Cultural Heritage and Urban Resilience in Scotland

Co- designing extreme rainfall impact assessment tools for adaptation

Research funded by the National Centre for Resilience and Historic Environment Scotland

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Date: 29 March 2022

Executive Summary

This rapid project developed a post-event damage survey template, risk pathway scenario tool and workshop for Historic Environment Scotland and wider heritage sector partners. The research team carried out an in-depth survey of damage and loss incurred at Edinburgh Castle during an extreme rainfall event on 4th July 2021. Key findings highlighted the damage to the internal fabric of the castle in two key rooms, loss of staff hours and opportunity costs as well as near miss scenarios due to the significant influence of COVID 19 and the timing of the event itself.

Rainfall radar data shows that the event was of very short duration and small scale which makes it difficult for, even state-of-the-art, weather models to capture it. We estimate that such an event was about a 1-in-a-hundred year event and that an hour's warning may have been possible. Using state-of-the-art climate models we estimate that the magnitude of 1-in-ten or 1-in-a-hundred year extreme rainfall events are likely to increase by about 15%, relative to the 1980-2000 norm, in the near term and by about 30% towards the end of the 21st century.

Two validation workshops provided an opportunity to validate and gather feedback on the newly developed post event damage survey. Key feedback included the opportunity to use the template:

- as a knowledge sharing tool,
- to connect multiple teams to share their actions during and after an event,
- to deliver a systematic and comprehensive process for data collection and organisational learning.

This project provided the first damage narrative for an extreme event on a HES property in care and has developed the first template for damage assessment to heritage buildings in Scotland. The template will now be integrated within HES property management systems and provide a foundation for critical climate risk data collection into the future.

Project recommendations:

- The event analysed had a relatively low impact due to low visitor numbers and time of day however was considered a 'near-miss', it is therefore essential for these findings to reach relevant HES partners responsible for event management at the castle and measures are taken to improve the castle drainage.
- HES, and other interested parties, discuss with the Met Office the potential to get timely warning of extreme rainfall events. Even one hour of warning would allow implementation of measures to reduce the impact.
- Staff believe that the template can be adopted to record, track and monitor response and recovery from a significant weather hazard event. Overcoming institutional memory loss and providing evidence for strategic decision making.
- The project should be scaled to examine a range of heritage types, develop quantitative functions for modelling and integrate the template within PiCAMs with some basic training for relevant staff.

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1. Background and project rationale

Scotland's cities are currently vulnerable to extreme rainfall and flood events. However, we are uncertain how these events will change due to climate change and how our historic buildings will suffer. Currently our resilience is being undermined as adaptation to climate change is not keeping pace with rapidly changing risks (Climate Change Committee, 2021). Economic losses are soaring as extreme weather events damage and destroy important sites for our livelihoods and culture. In some circumstance, such as extreme rainfall, heat and flood, these events threaten lives. Despite this, there is no systematic way of recording post-event damage and loss information in Scotland for heritage sites and for creating critical scenarios for adaptation. This project has addressed this gap through a new partnership with Historic Environment Scotland (HES) to:

1. Co-develop a novel post-event damage survey protocol.
2. Collect and document both the direct and indirect impacts of the heavy rainfall event on the 4th of July 2021 in Edinburgh, largely focusing on HES assets, and produce damage datasets to inform future vulnerability functions critical for future impact modelling.
3. Document the meteorological conditions which led to the heavy rainfall event.
4. Evaluate the ability of state-of-the-art convective permitting simulations so simulate such events and use them to estimate the change in risk of such an event due to human influence.
5. Carry out a combined training and scenario development workshop for partners and other stakeholders on the use and implementation of the damage survey protocol.

This project was implemented between December 2021 and March 2022 and co-funded by Historic Environment Scotland (HES) and the National Centre for Resilience (NCR).

This report outlines the project work plans, implementation, key findings and outputs, as well as future research directions.

1.1. Project summary

This project was designed in three separate work packages, each providing distinct but interconnected outputs. The damage survey and development of a template for the heritage sector was created in work package 1, the meteorological data gathering, and future modelling research was undertaken in work package 2 and the validation and dissemination of key outputs was carried out in work package 3. This section provides a summary of these work packages and key findings outlined in Figure 1.

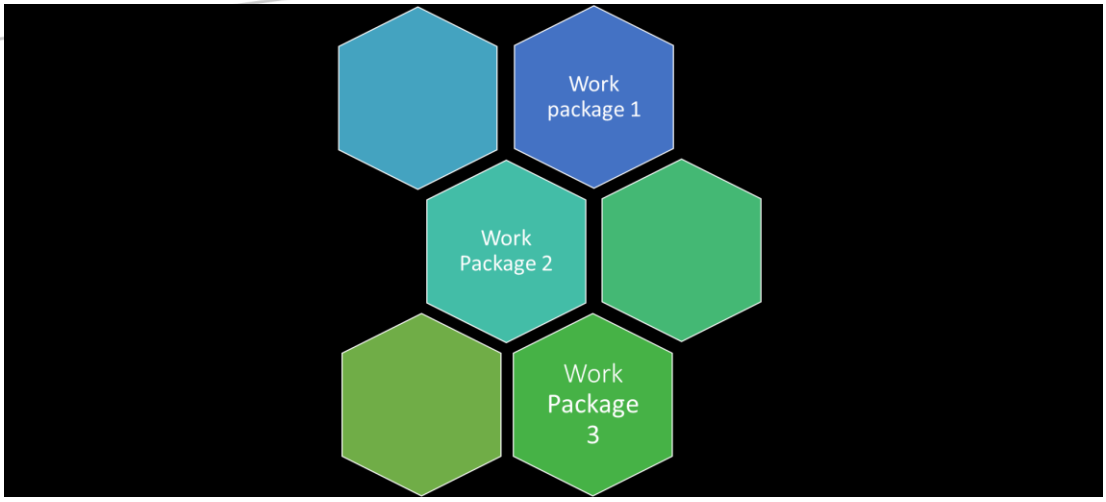


FIGURE 1. PROJECT WORK PACKAGES

TABLE 1. KEY PROJECT DELIVERABLES

WP	Deliverables	Delivered outputs
Work packages 1	• A novel framework and protocol for post-event damage surveys scalable across Scotland. • Direct damage dataset and vulnerability function critical for future impact modelling. • Indirect damage dataset	• Post event damage survey template– see Appendix 1 • Direct and indirect damage narrative see section 1 and 3. • Damage scenario – see Figures 11-14.
Work packages 2	• Rainfall-flood dataset • Deliverable: Extreme event attribution analysis	• Comprehensive meteorological narrative of the 4th July 2021 extreme rainfall event in Edinburgh • Projected future Mean Seasonal Maximum Hourly Rainfall (mm/hr) • Precipitation return values for 1 in 10 and 1 in 100 years
Work packages 3	• Trainings on use and implementation of damage survey protocol and co-created future extreme rainfall-flood impact scenario to evidence partner's adaptation planning for resilience. • To supplement the training, a How-to-Guide for use and implementation of damage survey protocol will be developed.	• Two workshops: see Appendix 3 - Workshop one: 14th March 2022 in Edinburgh - Workshop two: 16th March 2022 in Highlands

1.1.1. Work Package 1: Damage survey

During initial discussions with the HES team, Edinburgh Castle was identified as the core case study site for this project. HES had experienced loss and damage during the July 4th 2021 extreme rainfall event at the castle and it was considered an appropriate case study due to:

- The sites existing resilience.
- The damage experienced had not been recorded.
- The teams need for a post event survey.
- The castle was directly located within the extreme rain band according to radar data.
- The ability to capture a 'best case' scenario for HES and therefore us this to scale up and share learning across Scotland.

Through the partnership with HES the research team were able to collect damage and loss data, both qualitative and quantitative, that occurred due to the extreme rainfall and flood event on the 4th of July 2021 at Edinburgh Castle.

A series of semi-structure interviews with key castle staff were carried out between January-February 2022. This damage survey captured included: 1. Exposed asset data, 2. asset damage, and 3. indirect impacts. These are the three core areas required for scenario-based consequence or impact modelling.

1. Asset data involves understanding which elements of the building were impacted, either directly or indirectly. This information is essential for calculating damage functions in the future. This data informed the co-development of a post event damage survey protocol for HES and the wider heritage sector. This is the first of its kind and tailored for Scottish heritage. The damage survey was also the first in depth damage narrative of its kind carried out for HES.

2. Damage estimates are crucial for creating viable risk scenarios for adaptation and emergency management. Damage estimates were collected via semi structured interviews with key property staff. The information was then analysed and presented in the form of both a risk matrix and scenario flow diagram. This information fed the development of a new protocol for damage surveys essential for building a baseline dataset of damage, a training and knowledge sharing tool for heritage mangers and researchers, as well as the foundational information for impact modelling for adaptation planning.

3. Survey of indirect impacts such as repair costs, disruption time and economic losses were also captured during the interviews and presented in scenario flow diagrams (see section 3).

1.1.2. Work Package 2: Extreme rainfall event study

The meteorological conditions which led to the 4th July 2021 extreme rainfall event were studied from radar and observational data obtained from UK Met Office and Royal Botanic Gardens Edinburgh. The team attempted to identify whether current climate science data suggests that such extreme precipitation events are likely to occur more often in the future and/or if they are likely to be more intense. To do this, we used both radar data which observed the precipitation from this extreme event, as well as model data from the UK Climate Projections (UKCP18, specifically) which provide the most up-to-date assessment of how the UK climate may change in the future (Met Office) up to 2080. the model resolutions we have available are not able to refine this intense, very short, extreme precipitation which substantially increases the uncertainties in our estimates for future extreme precipitation events. Ideally, we would need models which can resolve on the 100 meter, rather than the kilometre scale, for localised events such as the July 4th event in Edinburgh.

For this event the radar suggests that a warning time of about an hour would have been possible from the rainfall radar.

1.1.3. Work Package 3: Scenario development and training

Findings were collated, synthesised and then validated with partners, and wider practitioners via a scenario development and capacity building workshops in March 2022.
These workshops included an introduction to climate risk pathways and the potential use and implementation of the novel damage surveys protocol were provided for HES staff and wider stakeholders across Scotland. These workshops were held in two locations to ensure accessibility beyond Edinburgh city. Both workshops explored the research findings, sought feedback from HES staff and wider heritage partners. The key feedback from the workshops is provided in the workshop report in Annex III.

1.1.4. Next steps

The damage survey framework and protocol will be integrated within HES's existing property management system. It will therefore become part of a 'live' heritage management process. The workshops provided the opportunity for HES staff to continue to improve and share the protocol into the future. The protocol was co-designed with HES to allow the incorporation data from a wide range of heritage sites over time.

1.2. Work package 1. Damage survey

The research team including HES managers identified Edinburgh Castle as the key case study for this research project. The research team then carried out a rapid literature review and developed an interview guideline for staff working at the castle. The semi-structured interviews were carried out in January 2022 with a guided site visit implemented on the 1st of February 2022.

This section outlines the key methods and analysis used as well as sharing key findings from the interviews, the damage narrative and the resulting risk matrix and scenario flow diagrams.

1.2.1. Semi-structured interviews

Damage estimates are crucial for creating viable risk scenarios for adaptation and emergency management. Damage functions have the potential to estimate damages across multiple scenarios when it is not feasible to directly simulate impacts using complex physical and economic models. Where critical empirical data is missing, interviews or expert elicitation is commonly used to gather relevant information.

In order to identify the core data required for a post-event damage survey protocol (see section WP3), semi-structured interviews were undertaken to collect damage (and the cause of damage) information from the 4th July extreme rainfall event across HES estate management teams. The aim of interviews were:

- To collect information to develop a systematic way of recording event damage and loss HES estates and creating critical scenarios for adaptation.

- To record direct and indirect impacts of the July extreme rainfall event at Edinburgh Castle – gathering an overview of the impacts for damage estimates (and the cause of damage).
- Gather feedback on the 'Dos and Don'ts' for developing a standardised data collection template refined and aligned with the HES building management system.

The semi-structured interviews were carried out six months after the flood event on the Edinburgh castle site during the period from 21st January to 1st February 2022 (see table 2). Information was collected covering identified key themes from 10 interviewees who have varying experience working at HES from 9 months to 25 years as a duty manager, senior guides, works managers (including mechanical and electrical engineers), architects and collection managers (including salvage planning co-ordinator).

TABLE 2. INTERVIEW DATES, DURATION AND INTERVIEWEE'S ROLE INCLUDING LENGTH OF SERVICES

Interview dates		Interviewee profile			On-site
Date	Duration	Role	Affiliation	Length of services	4th July 2021
25 Jan	14.00-15.00	Events & Guiding Manager	Commercial & Tourism	10 years	on duty
		Senior Guide	Commercial & Tourism	9 years	on duty
		Senior Guide	Commercial & Tourism	22 years	on duty
		Mechanical & Electrical Manager	Conservation	22 years	on site by duty call
27 Jan	10.00-11.00	Regional Architect	Architect	25 years	-
27 Jan	11.15-12.15	Salvage Planning co-ordinator & Regional Collections Manager	Collections	8 years (on & off)	-
24 Jan	14.00-15.00	Edinburgh District Manager	Collections	9 months	-
21 Jan	13.30-15.00	Edinburgh District Architect	Architect	12 years	-
		Regional Works Manager	Conservation	16 years	-
1 Feb	15.00-16.00	District Works Manager	Conservation	25-30 years	-

An interview guideline is built on the above three aims by using semi-structured questions (see the full interview guide in Appendix I).

1.2.2. Finding 1. Impacts on the castle of the July 4th Extreme Rainfall event

On Sunday, July 4th an extreme rainfall event caused rapid inundation of rooms accessed from Crown Square and other areas of the castle. The heavy rainfall started around 4 pm and lasted about 10-15 minutes. The Edinburgh Royal Botanic Garden (RBG) station recorded the daily rainfall as 57.6mm which is 53% of the total July rainfall and July 2021 hit the second-highest monthly rainfall since 2010.[1] Figure 2 shows the events of 4th July to date.

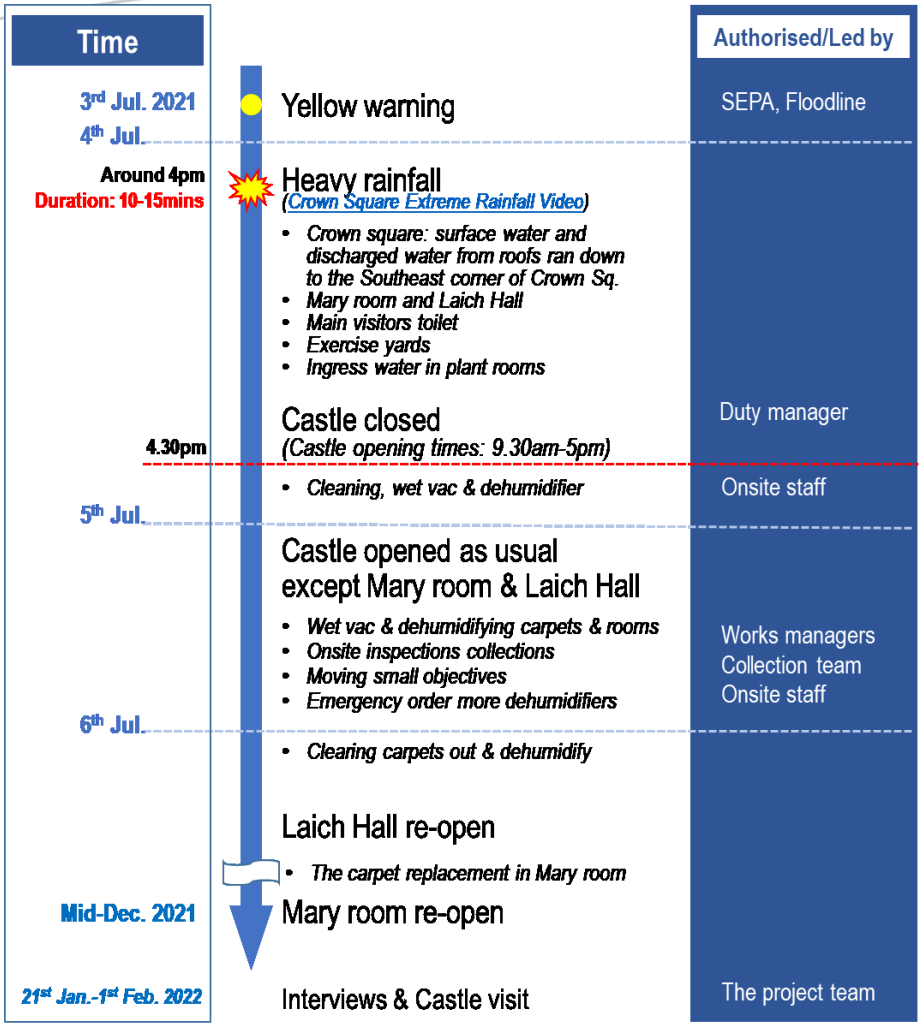


FIGURE 2. THE TIMELINE OF IMPACT ON EDINBURGH CASTLE FROM 4TH JULY 2022 EXTREME RAINFALL EVENT

The most serious damage occurred in the rooms accessed from Crown Square. The ground slopes in Crown Square towards the southeast corner where there is one small drain (no more than 100mm in diameter). On one side of this corner is an entrance to the Mary Room and the other adjacent side has a low vent in the back wall. Surface water and discharged water from the roof ran down to the southeast corner of Crown Square and the water pooled to approximately 15cm depth and then overflowed the step to Mary Room. The water flowed over the top of doorway step, to stair case down to the Mary Room, the vestibule between Mary room and Laich Hall, and finally stopped at the entrance to the Laich Hall. Water also flowed through a vent under the Stick Room, then continued into the Devil's elbow plant room and discharged to Devil's elbow side.

Due to the volume of rain, surface water also travelled down the steep path to the main entrance of castle, the majority of water travelled towards the draw bridge but some diverted into the main visitor's toilet. Even though there is a drainage channel in front of the toilet door, it was not able to stop water coming inside. The water rose about 50cm at the entrance to the visitor's toilet.
Other areas had ingress of water in particular the following plant rooms: 1) under Stick Room (Devil's elbow plant room), 2) David's tower plant room, and 3) Exercise Yard plant room.

Interviewees highlighted that they never had seen such an extreme rainfall event like this in their service time. Considering that half of the informants have been working at HES for more than 20 years, potential damage were not raised until the flood event happened. However, the insufficient drainage in Crown Square was a known issue but the cost of replacement was considered unjustifiable under normal circumstances.

"Seen similar things before where the (water spout) overflow been running. But not to such an extent with overtopped actual outlet drain in the corner (of Crown Square)."

"I've never seen anything like that happen"

"I have never seen rain like this up here the whole time I have been here"

1.2.3. Finding 2. Damage and Loss

Direct damage was constrained to the following:

- Major damage occurred from the flooded Mary Room
- Plant rooms remained dry
- Main visitors' toilet flooded but limited damage to the carpet and extra hours for cleaning
- Cobbles and infilling on pavements washed away
- No damage to collections in the Mary Room but extra staff hours required to monitor and evaluate potential indirect damage

Key damage narrative: The Mary Room had the most severe damage due to the water flooding the carpeted area. The paintings here were not removed, but they are very large and low to the ground approximately 30 cm off the ground in places. There are electricity sockets at floor skirting level but these were checked and deemed safe.
The carpet absorbed the water and seemed to have saved further damage. When it was lifted the floor beneath was dry.
During the recovery phase and removal of the carpet the VOC from the carpet tiles were a concern.
Water entered the Laich hall antechamber but there was no impact to the fabric of the room or any collections (the tapestry is behind a large encasement).
In David's tower, a small amount of water entered the plant room via a manhole above. This space has two large boilers which are at floor level. Some water entered the toilet area in David's tower but the floor is sealed stone and was easy to clean. There was no damage but additional cleaning was required.
The main entrance visitor toilets suffered from a surge of water running down the main pathway towards the entrance. Most of the water flowed down and through the main entrance, over the draw bridge, but some flowed towards the toilet area. A video was shown to the research team by cleaning staff on site. One member of cleaning staff noted that she was holding back the water by closing the glass doors to the toilet, but she could see water was coming through and decided to open the doors. Water levels were recorded at a depth of up to 50 cm in the main toilet area.
The carpet on the entrance has severe damage and is awaiting replacement (as of February 2022). The cleaning staff noted that they had to work that evening and early morning to clean before reopening the next day. The water ingress here was higher than in the Mary room and posed a threat to staff.

The exercise yard is enclosed with one drain from guttering above. There is a door at ground level leading to another small plant room, electric equipment and boilers are off the ground. This yard flooded with mud and debris, but no damage was recorded other than minor cleaning of the area being required.

Indirect losses

Here we describe any costs and time as losses.

Repair costs:
The main repair costs occurred from replacing the carpet in the Mary Room and vestibule between the Mary room and Laich Hall. Other costs included cleaning costs and purchasing equipment including two dehumidifiers.

Disruption time and economic losses:
Differences in ticket sales were minor compared to the day before the rainfall event. However, ticket sales were decreased by one-third since the COVID-19 pandemic. The castle was able to reopen to visitors the next day except for Mary room, which was closed until mid-December 2021.

Staff hours:
Onsite staff and emergency on-call works manager on Sunday, 4th July remained onsite to clean and check voluntarily. Other staff also committed extra unpaid working hours to monitor the situation. Even though there were no damages on collections, it consumed extra staff hours to monitor and coordinate the process of damage inspections and efforts to control room conditions to prevent the development of moulds and maintain the microclimate as well as coordinating across teams while the carpet was replaced. An interviewee provided estimates of extra hours from 7 colleagues working together on this task salvaging collection procedures. It was approximately 2 hours per day for a week from each colleague which could have been equivalent to a full week of staff hours.

Health and safety:
There were no reported injuries from the event.

A summary table of damage and losses

Based on the interview results we have gathered direct and indirect damage as well as the consequences of loss. The loss includes impacts on the site operations including economic/finance, staff working hours, external contractors and staff and visitors' health and safety. The damage and losses are categorised into four colour codes. The colour coding criteria are explained in the table 3 whilst the damage and loss is recorded in table 4.

TABLE 3: COLOUR CODING CRITERIA FOR DAMAGE AND LOSS TABLE

	Damage	Loss
	Business as usual	within regular maintenance costs
	Minor: only cleaning required	out of contracted hours/ volunteer, small emergency purchases, additional HR costs
	Moderate: partial repair required, limited access	High opportunity costs and potential additional resources required
	Severe: major operation required, or causing site closure	Impact on safety, major economic & monuments losses or required major salvaging collections

TABLE 4: DAMAGE AND LOSS RECORDED AT EDINBURGH CASTLE ACCORDING TO MINOR, MODERATE AND SEVERE CRITERIA.

	Damage		Loss		
	Direct	Indirect	Direct cost	Staff time	Safety
Building outdoor fabrics	Overflow of gutters & roofs	No water into inside from roofs, downpipes & gutters	n/a	Extra cleaning hours	No injured staff or visitors
Building indoor fabrics	Mary room flooded & closure Main visitors toilet flooded	Increased threat of mould due to humidity	Carpet replacement in Mary room	Extra cleaning, monitoring hours	n/a
Drainage system	Poor drainage Water rose: 15cm at the southeast corner of Crown Sq. & 50cm main visitors tolilet	Mary room, stick room, plant rooms, exercise yards	n/a **	Extra cleaning hours	n/a
Plant rooms	Water ingress but no M&E issues **Only some damage to gas meters**	n/a	Gas meters	Extra cleaning hours	n/a
Collections	No damages to collections	No moulds developments, no reputational risks	Two + dehumidifiers	1-2 weeks intensive monitoring, inspections & coordination over 6 months+	n/a
Pavements	Cobbles, infills were washed away	n/a	Pavement infills	Contractors	n/a
Site operation	30 mins earlier closure	No significant impact on ticket sale	No refund costs but a complaint	n/a	*** n/a

n/a: no damage or loss or have not reported
*Safety refers to staff and visitors' well-being threatened by direct and indirect damages causing injuries and risk or danger to health conditions.
**no extra cost incurred. Clearing blockage is within maintenance overage. The construction work has been discussed but not planned to operate due to improving drainage on the castle site is a major operation
***minor note: visitors were told to exit out into the heavy rain in order to close the castle.

Table 3 highlights some key areas of vulnerability, including the minor erosion on cobbled pathways, the potential for mould growth in wet rooms, as well as the extra cleaning hours required during recovery. The key influencing factors for this site focusses on the communications between multiple teams on site such as the role of the collections team during the immediate response and recovery.

Heritage buildings are distinctive in their potential for damage due to the collections and also the need to maintain the fabric in particular ways. The interrelationship between teams highlights the need for internal communications whilst the collections team also highlighted the need for regular external communications with those who may own the collections. Here there is a reputational risk if damage to collections was to occur. In this case, no damage occurred but the collections team noted an increase in opportunity costs due to the management of this unexpected event.

Although table 3 highlights the limited damage and loss that occurred the majority of interviewees noted how fortunate they were that nothing worse occurred:

> *"Looking at it afterwards it was quite **fortunate.** There didn't seem to be much damage in terms of moisture getting into the walls above the skirting level which is a bit surprising really. I think if that had happened, it would been much more difficult drying it out afterwards" (district architect)"*

> *"We were **lucky** because the paintings weren't damaged."*

> *"It was lucky the incident happened near to the closing time of the day. And since the covid pandemic, footfalls decreased the one third."*

2. Work package 2: Extreme rainfall event study

2.1 Extreme Rain: Risk Analysis

On July 4th 2021, an event of extreme precipitation occurred in Edinburgh which led to flooding in multiple areas of the city as well as sustained damage to infrastructure including the recently opened St. James Quarter shopping centre. The Royal Botanic Garden Edinburgh measured up to 50mm of precipitation, which is half of the amount of rainfall expected in a normal July. To make matters worse, this rain fell within 10-15 minutes and was very localised, with areas around Edinburgh barely affected. As part of this project, we tried to identify whether current climate science data suggests that such extreme precipitation events are likely to occur more often in the future and/or if they are likely to be more intense. To do this, we used both radar data which observed the precipitation from this extreme event, as well as model data from the UK Climate Projections (UKCP18, specifically) which provide the most up-to-date assessment of how the UK climate may change in the future (Met Office) up to 2080. We use a local, 2.2km resolution model because we are looking at extremely localised rainfall which would be harder to estimate on a larger resolution.

From existing climate science, we know that monthly rainfall is driven by changes in circulation and in the case of Scotland, this is largely driven by changes in the Atlantic storm track, which is the zone where storms travel. We do not yet accurately know how this storm track may change in the future.

On July 4th 2021 a thin line of heavy rainfall developed from 14:00 to 15:00 (3 a & b) developed between Glasgow and northern Northumbria, and then moved westwards passing over Edinburgh around 16:00 (Figure 3 c). Within this rain line there were small regions where 5-minute rainfall was more than 50mm/hour and when this passed over Edinburgh it grew and generated a short period of intense rainfall over parts of the City. Figure 4 shows the maximum observed radar rainfall above Edinburgh on July 4th 2021 on two different scales. The left is a higher resolution at 1km/15mins and it can be clearly seen how localised the rainfall was in Edinburgh. In the higher resolution data, the maximum rainfall is around 100mm/hour (though over a 15 minute timescale), whereas in the lower resolution data (right), it is at a maximum of 30mm/hour. Therefore, these scales tell different stories about the maximum rainfall within the same time period and we need to be careful with our interpretations of such data. We can conclude from this figure, that the most intense rain was in the centre of this weather system, it is apparent at a 1km scale and is smoothed out in lower resolution data. Figure 5 shows that much of this extreme precipitation occurred over a short time period of 15 minutes. The Botanics recorded more precipitation overall, than at Edinburgh Castle and it is clear once again that the lower resolution (right side) does not do justice to the amount of rainfall that occurred in much less than one hour. Further analysis will focus on distributions of the maximum rainfall in a season.

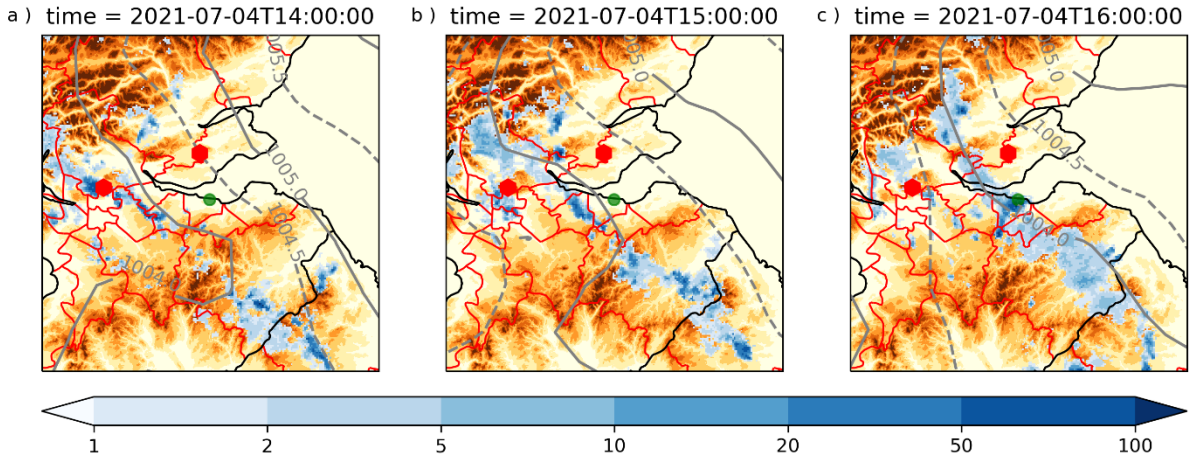


FIGURE 3: 5-MINUTE, 1KM RAINFALL (BLUES WITH LOGARITHMIC COLOUR BAR SHOWN BELOW) IN MM/HR FOR SOUTHERN SCOTLAND. YELLOW-ORANGE BACKGROUND SHOWS TOPOGRAPHY WITH DARKEST COLOURS CORRESPONDING TO THE HIGHEST LAND. RED LINES SHOW COUNTY BOUNDARIES WITH ANGLO-SCOT BORDER SHOWN IN BLACK. RED HEXAGONS SHOW THE LOCATION OF THE RAINFALL RADAR SITES WHILE GREEN DOT SHOWS THE LOCATION OF EDINBURGH CASTLE. GREY LINES ARE PRESSURE ISOLINES DRAWN EVERY 0.5 HPA. DASHED LINES ARE AT 0.5 HPA VALUES. PLOTS ARE FOR 14:00 (A), 15:00 (B) & 16:00 (C) UTC ON THE 4TH OF JULY 2021.

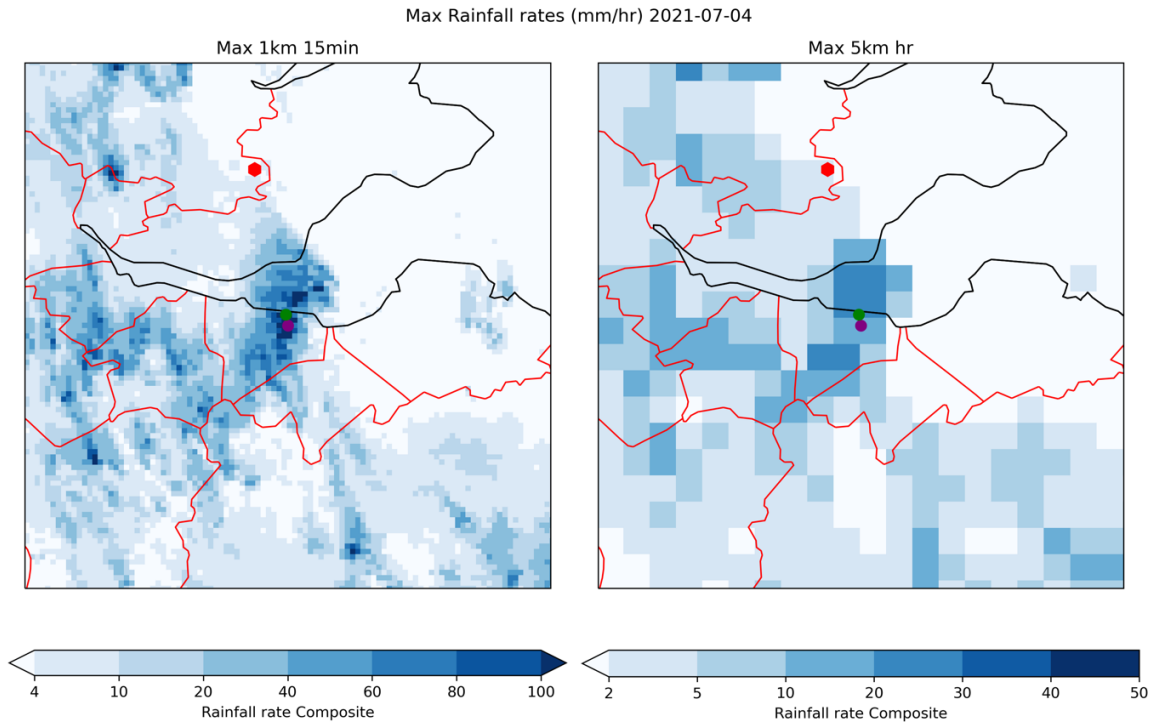


FIGURE 4: MAXIMUM RAINFALL FROM OBSERVATIONAL RADAR DATA. LEFT: 1KM/15MIN AVERAGE. RIGHT: 5KM/1HOUR AVERAGE. SCALES ARE IN MM/HOUR. GREEN DOT IS THE LOCATION OF THE ROYAL BOTANICAL GARDEN AND PURPLE IS THE SITE OF EDINBURGH CASTLE. OTHER DETAILS AS FIGURE 3.

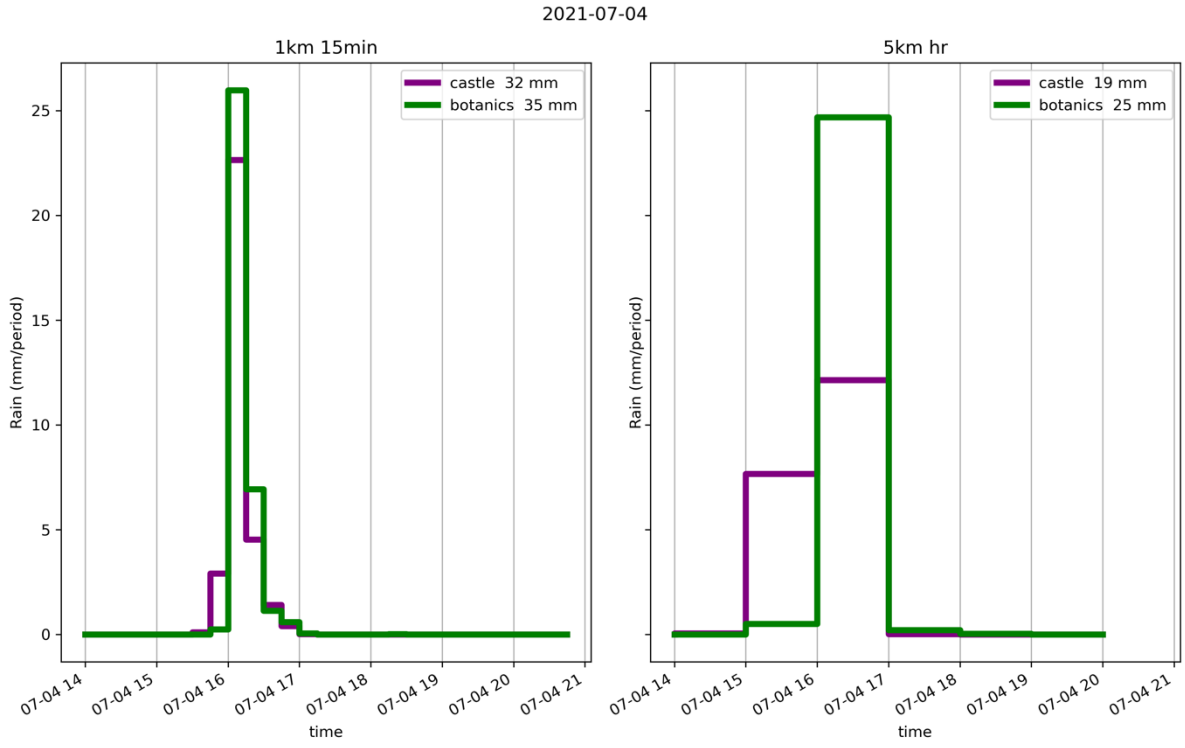


FIGURE 5: RADAR RAINFALL (MM/HR) BETWEEN 14:00 AND 21:00 GMT ON JULY 4TH IN EDINBURGH. LEFT: 1KM/15MIN AVERAGE AND RIGHT: 5KM/1HOUR AVERAGE.

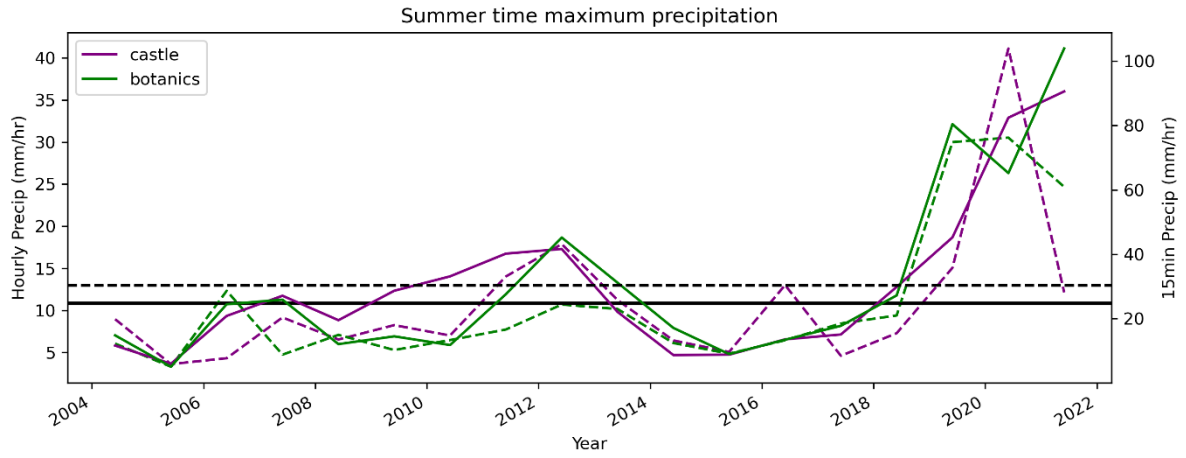


FIGURE 6: SUMMER MAXIMUM OF 15-MIN AVERAGE, 1 KM RESOLUTION RADAR DATA (SOLID; RIGHT HAND AXIS) AND OF HOURLY AVERAGE, 5 KM RESOLUTION RADAR DATA (DASHED; LEFT HAND AXIS) FOR EDINBURGH CASTLE (PURPLE) AND THE ROYAL BOTANIC GARDENS OF EDINBURGH (GREEN). SOLID (DASHED) HORIZONTAL BLACK LINE SHOWS AVERAGE SUMMER MAXIMUM FOR BOTH SITES FOR 15-MIN 1KM SUMMER MAXIMUM (HOURLY 5KM SUMMER MAXIMUM)

Figure 6 shows how summer maximum rainfall over the two Edinburgh locations varies since 2004 which is when radar rainfall data become available. Since 2019 15-minute extremes for both Edinburgh sites have been above the average value with the largest values in the series occurring in 2021. This is not the case for the 5km hourly rainfall maxima. Though the RBGE site does show larger maximum from 2019 on this is not so for the Castle. Fundamentally, extreme rainfall is noisy and no strong conclusions should be drawn from the timeseries.

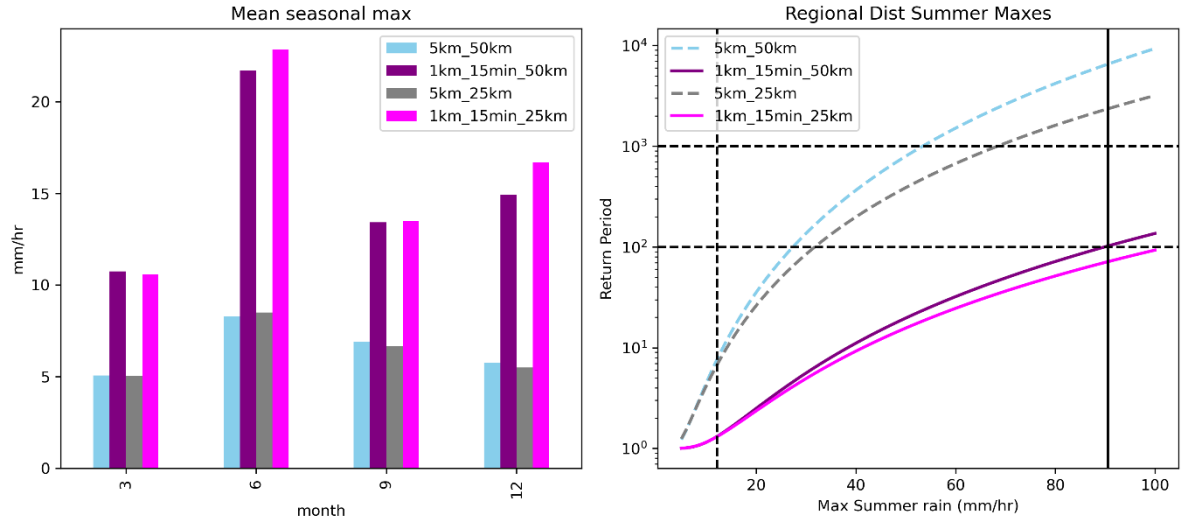


FIGURE 7: AVERAGE MAXIMUM RAINFALL WITHIN 50 AND 25KM OF EDINBURGH CASTLE (LEFT) FOR EACH SEASON FOR 15 MINUTE 1KM DATA (PURPLE AND RED) AND HOURLY 5KM DATA (BLUE AND GREY). PROBABILITY (SHOWN AS RETURN PERIOD ON Y-AXIS) OF MAXIMUM RAINFALL OR LARGER (X-AXIS) BASED ON GENERALISED EXTREME VALUE DISTRIBUTION FIT TO RADAR RAINFALL DATA FROM 2004-2019 WITH 25 OR 50KM OF EDINBURGH CASTLE. SHOWN ARE 1KM 15-MINUTE MAXIMUMS (SOLID LINES) AND 1 HOUR 5KM MAXIMUMS. COLOURS AS LEFT PLOT. HORIZONTAL LINES SHOW VALUES FOR RETURN PERIODS OF 100 AND 1000 YEARS

WHILE VERTICAL (DASHED) SOLID LINE SHOWS MAXIMUM VALUE FROM 15M MINUTE 1KM DATA (HOURLY 5 KM DATA) AT EDINBURGH CASTLE.

Figure 7 (left) shows the average, for each season, of maximum 15 minute average rainfall from the 1km data and the maximum from hourly average 5km rainfall. Maximum rainfall has been averaged over a 50 km and 25km region centred on the Castle. This shows that, around Edinburgh, summer has the largest 15 minute 1km rainfall while spring has the smallest values. There is some small sensitivity to changing the region size. Looking at the hourly 5km rainfall we also see that summer is the season with the largest extremes in the region and again spring has the smallest extreme values.

To determine how likely the event seen in July 2021 we fit a statistical distribution to all the maximum rainfall within 25km and 50km of Edinburgh Castle. A crude estimate of uncertainty is the differences between these two cases. However, in doing this we are assuming that spatial data is independent enough that these estimates are accurate. As the time span of the record is less than 20 years some caution is needed in interpreting this analysis. Looking the event that happened at the Castle we conclude that the hourly maximum at the 5km scale (Figure 7 (right)) is a *roughly* once a decade event while the 15 minute max rainfall is a roughly one in a hundred year event.

So in summary the extreme rainfall event that occurred on July 4th 2021 was a very short period, small scale, intense rainfall event. Based on radar rainfall data it appears to be about a one in a hundred year event. As the event is such an intense event even state-of-the-art models (see below) will have difficulty capturing it.

2.2. UKCP18 Model Data

In this section we use results from the recently released UKCP18 high resolution modelling study. The model has a resolution of 2.2 km and hourly average data is available from it. The 5km hourly average radar rainfall data is appropriate to compare with this data. The model data is an ensemble of 12 simulations at three time periods (1980-2000; 2020-2040; 2060-2080).

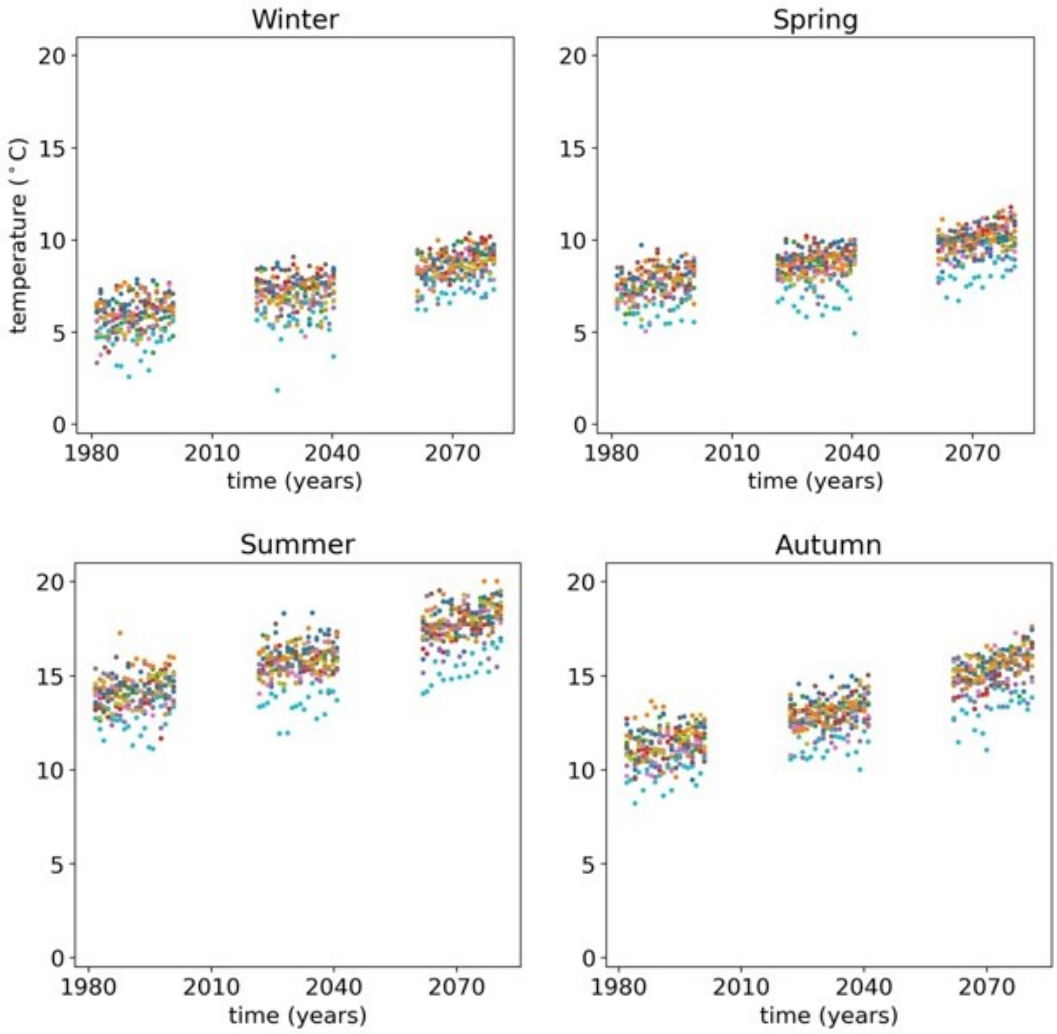


FIGURE 8: THE MEAN SEASONAL AIR TEMPERATURE AT SURFACE. THE DIFFERENT COLOURS SHOW THE DIFFERENT CLIMATE MODELS (ENSEMBLES) WHICH FORM ONE, LARGE CLIMATE PROJECTION– THE UKCP18.

The model results show that between the three timeslices – 1980-2000, which is the 'baseline', 2020-2040 and 2060-2080 – there are about 2°C warming each as shown in Figure 8. This suggests that the atmosphere is warmer and a warmer atmosphere can hold about 7% more water per °C warming. Therefore, between each time slice, we would expect more extreme rainfall events, when the entire air column precipitates. The intensity is therefore expected to increase by about 15% from the baseline to the current timeslice, and by about 30% from the baseline to the 2060-2080 timeslice. However, the average rainfall on a global scale is not expected to increase at this same rate. Therefore, the number of rain days, and average rain, for example, in summer, is likely to decrease, but individual, extreme events are likely to be more intense in the future.

In Figure 9, we show the mean seasonal maximum hourly rainfall for the UKCP18 model data at 2.2km resolution. Edinburgh is indicated by a black circle. The baseline values show that the average rainfall is the most intense in the summer, followed by the autumn and is slightly larger than the radar rainfall data. This is also reflected in the percentage increases for the 2020-2040 and 2060-2080 timeslices, although the percentage increases observed by the model data are substantially larger than what we

would expect based on the temperature changes in Figure 9 (i.e. 15% and 30% respectively). The summer months suggest increases up to 60%, with the autumn extreme rainfall events increasing drastically between the second and final timeslice. Uncertainties are also likely to be large. The percentage increases seen for both winter and spring are more in line with our expectations. Nonetheless, this suggests that the intensity of extreme rainfall events will increase particularly in the summer and autumn months.

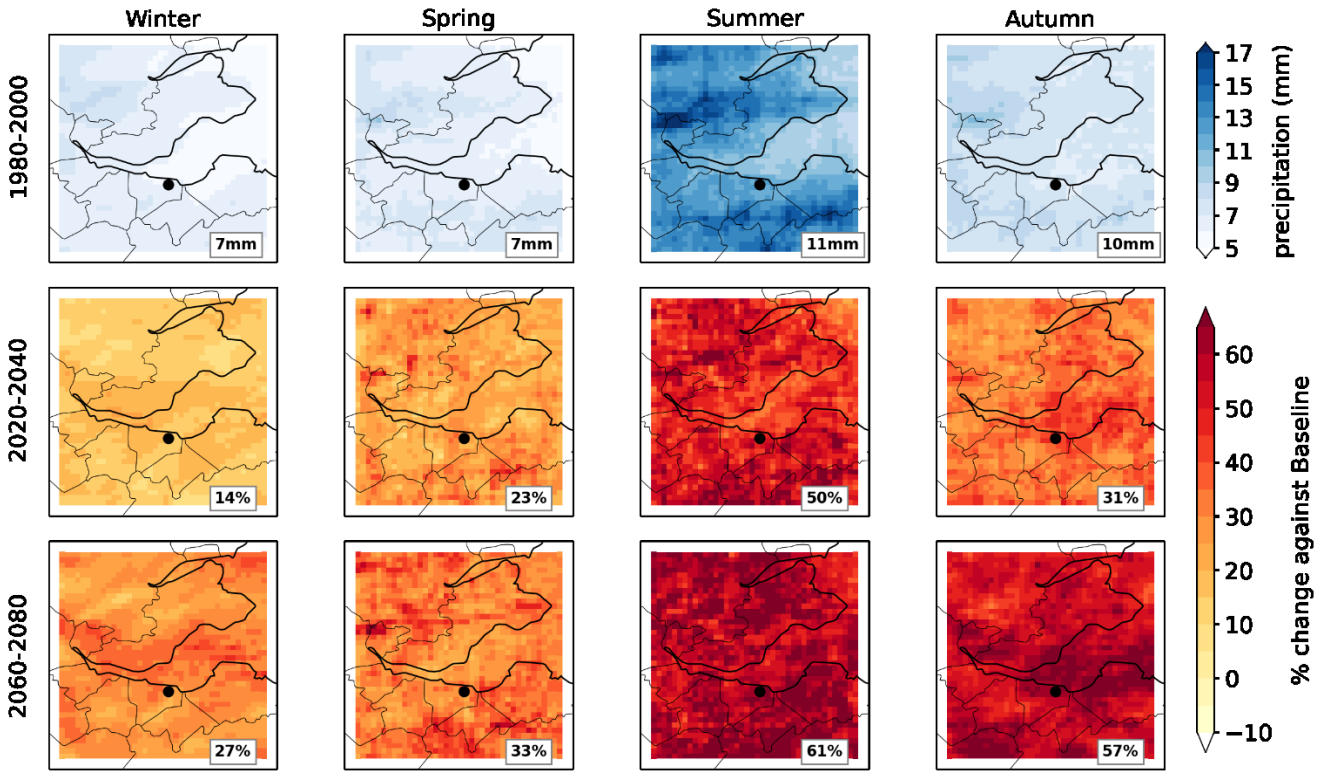


FIGURE 9: MEAN SEASONAL MAXIMUM HOURLY RAINFALL IN MM/HOUR FOR THE BASELINE PERIOD (1980-2000). VALUES IN THE BOTTOM RIGHT CORNER INDICATE THE AVERAGE RAINFALL FOR THE REGION SHOWN. FOR 2020-2040 AND 2060-2080, THE VALUES INDICATE THE PERCENTAGE INCREASE RELATIVE TO THE BASELINE VALUES. THE BLACK CIRCLE IS THE LOCATION OF EDINBURGH.

In Figure 10 we show the baseline precipitation values (mm/hour) for return periods of both 1 in 10 years and 1 in 100 years, followed by those for 2020-2040 and 2060-2080. To do this, we use a generalised extreme value distribution which estimates the extreme diversion from the median (i.e. the baseline) of these events. Similarly to Figure 9, we show that the intensity of extreme precipitation events are expected to increase, at both return periods considered. This data is likely to include large uncertainties as well, due to noise, and artefacts in the data and introduced through the analysis. In the summer, certain areas are red (i.e. a reduction of rainfall) but could be artefacts of the data analysis. The dark blue areas indicate more rainfall and the increase is clear for 2020-2040 and 2060-2080.

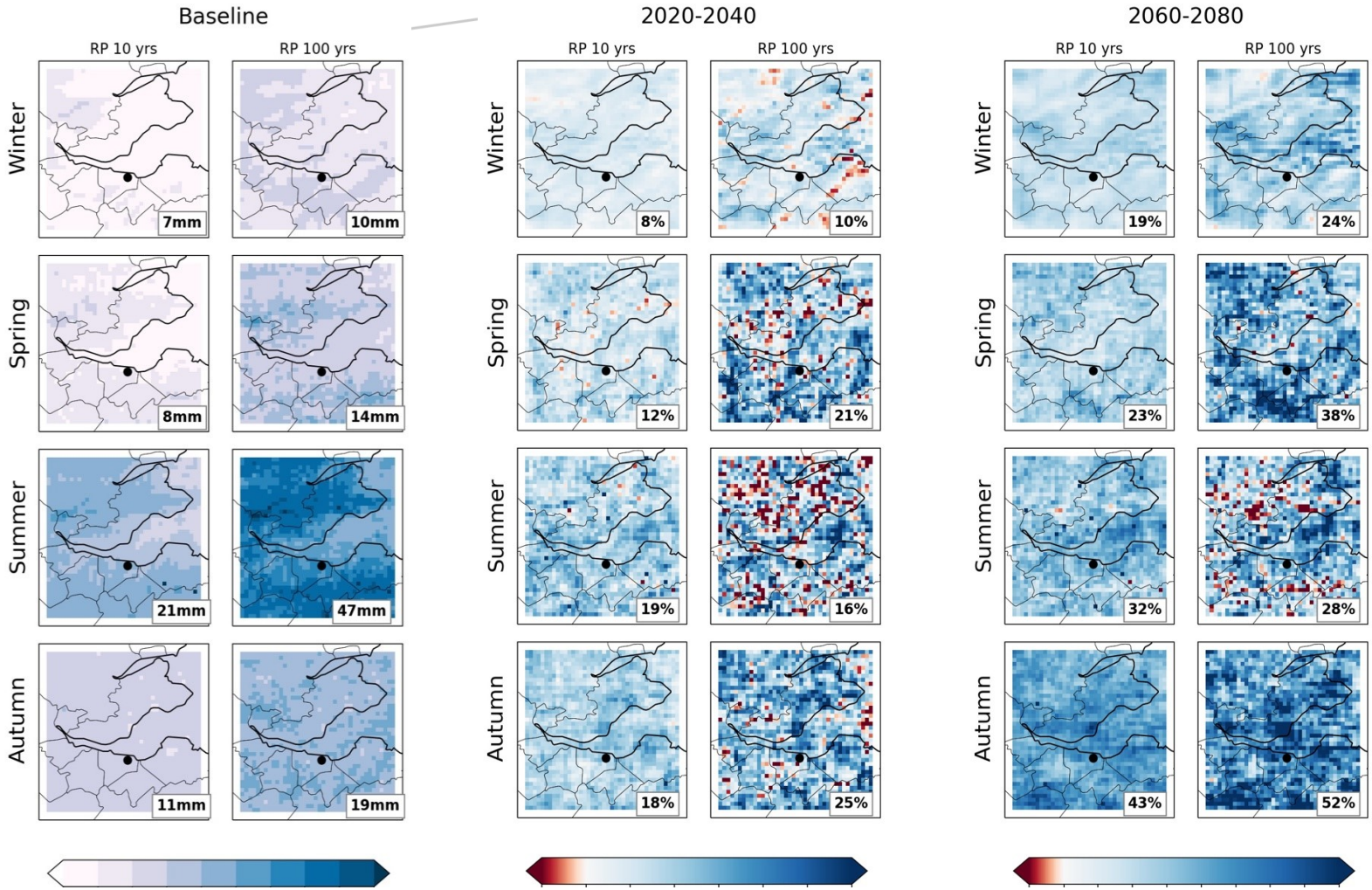


FIGURE 10: MEAN SEASONAL MAXIMUM PRECIPITATION (MM/HOUR) RETURN VALUES FOR 1 IN 10 AND 1 IN 100 YEARS. LEFT: BASELINE (1980-2000) VALUES, WITH THE AVERAGE RAINFALL IN THE BOTTOM RIGHT HAND CORNER. MIDDLE: 2020-2040 PERCENTAGE INCREASES COMPARED TO THE BASELINE. RIGHT: 2060-2080 PERCENTAGE INCREASES COMPARED TO THE BASELINE.

2.3. Summary

In the future, the average rainfall is expected to decrease in summer and increase in winter. However, and very importantly, the intensity and occurrence of extreme rainfall events is expected to increase. This requires adaptation to accommodate such events, in particular with regards to damage that could, and is increasingly likely, to occur at Edinburgh Castle or similar cultural heritage sites in the future. We should take into account the science that supports the increased risk of such events on both people and infrastructure and use it for mitigation.

As we have shown, the model resolutions we have available are not able to refine this intense, very short, extreme precipitation which substantially increases the uncertainties in our estimates for future extreme precipitation events. Ideally, we would need models which can resolve on the 100 meter, rather than the kilometre scale, for localised events such as the July 4th event in Edinburgh.

For this event the radar suggests that a warning time of about an hour would have been possible from the rainfall radar. If this is useful it would be worth HES talking to the Met Office to have a "nowcasting system" particularly for the Castle.

3. Work package 3: Scenario development and training

Findings from work packages 1and 2 were collated, synthesised and then validated with partners, and wider practitioners via scenario development and capacity building workshops in March 2022.

Training on climate risk pathways and the potential use and implementation of the novel damage surveys protocol were provided for HES staff and wider stakeholders as part of these workshops. These workshops were held in two locations to ensure accessibility beyond Edinburgh city. Both workshops explored the research findings, sought feedback from HES staff and wider heritage partners. The key feedback from the workshops is provided in the workshop report in Annex 3.

3.1. Collaborative approach to developing scenarios and survey template through co-designing

We have used a co-design approach to develop a post-event damage survey template so that it is informed by user needs and requirements, incorporating existing systems within their organisations and partners. A co-design approach can help develop tools that are directly informed by potential users and provide the most relevant information for their contexts (Dilling and Lemos, 2011; Shaw et al., 2009). In return, co-design with users can ensure tools are able to be practical by increasing user productivity and satisfaction (Trischler et al., 2019). Common methods for the co-design process include surveys, interviews and workshops. We used semi-structured interviews and hosted two workshops to implement a rapid co-design process and collect feedback on building scenarios and a post-damage event survey template (see Figure 11).

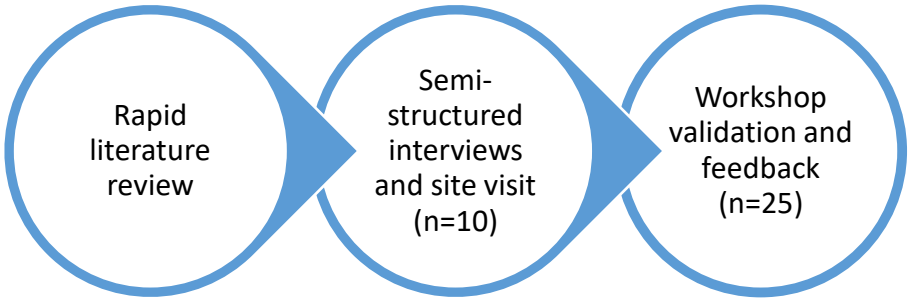


FIGURE 11: SUMMARY OF METHODS INCLUDING NUMBER OF PARTICIPANTS AND INTERVIEWEES (TOTAL ENGAGED N=34)

Figure 11 provides a summary of the process implemented and included:

1. Identify key template components for a post-event damage survey from existing literature
2. Interview results outlined options for a template format, the need for an inclusive (the whole disaster cycle) event template and outlined key points that were required in the template (e.g. useful data sets & existing data/system)
3. Workshops provided interactive activities for participants to interrogate and feedback (e.g. SWOT analysis) on the post-event damage survey

A full breakdown of participants and interviewees is provided in Appendix 3.

3.2 Finding 1. 'What if' scenarios (reflecting near misses from the July 4th extreme rainfall event)

The interview outcomes are summarised in the damage and loss table in section 1.2.2. The interviewees also highlighted a number of 'near-misses'. These near-miss narratives provide the basis for scenario development.

As the duration of the rainfall event was very short and occurred near the site closing time of the day, the economic impacts look small. In particular, the daily footfalls of the castle visitor decreased by one third compared to 2019 before the covid-19 outbreak and restrictions. Furthermore, the damage and loss would have been more severe if there were no equivalent resources that the Edinburgh castle maintained. A key message from the interviews highlighted that the site was fortunate to have one-site experts, already contracted teams and available resources including stocked equipment, available human resource on site and funds that could absorb the repair costs. The location of the site, in the central city, also helped in terms of a quicker response to emergency calls and increased accessibility of key staff located nearby.

The research team agreed that to visualise the complexity of the event flow diagrams would be used to demonstrate the event as well as various what if scenarios based on the interviews.

Figure 12 shows the damage and loss pathways representing high (red lines), medium (yellow and orange lines) and low or no damage (green lines) during the July 4th extreme rainfall event.[1]

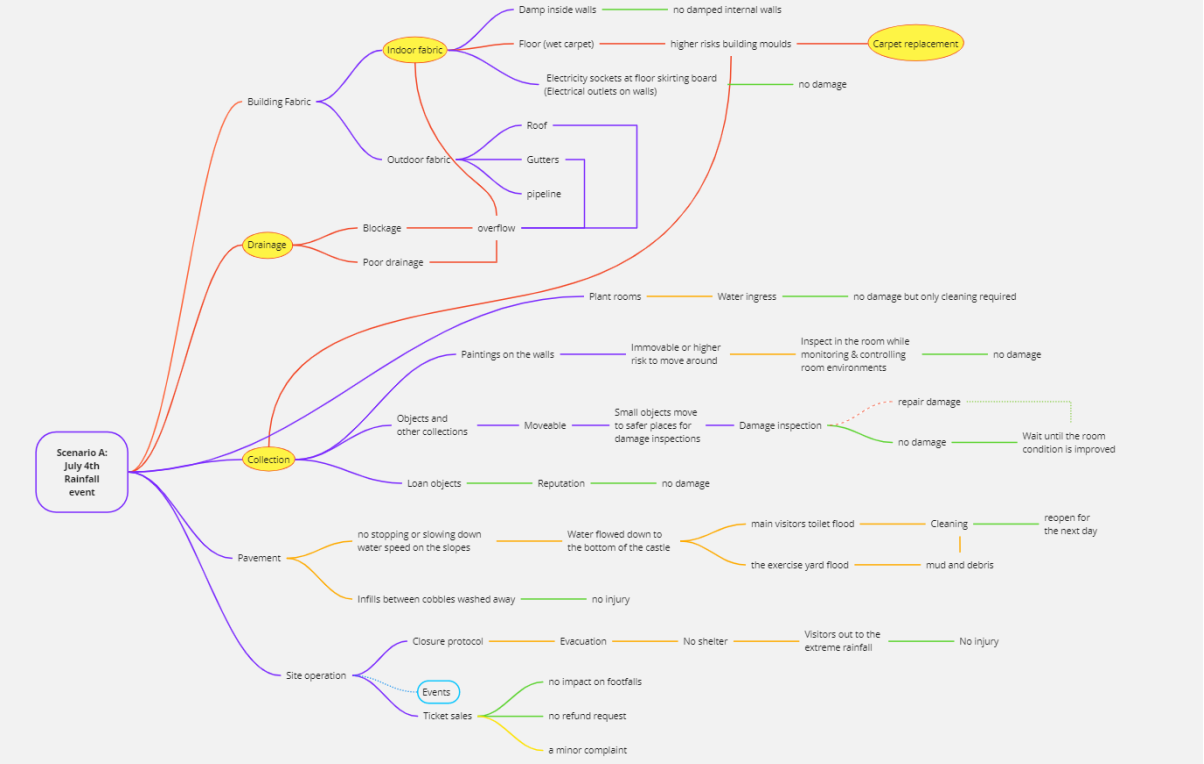


FIGURE 12. DAMAGE AND LOSS PATHWAYS: HIGH, MEDIUM AND LOW DAMAGE POTENTIAL BY USING THE JULY 4TH EXTREME RAINFALL EVENT AND ITS IMPACTS ON THE CASTLE SITE. FULL SIZE VERSION AVAILABLE ON REQUEST.

Figure 12 illustrates key pinch points (circled in yellow). These included the drainage, and then damage to the flooring in the Mary room and opportunity costs incurred by the collections team. Many of the risk pathways mapped demonstrated the actions taken to reduce risk (where red or orange lines turn green). Fundamentally these flow diagrams provide a visual for the event, demonstrating the importance of direct and indirect damage as well as enabling stakeholders to see key issues and develop alternative scenarios.

The next three flow diagrams demonstrate different potential 'what if' scenarios extended from the July 4th extreme rainfall event. The 'potentials' are based on interview results. The 'what if' scenarios focused on:

- (Scenario B) longer duration of the extreme rainfall event
- (Scenario C) the event occurred in winter (seasonal)
- (Scenario D) occurring during a normal busy festival peak summer time without COVID-19 measures

Figure 13 demonstrates a scenario 'what if extreme rainfall were heavier or occurred for a longer duration'. This includes executive days of rainfall where it would be harder to dry indoor fabrics. Under

[1] The flow charts were drawn by using a mind mapping template in Miro boards (https://miro.com/app/board/uXjVOESPdS4=/).

scenario B additional damage could have occurred to building fabrics (esp. walls), the plant rooms which may have to be shut down leading to challenges to energy supply. Further damage could occur if water interacted with electricity sockets at floor level (e.g. the humidifiers and wet vac use would be impacted). Furthermore, interviewees highlighted that if there were damage to the collections within the Mary Room it would result in higher salvation fees and have potential reputational risks, as well as consuming extra staff time. If a collection loan was severely damaged, it is possible that the government indemnity scheme would be instigated.

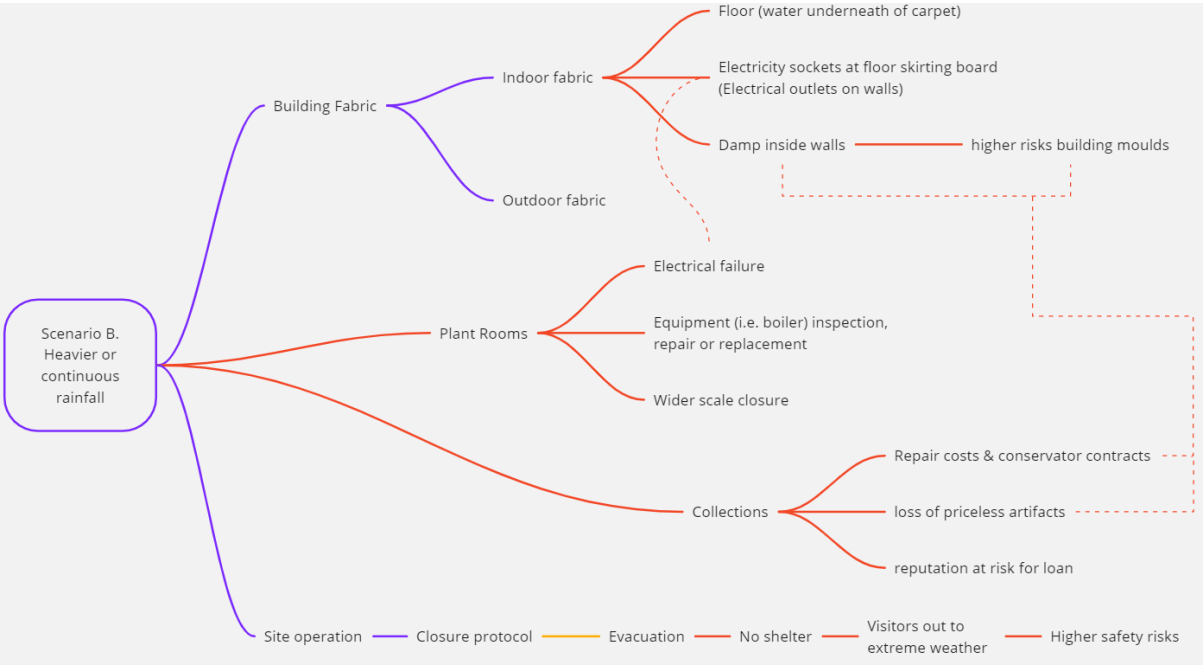


FIGURE 13. SCENARIO B: WHAT IF EXTREME RAINFALL WERE HEAVIER AND/OR OCCURRED FOR A LONGER DURATION

Seasonal comparison in work package 2 showed that winter extreme rainfalls are likely to be less severe than summer events. The damage incurred during the winter season could take long to repair due to managing challenging external weather conditions and humidity. These additional challenges were captured in Figure 14.

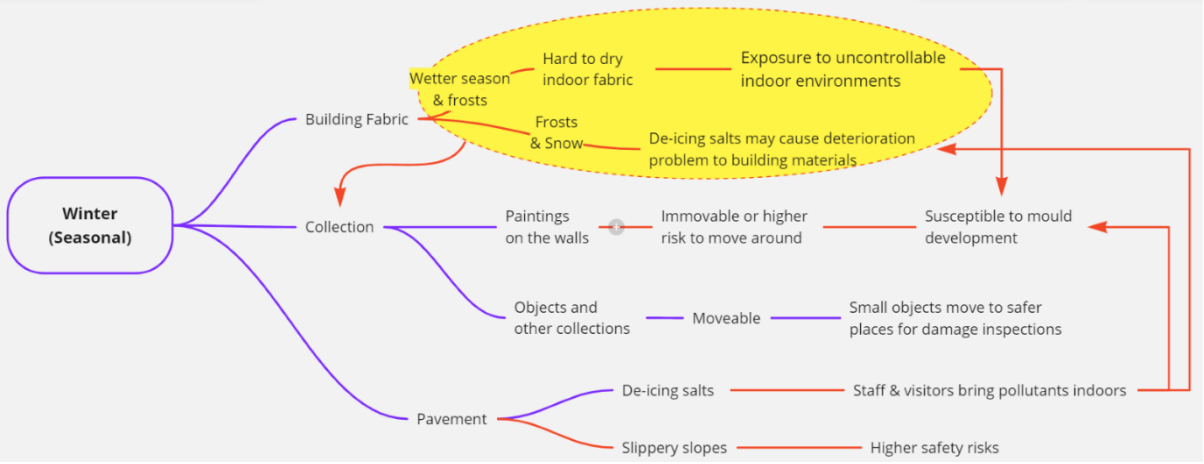


FIGURE 14. SCENARIO C: WHAT IF EXTREME RAINFALL OCCURRED IN WINTER (SEASONAL)

Figure 15 illustrates possible consequences of a similar event occurring during 'normal' non-COVID times. Here we illustrate the importance of the festivals in particular the Edinburgh Military Tattoo which runs events from June – August with the construction of a large arena in the castle parade ground. Here we highlight the potential for injury to staff and public attending these events as well as possible reputational risks and loss of ticket sales.

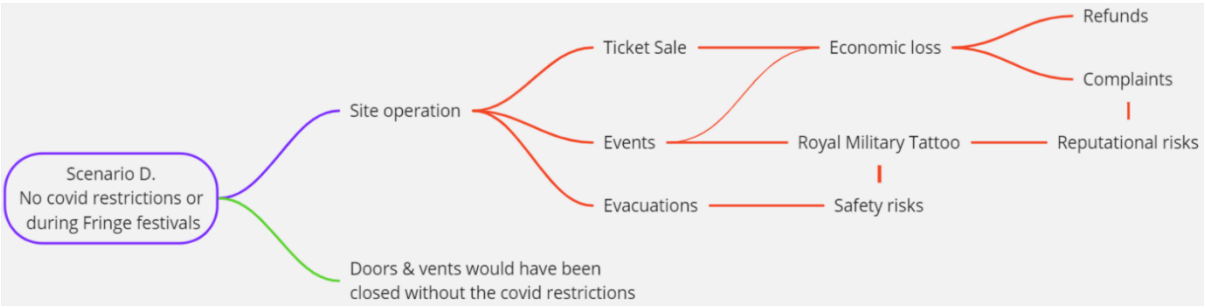


FIGURE 15. SCENARIO D: WHAT IF EXTREME RAINFALL OCCURRED IN EDINBURGH FESTIVAL FRINGE AND/OR EARLIER OPENING DAY WITHOUT COVID-19 MEASURES

There are more scenarios that were discussed such as rainfall creating a city wide disturbance.

Feedback from the workshops indicated that participants: 1) agreed with the damage & loss risk path and potential usages, 2) provided ideas for improvements and different approaches and 3) commented on concerns and limitations. Feedback is provided in Table 5.

TABLE 5: FEEDBACK FROM WORKSHOP PARTICIPANTS ON RISK PATHWAYS AND WHAT IF SCENARIOS

1) Agreed to the damage & loss risk path and potential usages	
A very logical and visual way of breaking down risk and impact	Useful to visualise impact in terms of resource
Potentially a more effective way of communicating risk and impact of an event	Can see clearly the risk pathways with flow chart and how to provide an action
Effective as it allows the 'what if' analysis to be more easily carried out	Very helpful for sharing with others, simple diagram to explain the purpose of damage survey
Very useful at compartmentalising issues that allows for focussing on the learning that can be achieved from the outcomes	Great to better understand and manage (prepare for/respond to) to climate impacts to improve resilience. Particularly like the mixed method approach and hope that qualitative data will continue to be as valuable as the numbers.
Good to calculate the staffing impact of the events as this is often overlooked	Share the flow chart with other organisations that don't have the resources to run them- so they can learn and use it to review their processes in light of vulnerabilities, exposure etc.
Like to think with different possible scenario	Exploration of doing flow chart in a 'bow tie' to monitor efficiency of what is in place.
2) Improvements and suggestions	
A comparative or circular flow chart that traces the adaptation option back to addressing the impact might be useful	Re. Drainage was there risk of sewer overflow? i.e. combined drainage system? (consideration for other sites only maybe)
Are some of the inputs going to be categorised? How many fields will be free text? Could become very onerous.	Wider stakeholder engagement - would this impact on say the tattoo?
Are the results going to be scored in some way? What will that look like/be confirmed?	It would be great to be able to factor in travel to this, especially as current transport infrastructure is not resilient. – how do visitors get home safely? – how do staff get home safely? – did the event prevent visitors/ staff to visit?
Scenario-missed links: no damage to sockets, no damage to plant rooms– this allowed for dehumidification and some environmental monitoring of collection and aids recovery	Refer to existing salvage plans
Could be useful to add learning section at the end? What can we learn for future?	The flow chart and post- event damage survey should be visible to every team (PiCAMs)
3) Concerns and limitations	
Prioritise issues – unable to fund solutions in every area, focussed resource allocations	
Refer to incident response folder	

To make data properly quantifiable there needs to be a good base data	

3.2. Finding 2. Post-event damage survey template

The interview participants were asked to share their thoughts on a post-event survey template. The participants noted that the use of a post-event damage survey template could provide a central space for information across current systems across teams and regions. Despite the initial aim of post-event damage survey template was to deliver a rapid template or protocol for immediate data collection interview information indicated that a whole disaster management approach was more appropriate – pre, during and post-event.

Key opportunities of applying the survey protocol identified from interview participants were:

- providing data that team to use as an evidence base for decision making (to create future business cases for resources and action).
- a) better communication for each stage of an event cycle, b) data recording for in-depth analysis and risk assessment (damage estimation/function)
- being able to gauge which staff are involved, what kind of equipment is required (also to guide later if pre-positioning of equipment is required)
- being able to record methodology for repair and recover (for training)
- Recording the 'bridging' tasks across teams
- setting up thresholds for estimating severity of damage for different heritage types

From this initial feedback the team were able to create a draft template and present this at the two workshops for further feedback and validation.

From the interviews the team were able to identify some guiding principles for the template design and its use, these included:

1. Fitting/bridging into a whole event cycle (full scale) within the existing systems including regular maintenance and repair, and defect report of damages in the PiCAMS.
2. Make sure there are flexibilities in the survey template by considering teams and position (on-site or off-site, district or regional level)
3. Clear guidance on alert thresholds and communications (e.g. SOP)

The final post-event damage survey template is provided in Appendix II. The research team suggested the following possible implementation options at the workshops.

- App development: full reporting system through an app development (Kanban board style survey presented)
- Paper-based form: see template (project output)
- Integrate with existing system: Series of select questions that link to existing maintenance or logs within PiCAMs or similar

Feedback on the post-event damage survey template used a Strength, Weakness, Opportunities and Threats (SWOT) analysis presented in Table 6.

TABLE 6 THE SUMMARY OF SWOT FEEDBACK ON THE POST-EVENT DAMAGE SURVEY TEMPLATE

Strengths	Weaknesses

• One place for all information
• Logical and thorough data collection
• Structured process and comprehensive
• Clear, scalable template and process
• Multiple users/teams feeding into
• Inclusive process, everyone gets to contribute
• Creates a streamlined response
• Makes a prompt debrief and learning for the futures easier
• Helps consistent reporting and prompt for staff
• Share knowledge and skills across the regions
• Useful tool outside of HES
	• Duplication and/or extra reporting works
	  - i.e. PRIME used for salvage
	• Time consuming (extra staff hours)
	  - training required
	  - needs to be simplified
	  - can be overlooked when busy
	• Not synchronised with other IT
	  - requires some adjustments to existing systems
	• Digital only access could be a problem (i.e. power cut incidents)

Opportunities	**Threats**

• Sharing knowledge and learning opportunities (sustain institutional memory)
  - Better understanding on how extreme events impact on sites and how resilience is built into the system
• Supporting other works
  - HES climate risk assessment and climate change impacts work
  - To feed into future climate risk assessments and keep information up to date
  - Cost analysis
  - Audit trail review
• Bridging teams and systems
  - To connect up systems into a single source
  - Could help connect teams up in disaster/emergency response
  - Connection with other existing forms, for example site closure plus defect forms.
• Weather warning can be used to actually mitigate against damage occurrence
  - Could help to anticipate information to collect and plan for that
• Increase systemic efficiency by automated reporting to relevant staff
• Flexibility to adapt to different situations (non-climate) or organisations
  - Could offer a useful template for small organisations for smaller teams
	• Acceptance and use of templates across the whole organisation
	• Some events and/or sites can be overlooked if there are no on-site staff (extra training required)
	  - More information on what is an event, training on multi-hazard events
	• Burdening existing system
	  - Creating another fragmented system
	  - Unresolved tasks at event closure could remain unresolved for years
	• No following funding
	  - Funding is currently reduced to deal with risk before it is gets out of control – we are in a reactive mode
	• A recording process with no action may lead to reputational damage

- Paper copy options to record and upload at a later time (i.e. power cut incidents)	

Further recommendations included:

- As the survey template includes the whole cycle of event phases it should be called something else instead of "post-event damage survey template".
- Add an entry for post analysis and learning
- Put a 'residual risk' section at the end to identify unresolved tasks: on-going damage and/or maintenances issues can burden the system for years.

The participants also identified some further questions relating to recording smaller events and the criteria of recording incidents (size or damage level):

- How do you record smaller events?
- What size of event or damage would qualify for the survey to be used?
- If survey used for all events, how to know when to record when a weather event is extreme?

Limitations

This project was extremely rapid and due to this the joint team focussed on one case study location. This provided a wealth of information but could not cover a range of HES site types. The damage survey was unable to collect accurate quantitative data in order to develop a vulnerability model. This was because there were few existing records of costs available and interviewees were unable to recall exact figures. This is not surprising given the time delay between the event and the interviews and both limitation highlight the importance of the post-event damage survey.

Conclusion and recommendations

This project rapidly examined the damage and loss from an extreme rainfall event in Edinburgh during 4th July 2021. The damage survey incorporated key informant interviews as well as a site walk through. The project also included a meteorological study of the rainfall event. The project concluded that:

- This type event is likely to increase in severity in summer and autumn months under high emission scenarios.
- The damage to the castle occurred due to insufficient drainage in crown square
- Threat to staff and public was considered a near-miss due to low visitor numbers
- Staff resources were essential during the response and recovery phase at the castle

The project team recommend the following:

1. The event analysed had a relatively low impact due to low visitor numbers and time of day however was considered a 'near-miss', it is therefore essential for these findings to reach relevant HES partners responsible for event management at the castle and measures are taken to improve the castle drainage.

We believe that if COVID restrictions had not been in place it would have been feasible that a member of public or staff could have suffered an injury. Surface water run off was rapid and pool in key sites, staff and public were exposed to these.

Ultimately, the damage to rooms occurred due to insufficient drainage in crown square. We recommend that HES review the drainage in this area and consider making space for water to dissipate and move to areas that can be flooded safely.

2. HES, and other interested parties, discuss with the UK Met Office the potential to get timely warning of extreme rainfall events. Even one hour of warning would allow implementation of measures to reduce the impact.
Multiple interviewees noted that they had been fortunate on the day. HES staff responded rapidly and efficiently yet given the speed of the event there was very little staff could do. However, we do believe that conversations with the UK Meteorological Office could provide a warning that would have allowed the safe evacuation of the site and implementation of flood defences in key positions.

3. Staff believe that the template can be adopted to record, track and monitor response and recovery from a significant weather hazard event. Overcoming institutional memory loss and providing evidence for strategic decision making.
Feedback during the workshops was overwhelmingly positive. Many participants discussed that there is currently no systematic or central mechanism for capturing event damage or action taken during the response or recovery. This can not only provide relevant data for climate scenarios but also provide a tracking system for on going activities and contribute towards organisational learning.
4. The project should be scaled to examine a range of heritage types, develop quantitative functions for modelling and integrate the template within PiCAMs with some basic training for relevant staff. Given the timeframe of this project one key case study was selected. Although the castle and the 4th July event provided a useful study, it does not capture the range of sites under HES care. There is an opportunity to carry out further geographically widespread forensic analysis of past events and their impact on heritage sites. There is also an opportunity to incorporate value within these studies. Better understanding the value of sites may support discussions on 'losing sites' well, where it is not vial to protect sites.
5. Finally, there is an opportunity to test and refine the template during future weather events.

Appendix I. Semi-Structured Interview Protocol

Date:
Duration: (60-90 minutes)
Participants:

1. Introduction (10 mins)
Key points for the introduction:

- Introduce interviewers
- Short introduction of the project & key topics of questionnaires – explain external grant and funding arrangements
- Ethical clearance and verbal consent recording
- Profile of interviewee

"Thank you again for participating in this interview. Before I continue; do you mind if the conversation is recorded from this point onwards? This will make it easier for us to process the results and prevent us from missing any valuable lessons."

Q1. Before we get into the recent flood event and damage survey, would you mind briefly introducing your role within HES?

- Name, role & position within HES, length of services

2. Experiences of recent flooding events

Q2. [Hazard types] What happened? Please tell us about the rainfall and the flooding.

- Description of rainfall: duration, the severity of rainfall etc.
- Flooding estimation (Surface water flooding including Sewage overflows): Depth of water, the velocity of flow (fast, slow, etc.) (water flow by surface and elevations?), debris in watercourses

Q3. [Response] What was your first reaction to the events? Actions that were taken to reduce impact?

- Is there any flood risk management or yellow weather warning response protocol within HES you are aware of?
- Do you know where emergency response stocks are (i.e. sandbags & salts etc.) and/or who is responsible to manage that?

Q4. [Damage function] What kind of damage occurred due to the flooding event?

- Types of damages & severity: building structures, fabrics of rooms, collections (wet, damp, only a little wet, or soaked, etc.) and service continuations (i.e. business closed during the event, temporal closure due to inspection/repair or permanent closure, etc.), contaminations (Floodwaters can carry raw sewage, leaked toxic chemicals, and runoff from hazardous waste sites, factory farms, and houses).
- Severity of impact? Measure of severity? Low – high impact and criteria e.g. closure of entire site for X days = high
- Closure of castle – for how long? Impact on normal business of castle?
- What do you consider to be the key factors contributing to the damage that you described from the above flooding event (i.e. drainage problems/overflow, no reducing velocity of surface water flooding due to lack of permeable surfaces or absence of operations control water path using send bags or multi-functional green space/reservoir etc., or maintenance issues)?

- Do you have **other experiences** in other damages that have been occurred by other types of hazards?

Q5. [Repair/Recovery] Can the damage that you have detailed in the above be repaired? How long did or will the damage take to repair/recover?

3. Damage inspection survey forms

The influence of maintenance on damage and limited monitoring of this for understanding future damage

Q6. Have you ever seen or used any forms for damage inspection within HES and/or other organisations?

- Does it work well?
- What frustrates you about using the existing recording/reporting system?

Q7. What are the strengths and weaknesses of the current approach to taking account of and managing the risks of flooding to inspect damages in regards to repair/maintenance?

- Compatibility or feasibility to combine to existing Cost of repairs and maintenance systems (PiCAMS)
- Further questions about PiCAMS:
  - How often do you use the system?
  - What is your main purpose of using the system?
  - Things to improve?
  - Should the damage assessment by linked into PiCAMS and what support is required?

Q8. Based on your experiences, would you recommend Dos and Don'ts for the rapid damage inspection form (mainly for examining impacts to the castle from the recent heavy rainfall)?

- Preferences on rapid damage & recovery inspection survey forms;
  such as a **Checklist for actions** & inspections **recording data types** you prefer or effective to report damages (i.e. narratives, pics, videos, or tick boxes)?
- Training requirements on climate change, risk and damage?

Finish by mentioning the workshop date and plan going forwards.

Appendix II. Post-event damage survey template

Post-event Damage Survey Template		PiCAMS
Basic Information		
User/Reporter	*Name, Team, Role, Date of reporting*	✓
Site details	*Property in care: Type of property or asset*	✓
Reporting events	*Event name and date*	-

*	Components	Attributes					
Preparation information							
Pre-event	Warning information	• *Primary hazard details* • *Threat type, warning level, est. duration and impact date* • *Possible secondary hazards*					Δ
	Primary hazard	*Insert what expected (i.e. closure protocol for strong wind)*					Δ
	Actions taken by anticipated impacts *(team, date, action)*	• *Communications with wider team:* *Which teams need to be alerted?* *External communications required?* • *Pre-position resources: wet & dry vacuum, dehumidifiers, other relevant to protect collections, etc.*					Δ
Hazard information							
Immediate	Primary hazard	*Measurement details per hazard:* • *Flood - depth and duration (if possible velocity)* • *Rainfall - duration and severity* • *Wind - duration and wind speed* • *Cold, frost and snow* • *Heat - temperature and duration etc.*					-
	Secondary hazards	*Hazards that are coincidental or triggered due to the primary hazard*					-
	Exposure	*Estimated % exposure of site*					Δ
	Actions taken	*During the event i.e. emergency calls, site closure protocol etc.*					-
	Event details	*Narrative to describe the event and immediate impact*					-
	Attached files	*Photos/Video of event*					-
Direct Damage and Loss							
Immediate (0-1 week)	**Direct damages**	**What**	**Where**	**How**	**Action taken**	**Who**	
	External building fabric						Δ
	Internal building fabric						Δ
	Collections						Δ
	Health and safety						Δ
	Damage to other assets	*This may include vehicles, equipment, heating systems, electrics, etc. Important to report this damage and estimate of cost and repair or replacement time*					O
	Direct loss	*Record complete loss of asset*					Δ
	Human resource tracker	*Keep track of on-site staff time in response and recovery including opportunity costs and voluntary time*					O
	Near-miss	*Space to record any near misses for future learning*					-
	Attached files	*Photos/Video of event*					-
	Indirect Damage and Loss Checklist						
	Health and safety	*Further risks/incidents caused direct damages threatening health and safety of staff and visitors*					O
	Resource allocations	*Redirection of resource or pausing projects*					O
	Reputational risks	• *Full or partial closure of site* • *Complaints from visitors and social medias* • *Collection loans*					Δ/O
	Impact on events	*i.e. festivals, school visits and other*					O
	Wider Impacts	*i.e. Regional transport networks, Electricity and power supplies and Other*					-
	Income loss	*Ticket sales & refunds, Visitor footfall, Event cancellation*					O
Further Impacts							
Longer recovery phase	Further hazard events						-
	Socio-economic impacts	*Additional external events that impact the recovery phase*					-
	Project management	*Top level list of repair and replacement projects underway by different teams - keep track of activities and costs*					-
	Monitoring the long term recovery phase	*Monitoring repair and replacement activities including:*	• *Asset repair type* • *Repair and replacement costs* • *Internal and external contractors/experts/consultants*				Δ/O
	Health and safety	*Longer term impacts on health and safety* actions					-
	Recovery damage	*Record additional damage due to the recovery phase*					-

Appendix III. Workshop report

Overview

Researchers at the University of Edinburgh together with HES have been working to address the gap in understanding the impacts of climate-related disasters on cultural heritage. This project is called “Cultural Heritage and Urban Resilience in Scotland: Co-designing extreme rainfall impact assessment tools for adaptation” and co-funded by HES and the National Centre for Resilience. The aim of this project is to enable a better estimate of loss and damage from future events and plan accordingly.

The workshop is delivered for the work package 3 of the project to enable a validation process with partners and wider practitioners in March 2022.

1. Aims of the workshop:

This workshop is designed to improve the understanding of extreme weather impacts on heritage sites in Scotland and collect feedback on a post-event damage survey protocol. The post-event damage survey protocol undertook a co-designed process by interviewing HES staff.

Two workshops were held, one in Edinburgh and the second in the Highlands. Both workshops explored the research findings and sought feedback from HES staff and wider heritage partners.

- Workshop 1: Monday, 14th March 2022 in Edinburgh
- Workshop 2: Wednesday, 16th March 2022 in the Highlands

FIGURE 16: FRONT SLIDE FOR VALIDATION WORKSHOPS HELD WITH HES STAFF AND STAKEHOLDERS IN MARCH 2022

2. Workshop programme and participation

We invited HES and their partners to an interactive day of discussions, presentations, and workshop sessions focusing on extreme weather impacts on heritage sites in Scotland, including a hands-on exercise in post-event damage survey protocol.

Total 25 attendees participated in workshops from HES (n=18) and their partners including National Trust for Scotland (n=3), Edinburgh World Heritage (n=1), Glasgow City Heritage Trust (n=1), Royal Edinburgh Military Tattoo (n=1), the Edinburgh City Observatory in Calton Hill (n=1) (see table 7).

TABLE 7: WORKSHOP PARTICIPANTS

Edinburgh Workshop Attendees (n=19)	Highlands Workshop Attendees (n=6)
• Historic Environment Scotland (n=14) • National Trust for Scotland (n=1) • Edinburgh World Heritage (n=1) • Glasgow City Heritage Trust (n=1) • Royal Edinburgh Military Tattoo (n=1) • City Observatory, Calton Hill (n=1)	• Historic Environment Scotland (n=4) • National Trust for Scotland (n=2)

3. Workshop programme

The workshop included training on climate risk pathways and the potential use and implementation of the novel damage surveys protocol. Both workshops had the same structure but for the second workshop in the Highlands, the "climate change impacts on Scotland" session was presented by Dr Kate Crowley (with the same materials prepared and presented by Anna Beswick, Adaptation Scotland at the workshop in Edinburgh).

10:00	**Arrival refreshments**
10:30	**Welcome and opening session** Dr Kate Crowley, UoE
10:40	**Climate change impacts on Scotland** Anna Beswick, Adaptation Scotland, Sniffer
11:00	**Climate Ready Historic Environment Scotland** David Harkin, HES
11:15	**Climate risk pathway** Dr Kate Crowley, UoE
11:30	**Mid-morning refreshments**
11:45	**Extreme rain: risk analysis** Prof Simon Tett and Ginna Geffer, UoE
12:05	**Damage narratives and estimation** Dr Kate Crowley and Dr YoungHwa Cha, UoE
12:20	**Hand-on exercise 1. Impacts** Attendee activities
12:30	**Lunch**
13:30	**Post-event damage survey protocol** Dr Kate Crowley and Dr YoungHwa Cha, UoE
14:00	**Hand-on exercise 2. Feedback on the post-event damage survey protocol** Attendee activities
14:30	**Afternoon refreshments**
14:45	**Sum-up activities and feedback**
15:00	**Next steps and takeaway messages** Close the event by 15:30

FIGURE 17: WORKSHOP AGENDA

Session 1. Risk of damage and loss pathway

After the first climate change, risk and HES adaptation sessions, the research team shared the key outputs of the project. The activity before lunchtime aimed to share the damage and loss from the Edinburgh Castle case study and to provoke discussion on their own site management including. Discussion included the near misses collected from interviews.

Participants provided feedback including 1) agreed to the damage & loss risk path and potential usages, 2) improving points and different approaches and 3) concerns and limitations. The detailed feedback on the damage and loss risk path flow diagram is here:

1) Agreed and complement to the damage and loss risk path

- Great to better understand and manage (prepare for/respond to) to climate impacts to improve resilience. Particularly like the mixed method approach and hope that qualitative data will continue to be as valuable as the numbers.
- A very logical and visual way of breaking down risk and impact
- Potentially a more effective way of communicating risk and impact of an event
- Effective as it allows the 'what if' analysis to be more easily carried out
- Very useful at compartmentalising issues that allows for focussing on the learning that can be achieved from the outcomes
- Good to calculate the staffing impact of the events as this is often overlooked
- Like to think with different possible scenario
- Useful to visualise impact in terms of resource
- Can see clearly the risk pathways with flow chart and how to provide an action
- Very helpful for sharing with others, simple diagram to explain the purpose of damage survey
- Share the flow chart with other organisations that don't have the resources to run them- so they can learn and use it to review their processes in light of vulnerabilities, exposure etc.
- Exploration of doing flow chart in a 'bow tie' to monitor efficiency of what is in place.

2) Improving points and different approaches

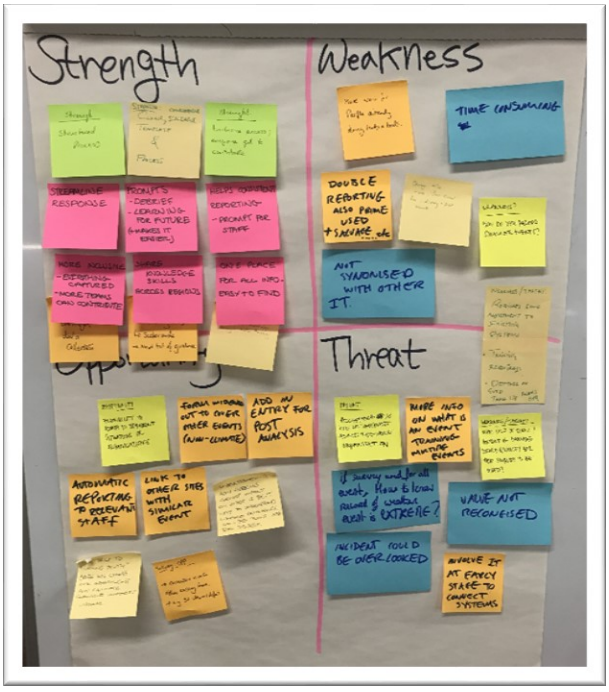
- A comparative or circular flow chart that traces the adaptation option back to addressing the impact might be useful
- Are some of the inputs going to be categorised? How many fields will be free text? Could become very onerous.
- Are the results going to be scored in some way? What will that look like/be confirmed?
- Scenario-missed links: no damage to sockets, no damage to plant rooms– this allowed for dehumidification and some environmental monitoring of collection and aids recovery
- Could be useful to add learning section at the end? What can we learn for future?
- Re. Drainage was there risk of sewer overflow? i.e. combined drainage system? (consideration for other sites only maybe)
- Wider stakeholder engagement - would this impact on say the tattoo?
- It would be great to be able to factor in travel to this, especially as current transport infrastructure is not resilient. – how do visitors get home safely? – how do staff get home safely? – did the event prevent visitors/ staff to visit?
- Refer to existing salvage plans
- The flow chart and post- event damage survey should be visible to every team (PiCAMs)

3) Concerns and limitations

- Prioritise issues – unable to fund solutions in every area, focussed resource allocations
- Refer to incident response folder
- To make data properly quantifiable there needs to be a good base data

Session 2. Feedback on the survey template

Feedback on the post-event damage survey template took under the category of Strength, Weakness, Opportunities and Threats (SWOT).



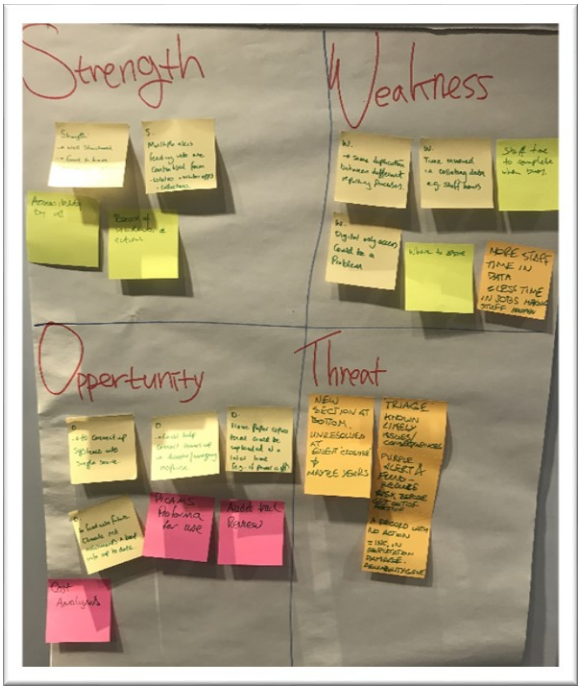


FIGURE 18 FEEDBACK ON THE DAMAGE SURVEY TEMPLATE AT THE WORKSHOP IN EDINBURGH ON MARCH 14TH

FIGURE 19 FEEDBACK ON THE DAMAGE SURVEY TEMPLATE AT THE WORKSHOP IN HIGHLANDS ON MARCH 16TH

The SWOT feedback on the post-event damage survey template

	Strengths	Weaknesses

Workshop on the 14th	Structured process and comprehensive Clear, scalable template and process Inclusive process, everyone gets to contribute Creates a streamline response Makes a prompt debrief and learning for the futures easier Helps consistent reporting and prompt for staff Very useful to have a template with the required information so people in site know what to look for etc. More inclusive Everyone captured and more teams can contribute Share knowledge and skills across the regions One place for all information and easy to find Template would all us to record data, currently not recorded this allows knowledge learning and better planning. Useful tool outside of HES – sector wide and a neat bit of guidance Logical and thorough data collection	More work for people already doing loads and loads Time consuming Expand the survey to resident of heritage areas (world heritage site and conservation areas) to record past events and provide evidence to support adaptation activities – would need to be simplified Double reporting, also prime used for salvage etc. Change the title – not post event but pre-, during and post event Not synchronised with other IT How do you record smaller events? Requires some adjustments to existing systems Training required Depends on good take up across organisation
Workshop on the 16th	Well-structured and good to have a centralised system Multiple users feeding into one centralised form (estates, visitor opps, collections) Recording of incidents and actions Accessibility by all	Some duplication between different reporting processes Time involved in collecting data e.g. staff hours Staff time to complete when busy Digital only access could be a problem Where to store the information? More staff time for data collection and less time for jobs making stuff happen
	Opportunities	**Threats**
Workshop on the 14th	To share better practice and key learning Flexibility to adapt to different situations or organisations Form widened out to cover other events (non-climate) Add an entry for post analysis Understanding how extreme events impact on sites is the best way to understand how resilience is built into the system Weather warning can be used to actually mitigate against damage occurrence HES prime accident reporting used to log events? Then collated by climate team? Connection with other existing forms, for example site closure plus defect forms. Will help to ground truth both HES climate risk assessment and climate change impacts work Automatic reporting to relevant staff Linked to other sites with similar events Could help to anticipate information to collect and plan for that Could offer a useful template for small organisations for smaller teams	Acceptance and use of templates across the whole organisation More information on what is an event, training on multi-hazard events What size of event or damage would qualify for the survey to be used? If survey used for all events, how to know when to record when a weather event is extreme? Value not recognised (value of heritage damage) Incident could be overlooked Involve IT at an early stage to connect all systems (otherwise a threat would occur) Organisations claim to take climate risk seriously - this is a step in putting commitment behind the issue. If collecting data on a national scale the manager of the survey needs to be specific to local areas, so training of multiple people is required.

Workshop on the 16th	To connect up systems into a single source Could help connect teams up in disaster/emergency response Have paper copies that could be uploaded at a later time, for example if power is lost To feed into future climate risk assessments and keep information up to date Cost analysis PICAMS proforma for use Audit trail review Put a residual risk section at the end to identify unresolved tasks	Unresolved tasks at event closure could remain unresolved for years Triage mode currently Issues are known Funding is currently reduced to deal with risk before it is gets out of control – we are in a reactive mode A recording process with no action may lead to reputational damage

Session 3. Next step & takeaway messages

The research team and HES shared the next steps with attendees at the end of the workshops. The recommendations for the next steps and 'critical needs' were taken from participants. Finally, before our participants left the venue, we asked them to leave a takeaway message.

Participants were also asked to suggest next steps for the process of implementing a post event damage survey:

(14th March)

- Trial this approach/template to other sites/buildings
- Try to look for crossovers/linkages/synergies with PiCAMS functions and data
- Think more of risk in a flow chart way and different scenario. Include cc adaptation in all steps
- Planning & designing for extreme weather
- Review incident response registers
- Create discussion and very good to have a good spread of organisations involved
- Speak with colleagues + share knowledge from today

(16th March)

- Introduce template to collection team;
    - case for more hours for support with gathering + evaluating damage data e.g. freelance Danielle or new post
    - overall aim for damage survey e.g. business case for more budget for salvage planning
    - decide where / with which team template should sit who should manage it
- Sell this approach to the powers that be & get them bought in
- Be more proactive rather than reactive forward planning
- Management agreement to back up teams

Personal take-away messages included:

(14th March)

- (reflections) not what I expected
    - Good to see thought of post event
    - Disappointing to see less focus on prevention + learning from existing environments rather than disasters

Recording and sharing evidence and data

- Documenting is key
- Building up as much evidence as possible

- Excellent project which will help evidence and portray work carried out through risk assessment modelling
- Recording details as soon as possible after the event when memories are fresh

Opportunities

- Strong opportunity to learn from outcome in order to build resilience into our management system
- Connection between all teams in incident happening even extend stakeholders
- Extreme events are more frequent and should be planned for

Re-thinking or food for thoughts

- How to make the most of extreme event to better adapt/be better organised / more resilient
- I work in carbon management in the climate change team at HES and this workshop has made me think more about the ways adaptation can factor into this. Ensuring net zero infrastructure +sustainable travel networks are resilient.
- Thank you for an inspiring workshop and helping to provoke thoughts

Critical needs were highlighted as the lack of resources to take action and connect to the existing system within HES. There were contrasting ideas as some participants recognised the lack of research in heritage management in the context of climate change, whilst works managers in remote sites emphasised that the knowledge is already here, but lack of resources to deliver the maintenance.

Critical needs outlined as:

(16th March)

- Resource to take action
- More resources to be able to resolve maintenance requirements
- Stopping work to assess/review/survey is a decision to let more problems form then assessment/survey etc. becomes out of date
- Lot of work on producing data
- More weather stations for country wide data collection

(14th March)

- Critical needs: think of event (reporting) in HES (PRIME, Defect etc.) with that risk perspective and post-event damage survey
- Lack of research/knowledge of climate change +historic environment +how to manage

Based on notes for “take away messages” from attendees, we demonstrated the importance of recording and sharing evidence and data for future risk assessment and preparing for adapting to climate change. The workshops also achieved sharing opportunities for learning about the impacts of extreme weather events and climate risks in Scotland. The opportunities in applying the post-event damage survey protocol were recognised as a potential strength to prepare for future risks by connecting across teams including external partners.

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