VI. ÖRÆFI DISTRICT AND MARKARFLJÓT OUTWASH PLAIN: SPATIO-TEMPORAL PATTERNS IN POPULATION EXPOSURE TO VOLCANOGENIC FLOODS

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1. Introduction

Characterisation of population exposure has recently gained importance in the assessment of flood hazards and is now incorporated in regulatory frameworks such as the European directive on the assessment and management of flood risks (European Parliament and Council, 2007). The EU Floods directive enjoins to make an inventory of the "inhabitants" living in areas identified at risk of flooding, but wisely does not forbid assessors to make therein further distinction between populations. Choosing which populations should be targeted in a flood exposure assessment is indeed much a matter of scale of analysis and objectives. Population exposure to floods has been assessed in recent years from various angles, such as age and disabilities (e.g. Chakraborty *et al.*, 2005; McGuire *et al.*, 2007) or socio-economic status (e.g. Gaillard *et al.*, 2001). In their assessment of variations in population exposure to lahar hazards from Mount Rainier, Wood and Soulard (2009) considered it necessary to make a distinction between residents, employees, and tourists, the last group outnumbering the first two groups in some of the counties exposed.

As in Mount Rainier, an assessment that would focus only on residents may not be fully satisfying in Icelandic areas characterised by strong seasonal patterns in population exposure due to tourist activities. In reality, it may be critical for the efficiency of the emergency response to look at spatio-temporal patterns and provide the Icelandic authorities with figures including also transient populations. Linkage of the road network in Icelandic floodplains and around is often reduced and therefore may not fit the needs for a sudden and massive emergency evacuation. The learning keys of the "full-scale" evacuation exercise organised by the authorities in the Markarfljót outwash plain in 2006 (Bird *et al.*, 2009) have been of limited value in this regard, as the exercise concerned the residents only and was performed in March, i.e. outside the high touristic season. Making a distinction between residents and transient population and quantifying their respective weight may be also necessary, as these two populations may have different understanding and perceptions of the pending hazards, show different levels of preparedness (Wisner *et al.*, 2004), and react subsequently in different manners to warnings and evacuation orders. Survey conducted in the Markarfljót outwash plain in 2009 suggests that tourists seriously lack knowledge of volcanic hazards, warning systems and emergency response procedures (Bird *et al.*, 2010).

In addition to making a distinction between residents and transients, it is useful to consider potential land accessibility loss (e.g. Leone *et al.*, 2013; Leone *et al.*, 2014) and include, in a population exposure assessment, an inventory of the populations that would be isolated as a consequence of the floods and exposed subsequently to other hazards relating to glaciovolcanism, such as ash fall and lightning (Gudmundsson *et al.*, 2008).

In this study, a spatiotemporal analysis of population exposure to floods is performed in the Markarfljót outwash plain and in the Öræfi district (Figure VI-1), two regions of Iceland that have been subjected to severe volcanogenic floods in the last millennium.

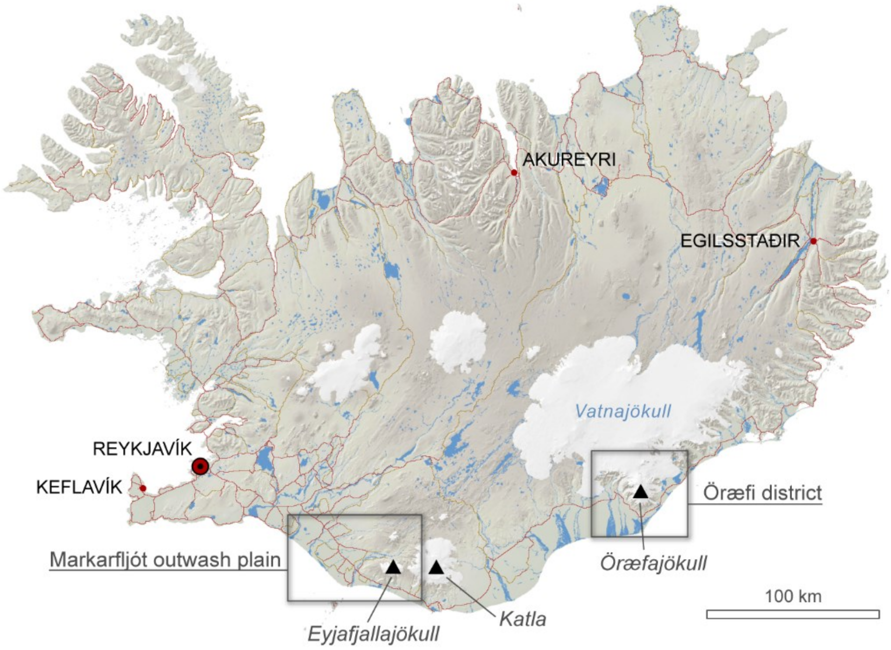


Figure VI-1: General location of the Markarfljót outwash plain and Öræfi district. Map base: Iceland Geosurvey, IMO, NLSI; Basemap: IMO.

The two regions host recreational areas that are very popular amongst Icelanders and foreign visitors during summertime. The main objective of the assessment is to provide the national and local authorities with a fair estimation, at different periods of the year and at particular locations within the two studied areas, of the likely number of residents and guests that would stand in the path of volcanogenic floods or be isolated as a consequence of the floods. Inventory of the populations exposed to floods is performed for night time, using daily overnights estimates weighted with road traffic data as an indicator. Results of the assessment in the Öræfi district are used in chapter VII (Pagneux, 2015) to estimate the time required for a full evacuation of areas at risk of flooding. Although having their importance in emergency planning, variations correspon-ding to demographic attributes such as age (e.g. Liu *et al.*, 2010; Scaini *et al.*, 2014), health (e.g. McGuire *et al.*, 2007) or nationality (e.g. Guðmundsson, 2014), are not addressed in the study. They could form, along with physical assets (buildings, infrastructure, and land), the subject of an extended exposure assessment coming as a sequel of the work presented hereafter.

2. Study areas

2.1. Markarfljót outwash plain

The Markarfljót outwash plain extends from the western margins of the Mýrdalsjökull ice-cap down to the Þjórsá River (Figure VI-2). The outwash plain corresponds, to a great extent, to the topographic envelope of glacial floods due to volcanic eruptions on the north-western slopes of the Mýrdalsjökull ice cap. The plain contains evidence of at least 11 volcanogenic floods having occurred before the settlement of Iceland (Larsen *et al.*, 2005). Only two jökulhlaups are known after Iceland was settled, which were caused by the Eyjafjallajökull eruptions in 1821–1823 CE (Óskarsdóttir, 2005) and 2010 CE (Snorrason *et al.*, 2012). None of these floods are known to have caused fatalities.

Hydraulic simulations performed by Hólm and Kjaran (2005) indicate that a 300,000 m^3/s flood originating from the Mýrdalsjökull ice-cap (Entujökull) would inundate an area of ~800 km^2 (Figure VI-2). Based on these simulations, Pagneux and Roberts (2015) estimated that flood hazard should be rated therein as high or extreme on 716 km^2 of land (85% of the flood area), meaning that floods could cause therein numerous fatalities and destroy or damage severely all types of habitation buildings standing in the path of the floods.

Driving through the plain is the most convenient option for moving along the south coast of Iceland and is a requirement for automobilists to reach Þórsmörk, a much popular recreational area nestled between the Mýrdalsjökull, Eyjafjallajökull, and Tindfjallajökull glaciers (Figure VI-2).

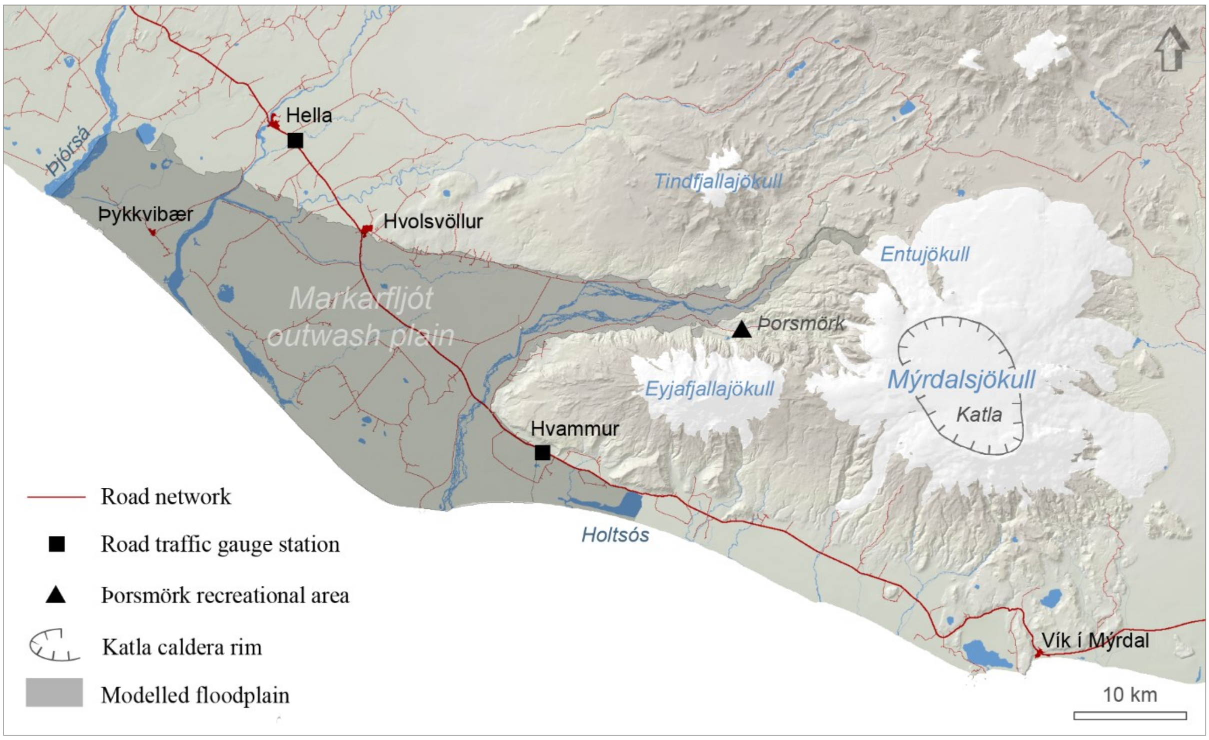


Figure VI-2: Markarfljót outwash plain. Extent of the floodplain corresponds to a simulated 300,000m^3/s flood originating from the Entujökull glacier (Hólm and Kjaran, 2005; Pagneux and Roberts, 2015). Driving through the plain is the most convenient option for moving along the south coast of Iceland and is a requirement for automobilists willing to reach Þórsmörk, a much popular recreational area nestled between the Mýrdalsjökull, Eyjafjallajökull, and Tindfjallajökull glaciers.

2.2. Öræfi district

The region bears it name — Öræfi (the "Waste land") — from the 1362 CE eruption of Öræfajökull Volcano and the resulting floods, which devastated most of the inhabited areas (Thorarinsson, 1958). These floods are likely to have caused, in combination with ash fall, the death of about 300 individuals (Thorarinsson, 1958). Floods due to the other historical eruption of Öræfajökull, in 1727 CE, are known to have caused three fatalities (Gudmundsson *et al.*, 2008).

Numerical simulations performed by Helgadóttir *et al.* (2015) indicate that a large portion of the district, ~350 km^2 of land, is at risk of flooding should an eruption of Öræfajökull volcano occur (Figure VI-3). Using thresholds in flow velocities and depths of flooding, alongside considerations on debris and water temperature, Pagneux and Roberts (2015) have proposed to rate flood hazard therein as high or extreme, exclusively.

The district hosts now the main service centre of the Vatnajökull National Park. Located in Skaftafell, west from the volcano, the centre is safe from floods due to eruptions of Öræfajökull (Figure VI-3) but is exposed to significant tephra fall, as can be inferred from the position of the 20-cm tephra isopach of the 1362 CE eruption (Thorarinsson, 1958).

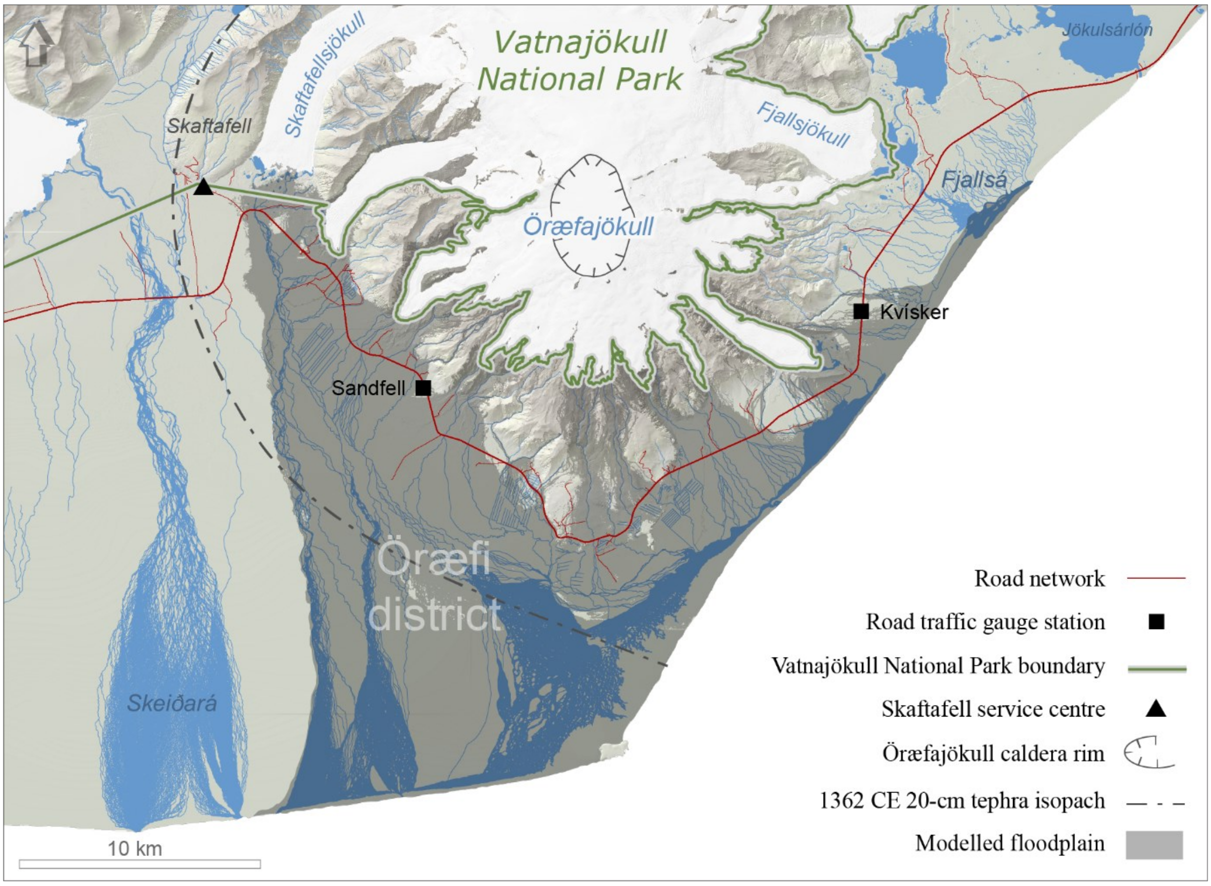


Figure VI-3: Öræfi district. The floodplain extends on ~350 km^2 of land (Helgadóttir et al., 2015). The district hosts the main service centre of the Vatnajökull National Park, located at Skaftafell, west from the volcano.

3. Methods

3.1. Populations targeted

The population was classified into residents and transient population. Transient population potentially includes the non-resident population staying overnight at given locations on a temporary basis: guests at accommodation premises, seasonal workers on worksites, people in institutional or community facilities (e.g. students in boarding schools) and public assembly structures, as well as owners and guests in secondary residences (summerhouses). Registered residents include in some cases seasonal workers who have declared themselves as residing on their worksite.

3.2. Data sources

Data on residents were extracted from the Population Register (Table VI-1). Data on transient population were obtained from various sources, including indoor accommodation premises, camping sites, local authorities, the Icelandic Road and Coastal Administration, and Statistics Iceland, over the period 2007–2012.

3.3. Temporal analysis

Multiple scales can be used in the identification of temporal patterns. One can look for instance at month-over-month variations, interdaily variations, make a distinction between working days and weekends (Liu *et al.*, 2010) or holidays (Camarasa-Belmonte *et al.*, 2011), or between summer and winter. At a finer scale of analysis, it is also sensible to identify circadian variations in exposure, making a distinction between daytime and night time (Camarasa Belmonte *et al.*, 2011), as well as changes throughout the day on an hourly basis (Liu *et al.*, 2010).

In this study, focus of the temporal analysis was set on the assessment of seasonal patterns due to tourist activities. A distinction was also made between day time (8 a.m.–8 p.m.) and night time (8 p.m.–8 a.m.) but the analysis was restricted, for feasibility reasons, to the assessment of night-time exposure, using daily overnight estimates as an indicator.

An assessment of daytime exposure would suffer, in the two study areas, of the lack of data to work with. In the last 15 years, data collection mainly concerned the Skaftafell natural site (e.g. Sæþórsdóttir *et al.*, 2001) and was framed to be used in tourism management or conservation perspectives. Though an effort has been engaged recently on surveying other sites, such as Jökulsárlón in the Öræfi district (Guðmundsson, 2014), yet acquisition of quantitative data at a precision and a time scale relevant for disaster risk management is missing. In Skaftafell for instance, quantitative surveys conducted on a permanent basis rely on automated counters that make no distinction between ingoing and outgoing visitors, so a fair estimation of the number of visitors actually on site during daytime is not possible.

3.3.1. Constraints

Estimating daily overnights at accommodation premises, institutional and community facilities and secondary residences is much of a challenge.

An important constraint, to be added to potential deliberate misreporting, consists of the fact that premise managers are not obliged to transmit overnights figures to Statistics Iceland at a temporal resolution higher than monthly aggregates; in other words, the day-over-day variations are masked in the official statistics.

Another constraint is due to the fact that Statistics Iceland is not allowed to provide third parties with data about individual premises; data that can be delivered are aggregates showing only the types of establishment, each type covering at least five different premises. As premises of a same type may be distant to each other of tens of kilometres within the areas studied, and therefore exposed to floods in a different manner, one will easily understand that the level of temporal and spatial aggregation available at Statistics Iceland does not allow an analysis of exposure at a high spatio-temporal resolution. In addition, information is lacking on occasional overnights at institutional or community facilities, and overnights at secondary residences.

Table VI-1: Data sources.

Data	Source
Indoor accommodation capacity	Accommodation premises
Overnights at indoor accommodation premises	Accommodation premises
Overnights at camping sites	Camping sites
Overnights at institutional and community facilities	Local authorities
Regional occupation rates at accommodation premises	Statistics Iceland
Residents	Registers Iceland, Population Register
Road traffic	Iceland Road and Coastal Administration

3.3.2. Calculations

For what concerns overnights at residences, the maximum overnights were assumed to equal the number of residents registered and were therefore considered in the analysis a spatiotemporal constant.

Due to insufficient information, overnights at institutional and community facilities and at secondary residences were provisionally kept out of the calculations.

For what concerns overnights at accommodation premises, statistical and legal constraints were partly bypassed using a two-step approach. As a first step, mean daily overnights at each premise and for each month of the year were approximated by multiplying the mean daily regional occupation rate for indoor premises and the premise accommodation capacity:

$$\overline{O}(m,p) = \overline{Oc}(m) \cdot A(p),$$

Where $\overline{O}(m,p)$ is the mean daily overnight for given month *m* and given indoor accommodation premise *p,* $\overline{Oc}(m)$ is the mean daily regional occupation rate for given month *m,* and $A(p)$ is the accommodation capacity of indoor premise *p.*

Regional occupation rates applying for south Iceland (Table VI-2) were used for the estimation of overnights daily means in the Markarfljót outwash plain. For the premises located in the Öræfi district, regional occupation rates for east Iceland were used. In order to avoid overestimations, the opening period of each premise was taken into account in the calculations.

Since Statistics Iceland does not take in to account the camping sites in their calculation of regional occupation rates, the camping sites were encouraged to provide, as an addition, their own overnights figures.

As a second step, daily road traffic (Figure VI-4) was used as a proxy for calculating minimum and maximum daily overnights, for each premise and each month of the year, based on the assumption that daily overnights for both residents and transient population follow, throughout each month, variations that are close to daily road traffic.

Thus, daily variation rates were estimated from road traffic daily averages over the period 2007–2011 at relevant gauges stations in the two surveyed areas (Figure VI-2, Figure VI-3, Table VI-3), and applied to the overnight daily means in order to obtain weighted daily overnights from which monthly minima and maxima were eventually extracted:

$$Ow(d,m) = \overline{O}(m) \cdot Vtr(d),$$

Where $Ow(d,m)$ is the weighted overnight for given day *d* and month *m,* $\overline{O}(m)$ the overnight daily mean for given month *m,* and $Vtr(d,m)$ the road traffic variation rate for given day *d* and month *m.*

Table VI-2: Regional occupation rates (rounded %) at indoor accommodation premises over the period 2007–2011 (Source: Statistics Iceland). Strong seasonal patterns can be seen, with occupation rates jumping from ~5% in December–January to ~75% in July.

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Capacity 1–59 beds												
Austurland	6	7	10	11	19	45	75	69	24	11	6	4
Suðurland	4	8	10	13	19	37	58	50	20	17	8	5
Capacity 60+ beds												
Austurland	5	7	11	15	25	46	76	63	25	12	7	3
Suðurland	8	19	22	24	26	41	70	61	25	25	17	11

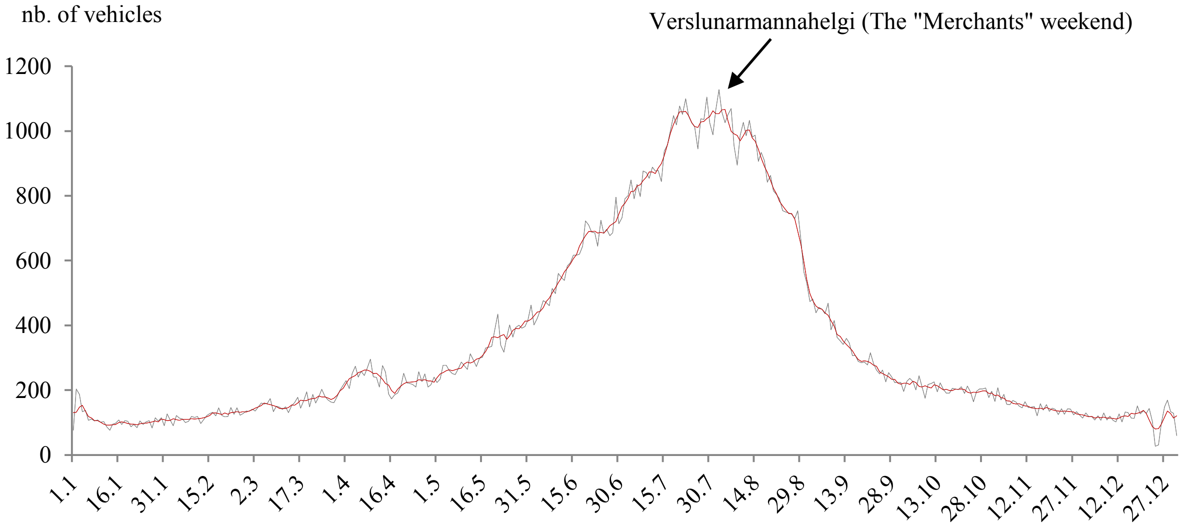


Figure VI-4: Road traffic daily averages at Sandfell gauge station, Öræfi district (2007–2011); 5-days moving averages are shown in red. The peaks in road traffic at the junction between July and August correspond to the "Merchants" weekend. Source: Iceland Road and Coastal Administration

Table VI-3: Gauging stations used to derive overnights estimates from road traffic. Source: Iceland Road and Coastal Administration.

Area surveyed	**Gauge station**	**Lat**	**Long**
Markarfljót outwash plain	Hvammur	63 34,689	-19 54,117
Öræfi district	Sandfell	63 56,327	-16 47,721

3.4. Spatial analysis

Estimation of overnights was limited to residences and premises located within a restricted area, herein labelled "extended flood hazard zone" (FHZ-X), which includes:

- The areas identified at risk of flooding in the simulations performed by Hólm and Kjaran (2005) and Helgadóttir *et al.* (2015), herein labelled FHZ-S;
- The manual additions to the FHZ-S made by Helgadóttir *et al.* (2015) and Pagneux

and Roberts (2015), herein labelled FHZ-M;

- The areas contiguous to the FHZ-S and FHZ-M that could be isolated - i.e. disconnected from the road network - should a flood happen, herein labelled FHZ-I.

Finally, estimates were plotted against the flood hazard rates computed by Pagneux and Roberts (2015).

4. Results

4.1. Residents

Based on the Population Register's 2012 figures, the number of residents in the Öræfi and Markarfljót Extended Flood Hazard Zones was estimated 86 and 1024, respectively.

4.2. Mean daily overnights at accommodation premises

The estimations based on accommodation capacity and regional occupation rates on one hand, on overnight figures transmitted by premise managers on the other, put a light on a strong seasonal pattern in exposure. Mean daily overnights jump from ~10 or less in January and December to ~250 and ~740 in the Öræfi and Markarfljót FHZ-Xs, respectively (Figure VI-5). The July peak represents increases of December-January figures by a factor 55 in the Öræfi FHZ-X and a factor 71 in the Markarfljót FHZ-X.

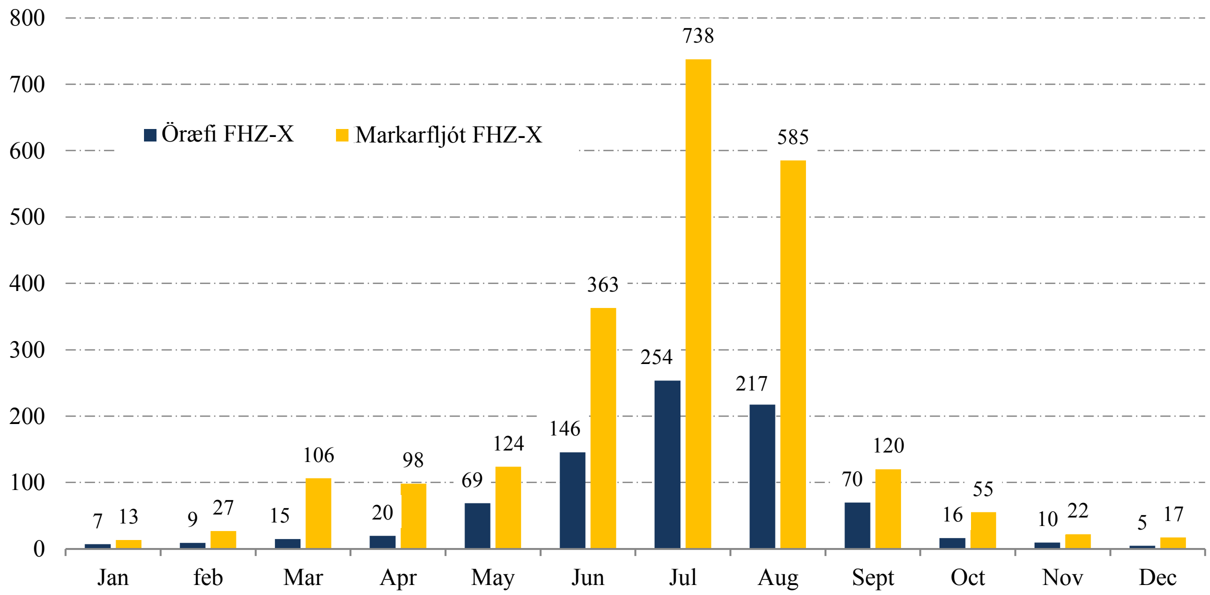


Figure VI-5: Mean daily overnights at accommodations premises in the Öræfi and Markarfljót Extended Flood Hazard Zones. For indoor accommodations, the estimates were derived from regional occupation rate and accommodation capacity. Estimation of overnights for camping sites was based on figures given by camping managers. Overnights at community facilities and summerhouses were not taken into account.

4.3. Correlation between road traffic and overnights

In the Öræfi district, overnight daily means including transient population and residents present monthly variations that are close to road traffic daily means (Figure VI-6, upper left). The correlation between month-over-month increase rates in road traffic and overnights is quite high (r^2=0.80).

Gaps can be seen between the curves during the spring and summer periods (Figure VI-6, bottom): In spring, the road traffic increases faster than the overnights, which may be due to the fact that many premises remain closed. During the summer, in turn, the overnights increase faster than the road traffic, which may be explained by an increase in the number of passengers per vehicle. The correlation is poor from January to May (r^2=0.18) but excellent from June to December (r^2=0.96).

The all-year round correlation between month-over-month increase rates in road traffic and overnights is not as good in the Markarfljót outwash plain FHZ-X (r^2=0.65; Figure VI-7) as it is in the Öræfi district. The correlation is poor from January to May (r^2=0.03) but excellent from June to December (r^2=0.92). However, the assumption that road traffic and overnights follow similar variations looks solid enough in the studied areas and justifies therein a careful use of daily road traffic as a proxy for the estimation of minimum and maximum daily overnights for at least seven months of the year.

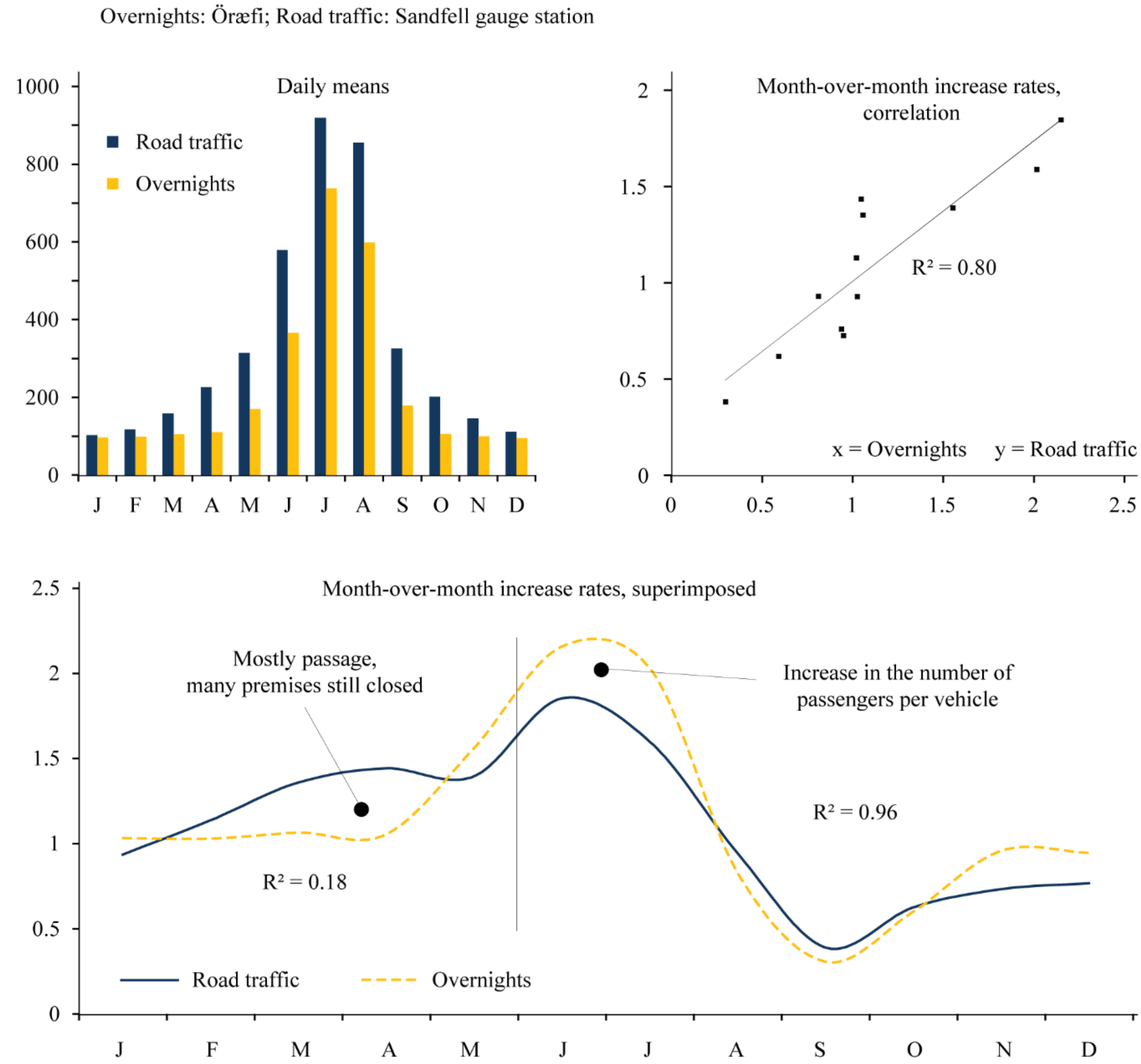


Figure VI-6: Mean daily figures for overnights in the Öræfi district (FHZ-X and surrounding settlements) and road traffic at the Sandfell gauge station (upper left) and how their respective month-over-month grow rates correlate to each other (upper right). Road traffic grows faster than overnights in spring, while overnights increase faster than road traffic during the summer (bottom).

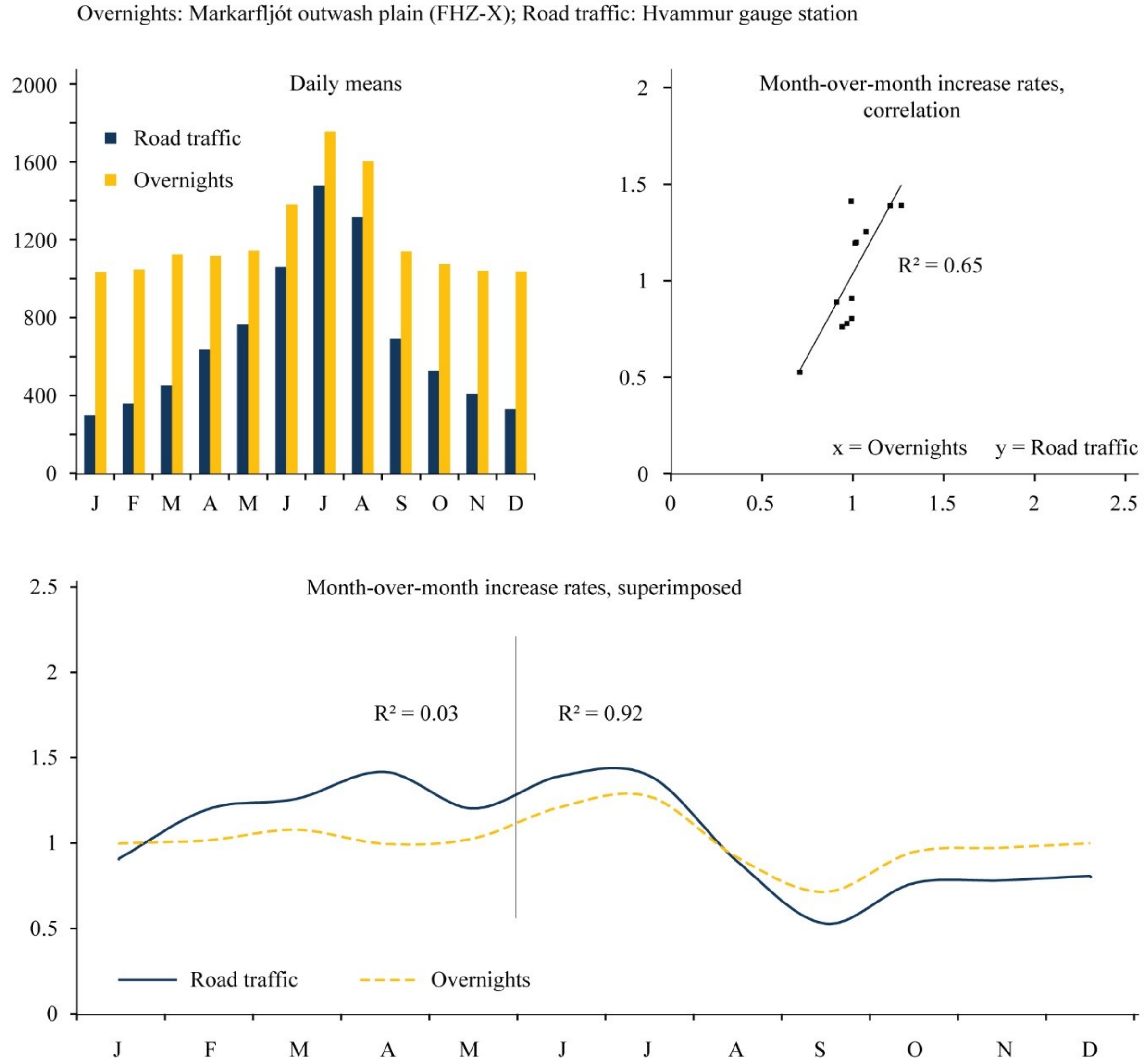
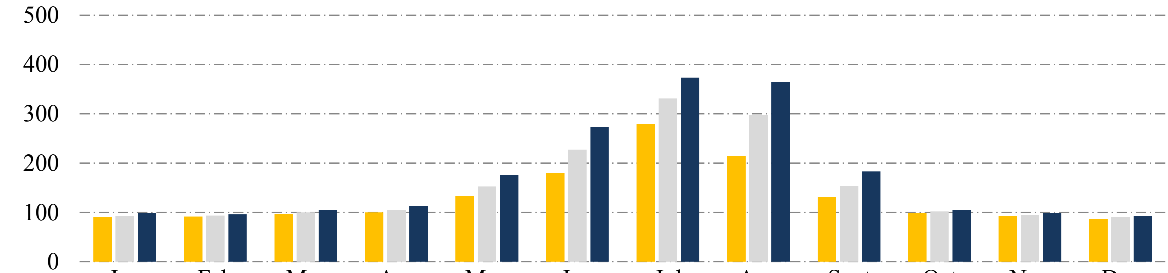


Figure VI-7: Mean daily figures for overnights in the Markarfljót outwash plain FHZ-X and road traffic at the Hvammur gauge station (upper left) and how their respective month-over-month grow rates correlate to each other (upper right).

4.4. Weighted overnights

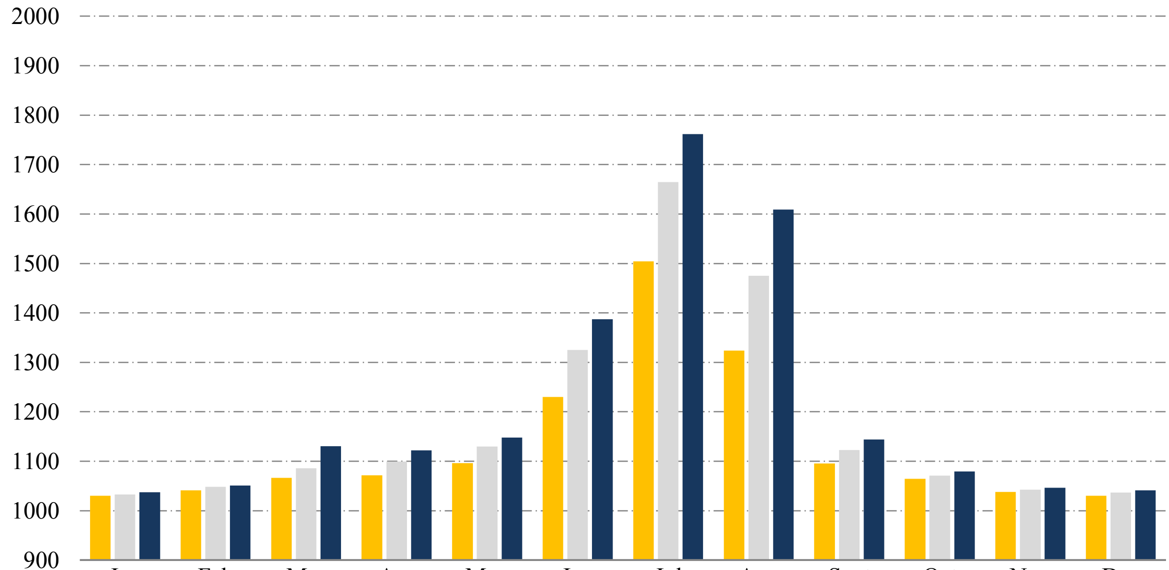
Using road traffic as a weighting factor, daily maxima of ~370 and ~1760 overnights were found in the Öræfi and Markarfljót Extended Flood Hazard Zones, respectively (Figure VI-8, Figure VI-9). Figures in the Öræfi FHZ-X represent 45% of the daily maxima in the Öræfi district (FHZ-X and surrounding settlements), which were estimated to ~830 overnights using the same methodology.

Transient population represents a maximum of 77% of the overnights estimates in the Öræfi FHZ-X and 42% in the Markarfljót FHZ-X (Table VI-4), attained in August. The maximum daily overnights represent a maximum increase of the daily means of 22% and 9% respectively (Table VI-5).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
min	91	92	97	100	133	180	279	214	131	99	93	87
mean	93	94	100	105	153	227	331	298	154	102	95	91
max	99	96	105	113	176	273	373	364	183	105	99	93

Figure VI-8: Daily overnights in the Öræfi Extended Flood Hazard Zone over the period 2007–2011. Daily road traffic was used to derive the minimum and maximum values for each month. The estimates include residents and transient population at accommodation premises (hotels, guest houses, camping sites, etc.).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
min	1030	1041	1066	1072	1096	1230	1504	1324	1096	1064	1038	1030
mean	1033	1048	1086	1099	1129	1325	1665	1475	1122	1071	1043	1036
max	1037	1051	1130	1122	1148	1387	1762	1609	1144	1079	1046	1041

Figure VI-9: Daily overnights in the Markarfljót Extended Flood Hazard Zone over the period 2007–2011. Daily road traffic was used to derive the minimum and maximum values for each month. The estimates include residents and transient population at accommodation premises (hotels, guest houses, camping sites, etc.).

Table VI-4: Share (%) of transient population in overnights in the Öræfi and Markarfljót Extended Flood Hazard Zones (FHZ-X) over the period 2007–2011.

FHZ-X	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Öræfi	13	10	18	24	51	68	77	76	53	18	13	8
Markarfljót	1	3	9	9	11	26	42	36	10	5	2	2

Table VI-5: Increase factor between maximum and mean daily overnight estimates.

FHZ-X	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Öræfi	1.06	1.02	1.05	1.08	1.15	1.2	1.13	1.22	1.19	1.03	1.04	1.02
Markarfljót	1	1	1.04	1.02	1.02	1.05	1.06	1.09	1.02	1.01	1	1

4.5. Spatial distribution

4.5.1. Öræfi

A maximum of 135 overnights was found in the area identified at risk of flooding (FHZ-S), representing 36% of the maximum overnights estimates in the FHZ-X and ~20% of the transient population staying overnight therein (Table VI-6, Figure VI-10). Overnights in the high and extreme hazard zones were estimated to a maximum of ~20 and ~110 respectively (Table VI-7). A maximum of ~240 overnights was found in the FHZ-I (Table VI-8, Figure VI-10), mostly disseminated in the Svínafell (44%) and Hof (53%) settlements' clusters

Table VI-6: Maximum daily overnights in the Öræfi extended flood hazard zone (FHZ-X) and around.

Area	Residents		Guests		Overall	
	n	%	n	%	n	%
FHZ-I	65	*76*	177	*61*	242	*64*
FHZ-M	0	*0*	0	*0*	0	*0*
FHZ-S	21	*24*	114	*21*	135	*36*
FHZ-X	86	*100*	291	*100*	377	*100*
Other *	4		448		452	

* Skaftafell, Bölti, Kvísker

Table VI-7: Maximum daily overnights in the Öræfi flood hazard zone identified in the numerical simulations (FHZ-S).

Area	Flood hazard level	Residents		Guests		Overall	
		n	%	n	%	n	%
	Low	0	*0*	0	*0*	0	*0*
	Moderate	0	*0*	0	*0*	0	*0*
	High	12	*57*	11	*10*	23	*17*
	Extreme	9	*43*	103	*90*	112	*83*
FHZ-S		21	*100*	114	*100*	135	*100*

Table VI-8: Maximum daily overnights in the Öræfi FHZ-I.

Area	Sector	Residents		Guests		Overall	
		n	%	n	%	n	%
	Svínafell	16	*25*	79	*45*	95	*40*
	Hof, Litla Hof	17	*26*	98	*55*	114	*47*
	Other	32	*49*	0	*0*	32	*13*
FHZ-I		65	*100*	177	*100*	242	*100*

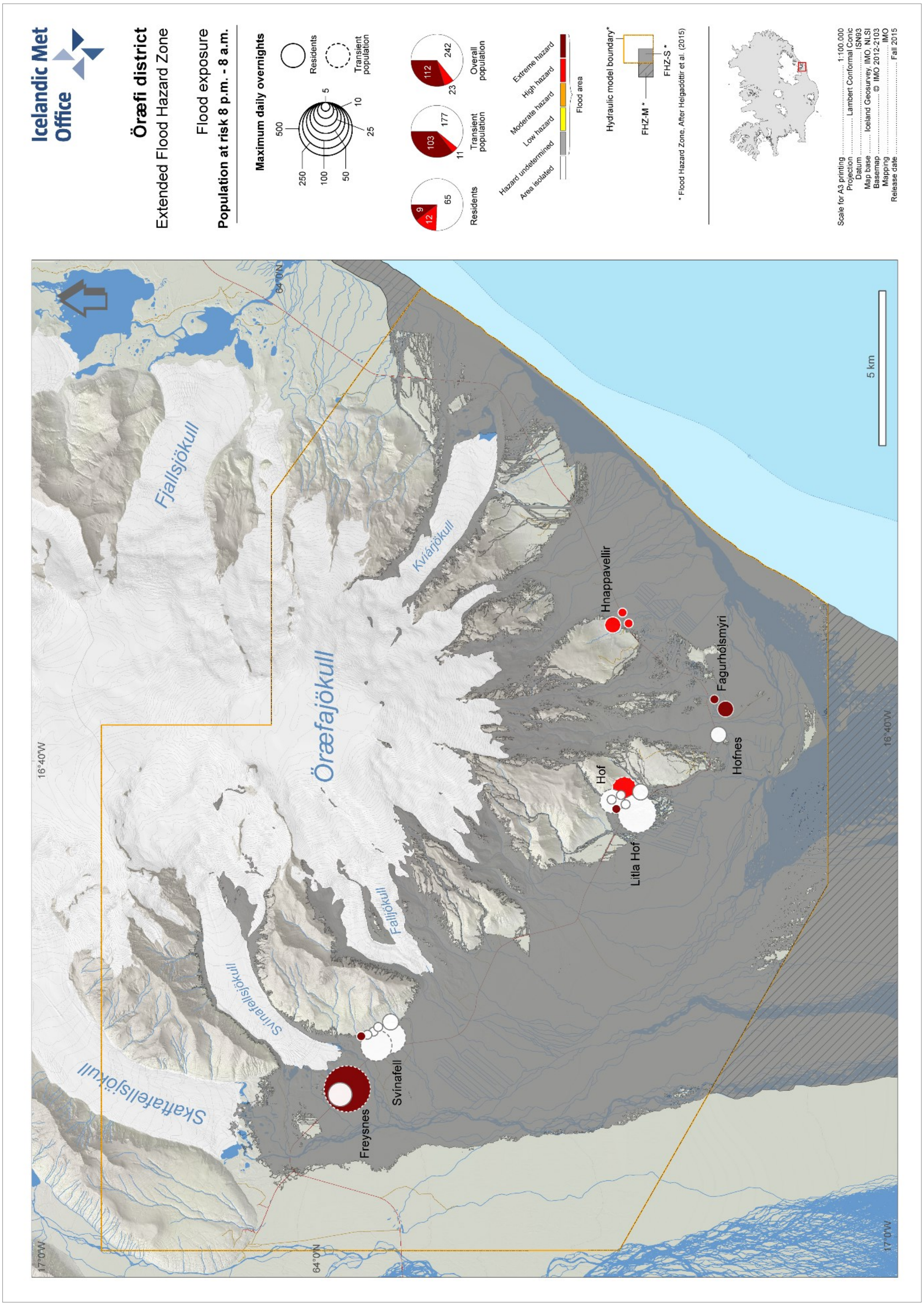


Figure VI-10: Maximum daily overnights in the Öræfi Extended Flood Hazard Zone (FHZ-X).

4.5.2. Markarfljót outwash plain

A maximum of ~1190 overnights was found in the area identified at risk of flooding (FHM-S and FHM-M), representing 80% of the residents and 50% of the transient population located in the FHZ-X (Table VI-9, Figure VI-11). Overnights in the high and extreme hazard zones proposed by Pagneux and Roberts (2015) were estimated to a maximum of ~475 and ~550 respectively (Table VI-10), i.e. 40% and 46% of the overnights in the flood area.

A maximum of ~580 overnights was found in the FHZ-I (Table VI-11), disseminated in the Fljótshlíð hillside (24%), the Þórsmörk recreational area (60%), and the north-western flank (4%) and south-western flank (12%) of Eyjafjallajökull Volcano.

Table VI-9: Maximum daily overnights in the Markarfljót extended flood hazard zone (FHZ-X).

Area	Residents		Guests		Overall	
	n	%	n	%	n	%
FHZ-I	204	*20*	372	*50*	576	*33*
FHZ-M	28	*3*	0	*0*	28	*2*
FHZ-S	792	*77*	366	*50*	1158	*66*
FHZ-X	1024	*100*	738	*100*	1762	*100*

Table VI-10: Maximum daily overnights in the Markarfljót flood area (FHM-S + FHM-M).

Area	Flood hazard level	Residents		Guests		Overall	
		n	%	n	%	n	%
FHZ-M		28	*3*	0	*0*	28	*2*
	Undetermined	28	*3*	0	*0*	28	*2*
FHZ-S		792	*97*	366	*50*	1158	*98*
	Low	49	*6*	0	*0*	49	*4*
	Moderate	22	*3*	62	*17*	84	*7*
	High	441	*54*	35	*10*	476	*40*
	Extreme	280	*34*	269	*73*	549	*46*
FHZ		820	*100*	366	*100*	1186	*100*

Table VI-11: Maximum daily overnights in the Markarfljót FHZ-I.

Area	Sector	Residents		Guests		Overall	
		n	%	n	%	n	%
	Fljótshlíð	121	*59*	20	*5*	141	*24*
	Þórsmörk	0	*0*	343	*92*	343	*60*
	North-western flank E15*	14	*7*	9	*2*	23	*4*
	South-western flank E15*	69	*34*	0	*0*	69	*12*
FHZ-I		204	*100*	372	*100*	576	*100*

* E15: Abreviation for Eyjafjallajökull

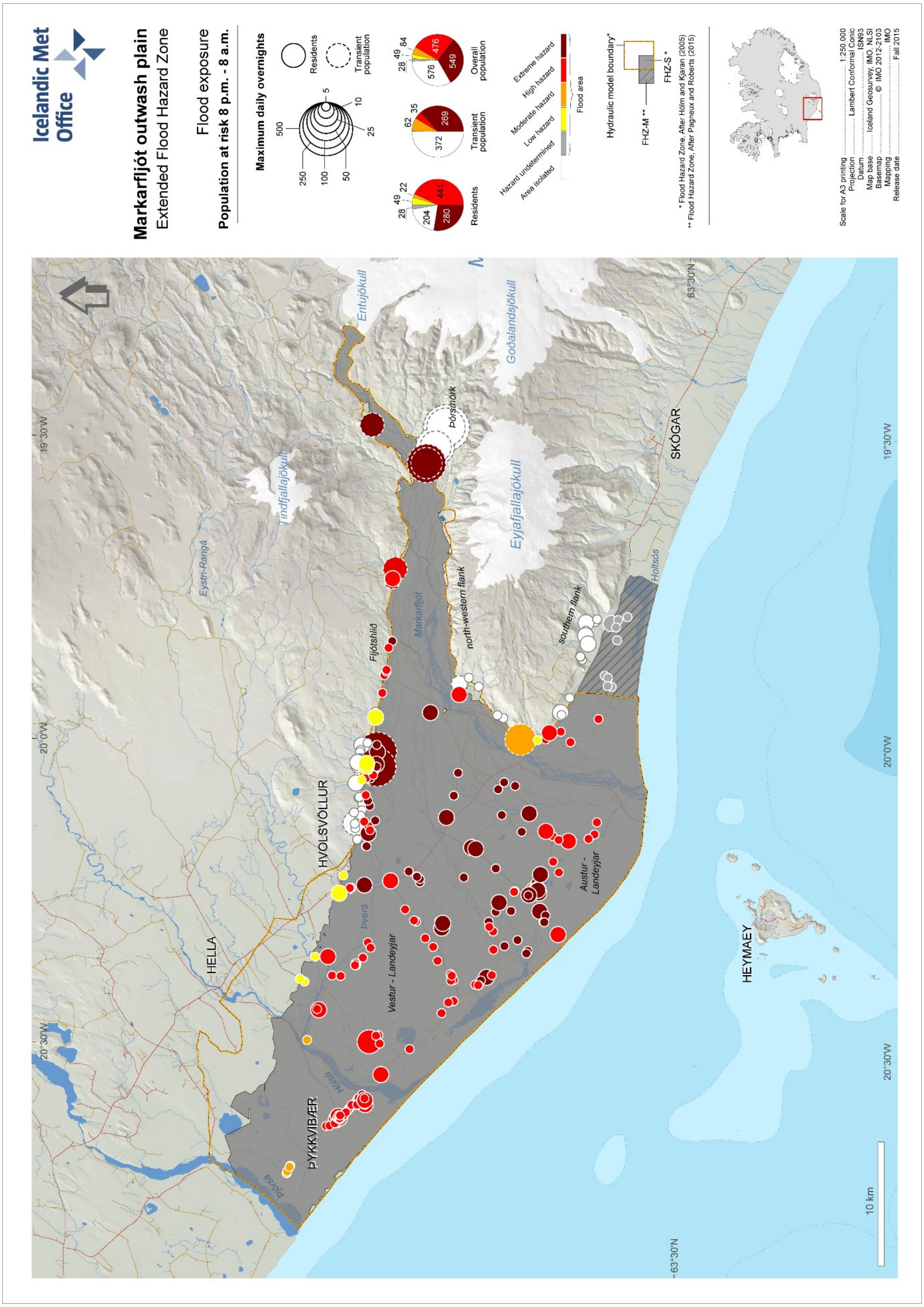


Figure VI-11: Maximum daily overnights in the Markarfljót extended flood hazard zone (FHZ-X).

5. Summary

A spatio-temporal characterisation of population exposure to floods was performed in the Markarfljót outwash plain and in the Öræfi district. The assessment consisted of an inventory of the populations — residents and transient population — exposed to floods during night time, using minimum and maximum daily overnights estimates as an indicator. Variations in daily road traffic were used as a proxy for the estimation of minimum and maximum daily overnights for each month of the year, based on the assumption that road traffic and overnights follow, in the two studied areas, similar variations.

The results indicate that exposure to floods in the two studied areas is subject to large seasonal changes. The July peak represents an increase of the December–January exposure minimum by a factor of 55 in the Öræfi district and a factor of 71 in the Markarfljót outwash plain.

A maximum of ~380 overnights was found in the Öræfi Extended Flood Hazard Zone, thereof ~135 overnights in the area identified at risk of flooding and ~245 overnights in the areas potentially isolated by floods (Figure VI-10):

- Overnights in areas potentially isolated are mostly disseminated in the Svínafell (44%) and Hof (53%) settlement clusters.
- Transients represent ~80% of the local population during the summer peak.
- Overnights in the high and extreme hazard zones proposed by Pagneux and Roberts (2015) were estimated to a maximum of ~20 and ~110, respectively.

A maximum of ~1760 overnights was found in the Markarfljót Extended Flood Hazard Zone, including ~1190 overnights in the area identified at risk of flooding and ~580 overnights in sectors potentially isolated (Figure VI-11):

- Overnights in areas potentially isolated are disseminated on the Fljótshlíð hillside (24%), the Þórsmörk recreational area (60%), and the western flank (4%) and southern flank (12%) of the Eyjafjallajökull volcano.
- Transients represent ~ 40% of the local population during the summer exposure peak.
- Overnights in the high and extreme hazard zones proposed by Pagneux and Roberts (2015) were estimated to a maximum of ~475 and ~550, respectively.

6. Recommendations

The night-time exposure figures do not account for overnights at secondary residences and at institutional or community facilities and, therefore, should be regarded as a low estimate. Caution is therefore advised in using the results, especially when it comes to make an assessment of the time available for evacuating areas exposed to volcanogenic floods, directly or indirectly.

An update of the estimations is recommended at a regular interval, e.g. every five years, such as to take into account changes in overnights at accommodation premises, whose capacity and number is likely to change in the coming years. Further research is needed on the integration of overnights at secondary residences and at institutional or community facilities, and on securing overnights at commercial accommodation premises. In that respect, changes in the rules and clauses of reporting overnights to the statistical authorities would certainly be helpful.

Further work is also needed that should focus on the characterisation of daytime exposure. Too little information is available as for now to be used in a direct or indirect counting effort. Should surveys or permanent monitoring of frequentation at visiting sites be performed in the future, it is crucial to have data collected in a way that is meaningful for the emergency response.

7. Acknowledgements

The author would like to thank Stéphanie Defossez and Tómas Jóhannesson for reviewing the chapter. Philippe Crochet is thanked for valuable feedback on methodological aspects during the framing of the research, as well as Ásdís Helgadóttir and Trausti Jónsson for proof-reading the chapter.

The present work was funded by the Icelandic Avalanche and Landslide Fund, the National Power Company, and the Icelandic Road and Coastal Administration.

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