plan: Part 2 [online].
 717 <https://www.portsmouth.gov.uk/ext/documents-external/cou-flood-response-plan.pdf>.
 718 [accessed 1 October 2014]
- 719 • Portsmouth City Council. (2011b) Multi agency flood response plan [online].
 720 [https://www.portsmouth.gov.uk/ext/documents-external/cou-multi-](https://www.portsmouth.gov.uk/ext/documents-external/cou-multi-agencyfloodplan.pdf)
 721 [agencyfloodplan.pdf](https://www.portsmouth.gov.uk/ext/documents-external/cou-multi-agencyfloodplan.pdf). [accessed 1 October 2014]
- 722 • Portsmouth City Council. (2011c) Strategy approval report. Environment Agency
 723 [online]. [https://www.portsmouth.gov.uk/ext/documents-external/pln-local-dev-](https://www.portsmouth.gov.uk/ext/documents-external/pln-local-dev-portseaisland-coastal-strategy-study.pdf)
 724 [portseaisland-coastal-strategy-study.pdf](https://www.portsmouth.gov.uk/ext/documents-external/pln-local-dev-portseaisland-coastal-strategy-study.pdf). [accessed 1 October 2014]
- 725 • Public Health England. (2015) Flooding advice for the public [online].
 726 [https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/401980](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/401980/flood_leaflet_2015_final.pdf)
 727 [/flood_leaflet_2015_final.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/401980/flood_leaflet_2015_final.pdf) [accessed 22 January 2018]
- 728 • Ramieri, E. Hartley, A. Barbanti, A. Duarte Santos, F. Gomes, A. Hilden, M.
 729 Laihonon, P. Marinova, N. and Santini, M. (2011) Methods for assessing coastal
 730 vulnerability to climate change. European Topic Centre on Climate Change Impacts,
 731 Vulnerability and Adaptation (ETC CCA) *Technical Paper, Bologna (IT)* 93.
- 732 • Renn, O. (1992) *Concepts of risk: A classification*. In: *Social theories of risk*. Praeger,
 733 Westport.
- 734 • Rougier, J. Sparks, S. and Hill, L. (2013) *Risk and uncertainty assessment for natural*
 735 *hazards*. Cambridge University Press.
- 736 • Rygel, L. O'Sullivan, D. and Yarnal, B. (2006) A Method for Constructing a Social
 737 Vulnerability Index. *Mitig Adapt Strat Gl* 11 (3), 741-764.
 738 <http://doi.org/10.1007/s11027-006-0265-6>
- 739 • Sullivan C.A and Meigh J. (2005) Targeting Attention on Local Vulnerabilities Using
 740 an Integrated Index Approach: The Example of the Climate Vulnerability Index. *Wat*
 741 *Sci Tech* 51 (5), 69-78.
- 742 • Tapsell, S. McCarthy, S. Faulkner, H. and Alexander, M (2010). Social vulnerability
 743 to natural hazards. State of the art report. *CapHaz-Net's WP4. London*.
- 744 • Tierney, K.J. Lindell, M.K. and Perry, R.W. (2001) *Facing the unexpected: Disaster*
 745 *preparedness and response in United States*. Washington, D.C, Joseph Henry Press.

- 746 • United Nations Office for Disaster Risk Reduction (UNISDR). (2009) Terminology
 747 on disaster risk reduction [online].
 748 <https://www.unisdr.org/we/inform/publications/7817> [accessed 24 April 2018]
- 749 • Wadey M.P. Nicholls R.J. and Hutton, C. (2012) Coastal Flooding in the Solent: An
 750 Integrated Analysis of Defences and Inundation. *Water-Sui.*, 4 (2), 430–459. doi:
 751 10.3390/w4020430
- 752 • Wadey, M.P. Nicholls, R.J. and Haigh, I. (2013) Understanding a Coastal Flood
 753 Event: the 10th March 2008 Storm Surge Event in the Solent, UK. *Nat Hazards.*, 67
 754 (2), 829–854. doi: 10.1007/s11069-013-0610-5
- 755 • Wamsler, C. (2006) Mainstreaming Risk Reduction in Urban Planning and Housing: a
 756 Challenge for International aid Organisations. *Disasters.* 30 (2), 15–177.
- 757 • White, P. Pelling, M. Sen, K. Seddon, D. Russel, S. and Few, R. (2004) Disaster Risk
 758 Reduction: A Development Concern [online]. Department for International
 759 Development (DFID). <https://www.preventionweb.net/publications/view/1070>
 760 [accessed 1 October 2014]
- 761 • Wilkinson, M.E. Mackay, E. Quinn, P.F. Stutter, M. Beven, K.J. MacLeod C.J.A.
 762 Macklin, M.G. Elkhatab, Y. Percy, B. Vitolo, C. and Haygarth, P.M. (2015) A Cloud
 763 Based Tool for Knowledge Exchange on Local Scale Flood Risk. *J Environ Manage.*,
 764 161, 38-50. doi: 10.1016/j.jenvman.2015.06.009
- 765 • Wilson, L. O’Brien, G. O’Keefe, P. and England, K. (2014) Barriers to Adaptation in
 766 Newcastle upon Tyne, UK: Preliminary Findings. *Urban Climate.*, 7, 33-46.
 767 <http://doi.org/10.1016/j.uclim.2013.10.003>
- 768 • Wisner, B., Blaikie, P, Cannon, T, and Davis, I (2004). *At risk: natural hazards,*
 769 *people’s vulnerability and disasters.* Second edition. Taylor and Francis, London.

771 **Word Count**

772 5980

774 **Figure Legends**

775 Figure 1. Location map of Hilsea and Portsmouth. Inset boxes shows the location of Hilsea
 776 within Portsmouth and Portsmouth within the UK. Map data © OpenStreetMap

777

778 Figure 2. CoFRI and CoFVI model including data variables and vulnerability factors. NC:
779 UK 2011 National Census. LU: Land Use

780

781 Figure 3. CoFVI for Hilsea ward at OA level - Day & Night. Numbers (Table 1) highlight
782 certain neighbourhoods due to resulting vulnerability levels. ©Crown Copyright/database
783 right supplied by Ordnance Survey and Contains National Statistics data © Crown copyright
784 and database right [2017] (for ONS)

785

786 Figure 4. CoFRI for Hilsea ward at OA level – Flood Zone 3 and 2, Day & Night. Numbers
787 (Table 2) highlight certain neighbourhoods due to resulting risk levels. ©Crown
788 Copyright/database right supplied by Ordnance Survey and Contains National Statistics data
789 © Crown copyright and database right [2017] (for ONS)

790

791

Captions

792 Figure 1 – Hlisea

793

Tables

794 Table 1 Coastal Flood Vulnerability Index (CoFVI), Coastal Flood Hazard Index (CoFHI) and
795 Coastal Flood Risk Index (CoFRI) results for each neighbourhood (OA) within Hilsea, during the day
796 time, for floods of different magnitude (FZ3 and FZ2). Numbers highlighted in bold indicate
797 neighbourhoods with notable vulnerability and risk levels during the day time

| Hilsea Neighbourhoods | Output Area Codes | Day Coastal Flood Vulnerability Levels | Coastal Flood Hazard Levels - Flood Zone 3 | Coastal Flood Hazard Levels – Flood Zone 2 | Day Coastal Flood Risk Levels (Flood Zone 3) | Day Coastal Flood Risk Levels (Flood Zone 2) |
|--------------------------|----------------------|--|---|---|--|--|
| 1 | E00086307 | 0.404 | 0.056 | 0.848 | 0.023 | 0.343 |
| 2 | E00086279 | 0.551 | 0 | 0 | 0 | 0 |
| 3 | E00086288 | 0.417 | 0 | 0 | 0 | 0 |
| 4 | E00086289 | 0.414 | 0 | 0 | 0 | 0 |
| 5 | E00086290 | 0.484 | 0 | 0 | 0 | 0 |
| 6 | E00086283 | 0.41 | 0 | 0 | 0 | 0 |
| 7 | E00086287 | 0.349 | 0 | 0 | 0 | 0 |
| 8 | E00086316 | 0.311 | 0.329 | 0.853 | 0.102 | 0.265 |
| 9 | E00086282 | 0.431 | 0 | 0 | 0 | 0 |
| 10 | E00086285 | 0.383 | 0 | 0 | 0 | 0 |
| 11 | E00086284 | 0.426 | 0 | 0 | 0 | 0 |
| 12 | E00086286 | 0.369 | 0 | 0 | 0 | 0 |
| 13 | E00086281 | 0.431 | 0 | 0 | 0 | 0 |
| 14 | E00086318 | 0.341 | 0 | 0 | 0 | 0 |
| 15 | E00086314 | 0.372 | 0 | 0.001 | 0 | 4E-04 |
| 16 | E00086315 | 0.386 | 0 | 0 | 0 | 0 |
| 17 | E00086304 | 0.321 | 0 | 0.043 | 0 | 0.014 |

| | | | | | | |
|-----------|------------------|--------------|--------------|--------------|--------------|--------------|
| 18 | E00086311 | 0.44 | 0 | 0.355 | 0 | 0.156 |
| 19 | E00086320 | 0.316 | 0 | 0 | 0 | 0 |
| 20 | E00086310 | 0.296 | 0 | 0 | 0 | 0 |
| 21 | E00086313 | 0.395 | 0.01 | 0.168 | 0.004 | 0.066 |
| 22 | E00086278 | 0.404 | 0.777 | 1 | 0.314 | 0.403 |
| 23 | E00086300 | 0.6 | 0.89 | 1 | 0.534 | 0.6 |
| 24 | E00086301 | 0.556 | 0.095 | 0.92 | 0.053 | 0.512 |
| 25 | E00086305 | 0.397 | 0 | 0.636 | 0 | 0.252 |
| 26 | E00086303 | 0.428 | 0.111 | 1 | 0.047 | 0.428 |
| 27 | E00086309 | 0.347 | 0.779 | 1 | 0.27 | 0.347 |
| 28 | E00086317 | 0.396 | 0.224 | 0.649 | 0.089 | 0.257 |
| 29 | E00086319 | 0.373 | 0 | 0.064 | 0 | 0.024 |
| 30 | E00086312 | 0.361 | 0.922 | 1 | 0.333 | 0.361 |
| 31 | E00086308 | 0.459 | 0.006 | 0.621 | 0.003 | 0.285 |
| 32 | E00086299 | 0.435 | 0.39 | 1 | 0.17 | 0.435 |
| 33 | E00086306 | 0.481 | 0.54 | 1 | 0.26 | 0.481 |
| 34 | E00086298 | 0.306 | 0.699 | 1 | 0.214 | 0.306 |
| 35 | E00086296 | 0.584 | 0.934 | 1 | 0.546 | 0.584 |
| 36 | E00086295 | 0.332 | 0.414 | 1 | 0.137 | 0.332 |
| 37 | E00086294 | 0.529 | 0.966 | 1 | 0.511 | 0.529 |
| 38 | E00086293 | 0.373 | 0.9 | 0.999 | 0.335 | 0.372 |
| 39 | E00086297 | 0.436 | 0.981 | 1 | 0.427 | 0.436 |
| 40 | E00086302 | 0.398 | 0.845 | 1 | 0.337 | 0.398 |
| 41 | E00086291 | 0.461 | 0.601 | 0.971 | 0.277 | 0.448 |
| 42 | E00086292 | 0.248 | 0.691 | 0.999 | 0.171 | 0.248 |
| 43 | E00086280 | 0.28 | 0.83 | 1 | 0.233 | 0.28 |

798

799

800

801

802

Table 2 Coastal Flood Vulnerability Index (CoFVI), Coastal Flood Hazard Index (CoFHI) and Coastal Flood Risk Index (CoFRI) results for each neighbourhood (OA) within Hilsea, during the night time, for floods of different magnitude (FZ3 and FZ2). Numbers highlighted in bold indicate neighbourhoods with notable vulnerability and risk levels during the night time

| Hilsea Neighbourhoods | Output Area Codes | Night Coastal Flood Vulnerability Levels | Coastal Flood Hazard Levels - Flood Zone 3 | Coastal Flood Hazard Levels – Flood Zone 2 | Night Coastal Flood Risk Levels (Flood Zone 3) | Night Coastal Flood Risk Levels (Flood Zone 2) |
|-----------------------|-------------------|--|--|--|--|--|
| 1 | E00086307 | 0.394 | 0.056 | 0.848 | 0.022 | 0.334 |
| 2 | E00086279 | 0.542 | 0 | 0 | 0 | 0 |
| 3 | E00086288 | 0.414 | 0 | 0 | 0 | 0 |
| 4 | E00086289 | 0.405 | 0 | 0 | 0 | 0 |
| 5 | E00086290 | 0.478 | 0 | 0 | 0 | 0 |
| 6 | E00086283 | 0.41 | 0 | 0 | 0 | 0 |
| 7 | E00086287 | 0.354 | 0 | 0 | 0 | 0 |
| 8 | E00086316 | 0.307 | 0.329 | 0.853 | 0.101 | 0.262 |
| 9 | E00086282 | 0.43 | 0 | 0 | 0 | 0 |
| 10 | E00086285 | 0.384 | 0 | 0 | 0 | 0 |
| 11 | E00086284 | 0.424 | 0 | 0 | 0 | 0 |
| 12 | E00086286 | 0.367 | 0 | 0 | 0 | 0 |
| 13 | E00086281 | 0.426 | 0 | 0 | 0 | 0 |
| 14 | E00086318 | 0.339 | 0 | 0 | 0 | 0 |
| 15 | E00086314 | 0.376 | 0 | 0.001 | 0 | 4E-04 |
| 16 | E00086315 | 0.382 | 0 | 0 | 0 | 0 |
| 17 | E00086304 | 0.308 | 0 | 0.043 | 0 | 0.013 |

| | | | | | | |
|-----------|------------------|--------------|--------------|--------------|--------------|--------------|
| 18 | E00086311 | 0.432 | 0 | 0.355 | 0 | 0.154 |
| 19 | E00086320 | 0.315 | 0 | 0 | 0 | 0 |
| 20 | E00086310 | 0.302 | 0 | 0 | 0 | 0 |
| 21 | E00086313 | 0.385 | 0.01 | 0.168 | 0.004 | 0.065 |
| 22 | E00086278 | 0.421 | 0.777 | 1 | 0.327 | 0.42 |
| 23 | E00086300 | 0.614 | 0.89 | 1 | 0.547 | 0.614 |
| 24 | E00086301 | 0.519 | 0.095 | 0.92 | 0.05 | 0.478 |
| 25 | E00086305 | 0.384 | 0 | 0.636 | 0 | 0.244 |
| 26 | E00086303 | 0.422 | 0.111 | 1 | 0.047 | 0.422 |
| 27 | E00086309 | 0.337 | 0.779 | 1 | 0.263 | 0.337 |
| 28 | E00086317 | 0.395 | 0.224 | 0.649 | 0.088 | 0.257 |
| 29 | E00086319 | 0.378 | 0 | 0.064 | 0 | 0.024 |
| 30 | E00086312 | 0.363 | 0.922 | 1 | 0.335 | 0.363 |
| 31 | E00086308 | 0.438 | 0.006 | 0.621 | 0.003 | 0.272 |
| 32 | E00086299 | 0.423 | 0.39 | 1 | 0.165 | 0.423 |
| 33 | E00086306 | 0.461 | 0.54 | 1 | 0.249 | 0.461 |
| 34 | E00086298 | 0.309 | 0.699 | 1 | 0.216 | 0.309 |
| 35 | E00086296 | 0.566 | 0.934 | 1 | 0.529 | 0.566 |
| 36 | E00086295 | 0.326 | 0.414 | 1 | 0.135 | 0.326 |
| 37 | E00086294 | 0.517 | 0.966 | 1 | 0.499 | 0.517 |
| 38 | E00086293 | 0.396 | 0.9 | 0.999 | 0.357 | 0.396 |
| 39 | E00086297 | 0.438 | 0.981 | 1 | 0.43 | 0.438 |
| 40 | E00086302 | 0.391 | 0.845 | 1 | 0.331 | 0.391 |
| 41 | E00086291 | 0.455 | 0.601 | 0.971 | 0.274 | 0.442 |
| 42 | E00086292 | 0.253 | 0.691 | 0.999 | 0.174 | 0.252 |
| 43 | E00086280 | 0.282 | 0.83 | 1 | 0.234 | 0.282 |
