Exploring the Communication of Flood Risk through Online Geographic Visualisation

by

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This thesis presents results of original research undertaken by the author. The work has been conducted in accordance with the University of Nottingham's Code of Research Conduct and Research Ethics and in accordance with the School of Geography's risk assessment procedures.

ABSTRACT

There is a growing need for effective flood risk communication in the UK, the Projection Augmented Relief Model (PARM) simulator is a unique, online geovisualisation tool that presents geographical information in a unique and engaging way. This research investigated the acquisition of geographical knowledge and the quality of user experience with a PARM simulator. The research explored how user-centred testing can be used to gain feedback and critical insights on the PARM simulator content, obtaining input from both technical and non-technical audiences. This was novel as there has been minimal formal testing of this kind on 3D PARMs, but the PARM content has also never been replicated online into a 'simulator' in this way. Without the replication of 3D content, this enabled the isolation of issues related directly to content rather than the display model. The methodology employed during this research included interviews where participant interactions with the simulator were observed and feedback was collected (Stage 1). Recommendations made by participants in Stage 1 were then implemented, modifying the PARM Simulator content. The PARM simulator was then made public, and a feedback survey was used to gain further insights into the successes and failures of the simulator (Stage 2). The overall findings highlighted that the local story of 'What causes Skipton to flood?' was deemed, on average, the most engaging thematic section. The catchment-scale imagery and explanations used here should be replicated for future displays that aim to convey flood risk. The 'Scenario Animations' were statistically proven to be rated, on average, significantly more engaging by those who were familiar with Skipton compared to those who were not. Yet, familiarity of location did not provide users with a significant advantage in knowledge acquisition from the simulator overall, meaning that the PARM narrative was more accessible than previously expected. Graphic representation of different flood events (% AEP) was the most useful in helping users understand flood risk in Skipton, however future deigns should incorporate 'return period' language into the PARM narrative and an explanation of language used,

especially for stand-alone displays. This research presents a list of feedback from both stages of investigation to be considered when designing and creating content for PARM displays in the future. The PARM simulator was proven to evoke behavioural change amongst users, who signed up to a flood warning scheme as a result of engaging with the simulator. Future work should consider how PARM displays can inform users on private flood risk reduction behaviours. It was also found that alternative online platforms for the simulator should be explored, such as websites, to produce a more intuitive risk communication tool that could be disseminated further to engage non-technical audiences.

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1. INTRODUCTION

Floods are among Earth's most common, and most destructive natural disasters (Llasat *et al*., 2009; Smith 2013; Kousky, 2014). In the UK, flooding is also the greatest threat posed by climate change (Reynard *et al.*, 2017). Consequently, flood risk management is now rigorously incorporated into policy across a wide scale of managing bodies. Within water management, the use of meaningful flood risk communications (FRC) emerged in the early 2000s as a crucial aspect of flood risk management (DEFRA, 2004; Kuser *et al*., 2018). FRC is critical to help people understand their own flood risk, what is being done to manage flood risk, and how, personally, they can respond to flood risk.

New technology is continually offering opportunities to teach geographic information in novel and engaging ways, geovisualisation tools such as physical relief models, are an increasingly popular method. Projection Augmented Relief Models (PARM) are tangible displays which combine digital surface projection and physical landscape models to convey information. Previous research has demonstrated the engaging power of projection-enhanced relief models (Priestnall *et al*., 2012; Priestnall *et al*., 2017; Priestnall and Cheverst, 2019) but as yet there has been no research into the use of PARM to communicate environmental risk. Therefore, it is of great interest to assess the usefulness of the current PARM narrative by examining how both technical and non-technical audiences receive this information. The approach here will address the research gap described by obtaining in-depth feedback on the narrative content and user experience of an online version of the Skipton PARM, called the PARM simulator. This will allow emphasis to be placed on the evaluation of content, away from the novelty of the PARM display technique.

This research involves two stages, encompassing both qualitative and quantitative methods. Firstly, (Stage 1) online interviews will be conducted with 'experts' who hold some experience or knowledge in river management. These interviews will employ user-centred testing (MacEachren and Kraak, 2001) to gain critical insights into the quality of the PARM Simulator content and observations of user experience with the online format. Feedback from Stage 1 will be used to implement changes to improve the PARM simulator content prior to Stage 2. In Stage 2, the revised PARM simulator will be made public, with an accompanying online feedback survey. This technique will be used to assess how the simulator content performs in its capacity to convey geographical information to a non-technical audience. Stage 2 will result in an overview of feedback but will also use open questions in the survey to allow for specific critiques of the simulator. By obtaining survey responses from both those who are familiar with Skipton and those who are not, it will be interesting to see if the simulator is of greater benefit or can be more easily understood by those with location familiarity. These methods will be analysed separately but the feedback will be combined to ultimately make recommendations applicable to future PARM displays. The value of this research lies in the potential to further the PARM as a flood risk communication tool, to not only empower people with a greater understanding of flooding risk, but to motivate users into protective behaviour changes to reduce personal flood risk through uniquely engaging content.

2. LITERATURE REVIEW

2.1 Introduction to Flooding

A flood can be defined as a great flow of water, causing overland flow and inundation. Different mechanisms can lead to different types of flooding, such as fluvial (river), pluvial (flash), urban, coastal and sewer floods (Ashraf *et al*., 2017). Fluvial floods can be caused by extreme rainfall events (Hunt, 2005; Zheng *et al*., 2013), but also may occur due to land-use change including deforestation, altering the river channel, impoundments, agricultural drainage and increased run off generation (Nilsson *et al*., 2005; Dadson *et al*., 2017; Rogger, *et al*., 2017). The socio-economic and environmental impacts of flooding vary spatially across the globe. The damage and disruption that flooding can cause to infrastructure, transport, food and water supplies has been clearly demonstrated (DEFRA, 2005) and observed. Flooding can also result in increased occurrence of infectious diseases (Waite *et al*., 2017), causing significant long-term health impacts (Munro *et al*., 2017) and in the worst cases, result in mortality (Milojevic *et al*., 2012).

2.1.1 Flooding as a hazard

Flooding is a major hazard that poses a prevalent, current and future risk to the UK and the rest of the world (de Moel *et al*., 2009). The UK has experienced drastic annual winter flood events in the last decade, causing major disruption in areas including but not limited to Cumbria, Lancashire, Yorkshire and Somerset. The economic losses from the winter 2019/20 floods alone are estimated at £333 million, (Environment Agency, 2020a) demonstrating the immense damage caused by these environmental hazards.

The frequency and intensity of flood events is predicted to increase globally, accompanied by increased annual expected damages associated with flooding, as a result of climate change (Evans *et al*., 2004; CCC, 2016; HM Government, 2016; Tanoue *et al.*, 2016). In England and Wales, studies have predicted that localised flooding will increase up to four-fold by the 2080s (Burningham *et al*., 2008) and at present, 5.2 million homes are at risk from flooding or coastal erosion (Environment Agency, 2019).

Current estimates also anticipate that due to increasing urbanisation and socio-economic development, the number of properties in the UK built on floodplains will double by 2065, meaning a rise of 'at risk' communities (Met Office, 2019). This inevitable escalation of flood risk severity will continue to create new challenges for scientists, governing authorities and the general public (EU, 2007), requiring the development and implementation of intensive and adaptive flood risk management in order to protect lives and infrastructure.

2.2 Flood Risk Management - FRM

German sociologist Ulrich Beck (1992) suggested that 'the risks we face have become incalculable and unpredictable to such an extent that we live in a risk society'. Historically, 'risk' has been understood as a function of probability and consequence. Probability is the chance of a pathway leading to an event, and the associated chance of suffering adverse consequences (Samuels *et al*., 2010). In the context of flooding, consequences are dependent on exposure and vulnerability to the flood hazard itself, which inevitably vary regionally. Therefore, flood risk depends both on the magnitude and timing of the flood event and the vulnerability of the exposed person, property or environment (Skidmore *et al*., 2009).

Research in the late 1990s identified a common cycle of response to flooding involving three stages; (1) flooding, (2) investment and (3) complacency until the next large event (EUROTAS, 1998). Fleming (2001) suggests that in the UK, prior to 1998 there had not been a flood event 'with sufficient significance to capture the attention of the UK population on mass', and that the 1998 floods and regular subsequent national flooding (e.g. 2000, 2002, 2005, 2007, 2009, 2012, 2013, 2015, 2019) have 'awoken' the country to the risk of flooding. Research has documented the evolution of a societal response to flooding. Samuels *et al*. (2006) and Klijn *et al*. (2008) describe the paradigm shift from a focus on flood defence to greater focus on flood risk management (FRM) practices. FRM is defined as a process of “holistic and continuous societal analysis, evaluation and reduction of flood risk” (Schanze, 2006), and is now embedded in many policy documents across the UK and the rest of the world. The overall aim of FRM is to enhance community resilience to flooding, minimising harm, meaning that the likelihood of flooding is reduced, as are the impacts when flooding occurs (Van Alphen *et al*., 2009; Rollason *et al*., 2018).

FRM is a complex system (Figure 1) that occurs at a variety of scales (Schanze *et al*., 2010), from local decisions to specific communities, to whole basin scale planning – as is advocated by the European Floods Directive (European Union, 2007). FRM can be categorised into three main components: precaution, coping and recovering (Kienholz *et al.,* 2004). Samuels *et al*. (2010) remarks on the inherent complexity of FRM as all decision making must embrace the fundamental uncertainty about future loading and performance of flood defences.

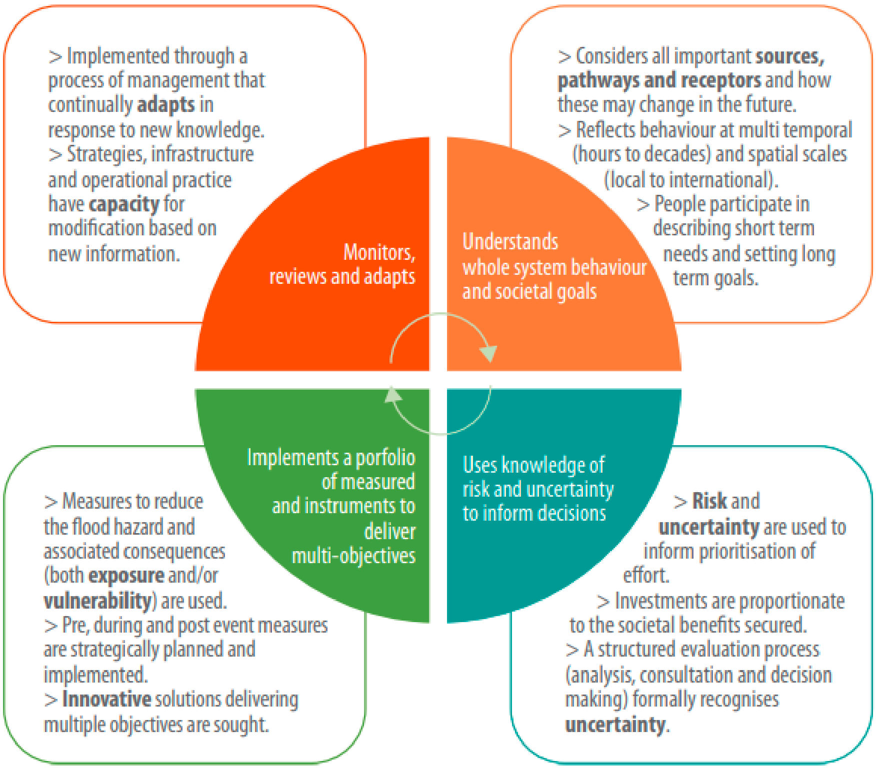


Figure 1. Four characteristics of good flood risk management, taken from Sayers *et al*. (2013).

A key element of flood risk management is to "strengthen people's awareness and to motivate the population at risk to take preventative actions and to be prepared" (Hagemeier Klose and Wagner, 2009). Literature has shown that levels of flood risk awareness (flood risk perception) directly influence people's action before and during a flood (Grothmann and Reusswig, 2006). Therefore, understanding risk perception allows for predictions of how people will respond to natural disasters such as flooding (Cologna *et al*., 2017). A poll survey conducted in 2016 in the UK found that only 45% of people living in at-risk areas appreciate their risk and only 7% could identify any risk to their own property (Environment, Food and Rural Affairs Select Committee, 2016). Similar findings of an unappreciation of flood risk were found by the 'Know Your Flood Risk' campaign (Davies, 2015) who reported that '31% of at risk households surveyed had no flood plan and would not know what to do in the event of flooding'.

2.2.1 The role of perception in flood risk management

The components of flood risk perception are outlined in Figure 2. Research into factors impacting flood risk perception can be conflicting. Wachinger *et al*. (2013) describes three key factors influencing risk perception: 1) previous experience of events, 2) information provided by communication channels and 3) trust in authorities and flood defence measures. Burningham's *et al*. (2008) widely cited study found that flood experience, length of time at present address, tenure, age and class all have an important effect (are significant) in predicting flood risk perception. However, Kazmierczak and Bichard (2010) found that flood risk perception did not depend on past experiences. To explain these contrasting findings we can look back to Renn (2005) who proposed that because people perceive natural hazards as 'cyclical phenomena' those with direct experience of flood events may believe they are very unlikely to experience a comparable event in their lifetime. It is accepted that more research is required on socio-cultural dimensions of risk perceptions (Butler *et al*., 2016).

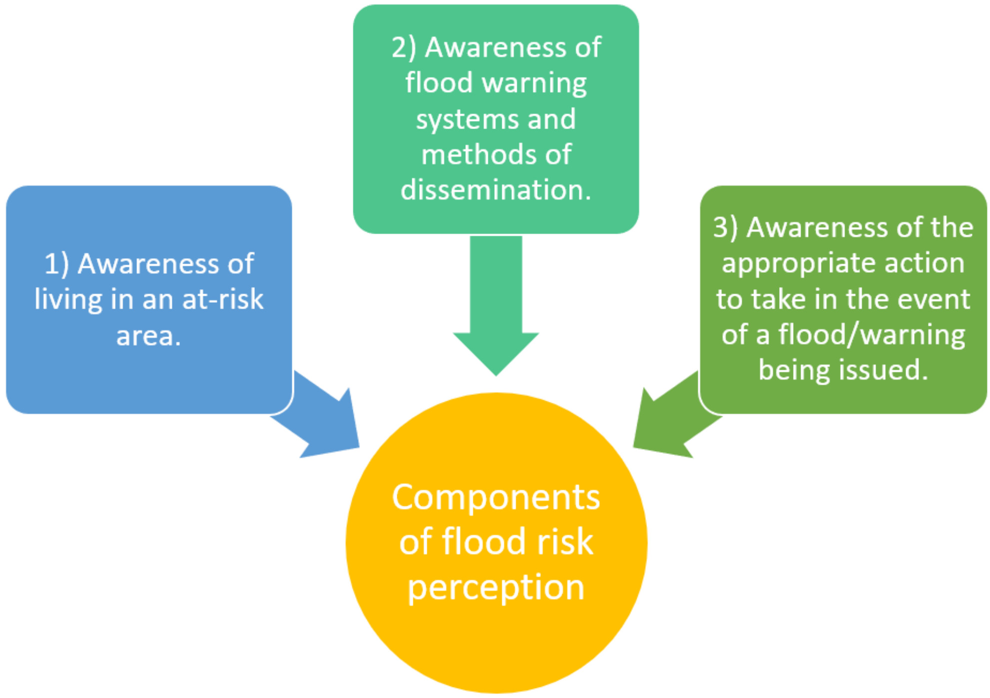


Figure 2. Three components of flood risk perception as presented by Burningham *et al*. (2008).

How can flood risk awareness be raised without people having to experience a flood event? The answer therefore lies in how risk managers influence the perceptions of the general public in order to initiate engagement with flood risk. This is most challenging in areas where the probability of flooding is low, but the consequences of such events are high. Since those in low-probability flood risk zones do not perceive floods as a major hazard, they often have a poor understanding of the impact a major flood event would cause, meaning there is a tendency to 'under react' to flood risk communications (Shaw *et al*., 2005). Many studies (Parker *et al.,* 2009; Van Alphen *et al*., 2009; Wachinger *et al*., 2013; Kellens *et al*., 2013) have shown that 'risk communication' influences risk perception, as communicating risk will ultimately influence people's perception of risk (Wiedemann and Schutz 2000).

2.3 Flood Risk Communication (FRC)

To communicate research, scientific information needs to be tailored for non-technical audiences across the environment-society interface (McNie, 2007; Liu *et al*., 2008; Sutherland *et al*., 2012). Risk communication is now an increasingly prominent feature of regulation across a wide range of domains (Leiss, 1996; Demeritt and Novert, 2014), defined by Wiedemann and Schutz (2000) as 'an interactive information exchange between individuals, groups or institutions, about the nature of risks, risk related opinions, anxiety and coping strategies'. Flood risk communications are crucial to encouraging participation in local flood risk management and to develop community resilience to flood events (EA, 2020). 'Participation' here can be considered as making an individual consider response preparation, acting on a decision.

Historical narratives show that risk communication has not always been a process of steady accretion of understanding but, instead, as a series of 'developmental phases' with each phase offering a new set of information for the user (Leiss, 1996). More recently, risk communication is understood as an ongoing social process, which is dependent on the characteristics of the message, the audience, the channel of communication and the hazard itself, combining various understandings in order to communicate risk effectively. A large emphasis of recent studies is to re-focus on the needs of an individual, group or community to whom the risk communication is directed (Höppner *et al*., 2010). Flood risk communication is a preventative activity that can be used to prevent both static (pre-flood event) and live risk (during a flood event), and has two ultimate goals: 1) creating awareness of the possibility of a future flood event so that people are prepared, 2) promoting action to prevent or limit the impacts of future flooding (Environment Agency, 2015). Figure 3 uses Wardman's (2008) conceptual framework of risk communication to give examples of flood risk communication, grounded in four different theoretical traditions, that suggest different ways of defining 'good' risk communication.

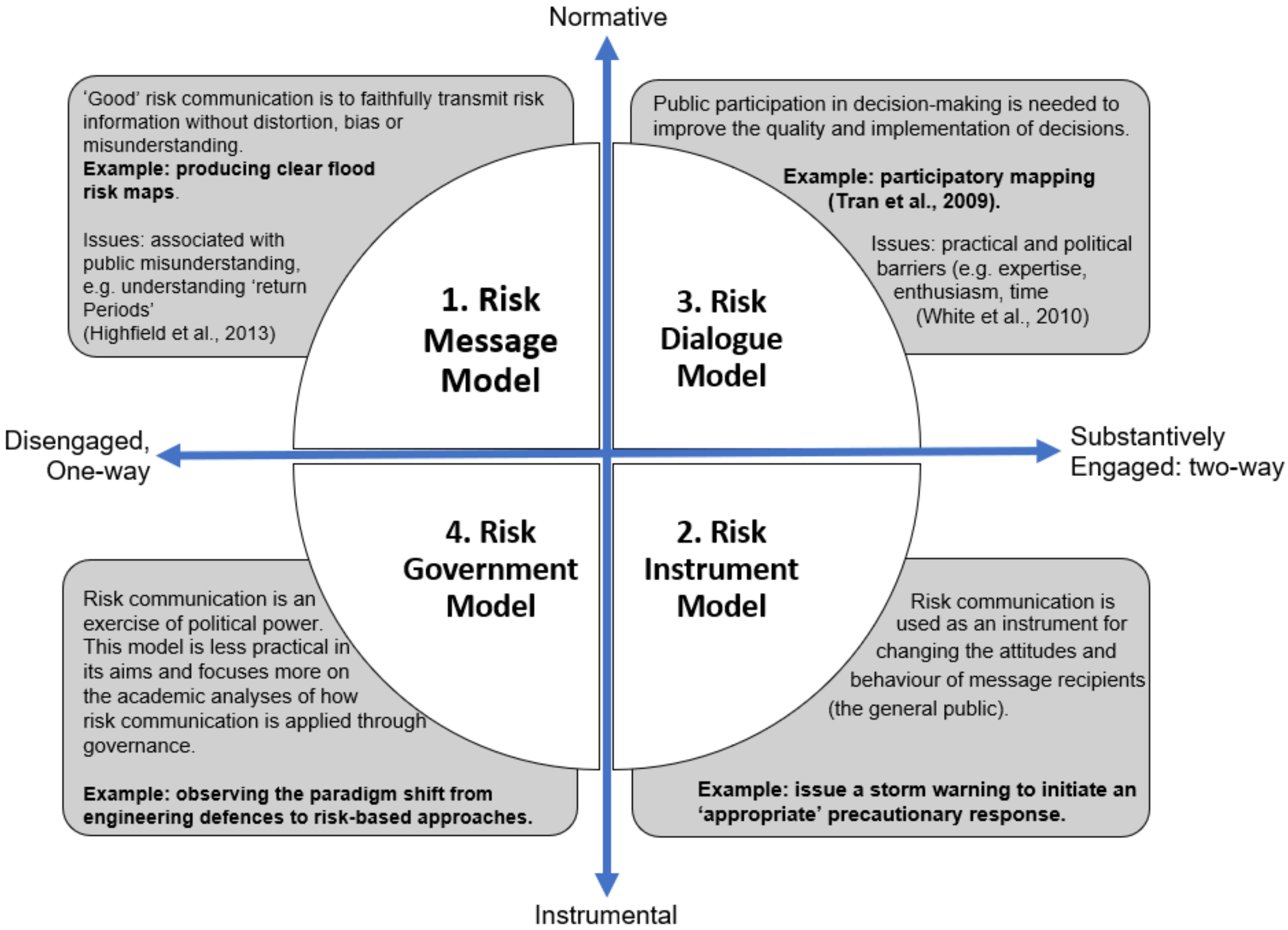


Figure 3. After Wardman (2008), a conceptual framework for risk communication models with added examples from other sources to explain how flood risk communication may occur in each category. The vertical axis distinguishes risk communication by its underlying rationale, whereas the horizontal axis distinguishes between engaged and interactive communication types.

Risk communication engagement methods have begun to favour two-way engaged approaches where citizen participation can effectively link expertise of local-level resilience with expert practitioners in an at-risk community (de Moel *et al*., 2009; Butler and Pidgeon, 2011; Lane *et al*., 2011; Tsouvalis and Waterton, 2012). One example of this is the long-term use of flood hazard and flood risk maps to provide the basis for spatial planning of local flood risk hazard assessments (Rollason *et al*., 2018). Meyer *et al*. (2011), using three-stage risk map workshops, proved the importance of involving participants who held knowledge of the local area. They concluded that an iterative participation process of communication should occur early and often in the planning process. Further studies support that the exclusion of risk communication users from the process of creating risk communications can be detrimental and create an over-reliance on experts (Woods et al., 2012; Rollason *et al.*, 2018). The literature concludes; by providing people with a greater understanding of their local flood risk, this will enhance flood perception and they may be inspired to participate in preparation procedures, which will help when flood risk warnings are issued (Kasperson *et al*., 1988). Table 1 gives some further examples of flood risk communication approaches.

Table 1. Techniques for flood risk communication common in England and Wales adapted from Environment Agency, 2015.

Technique	**Static or Live**	**Communication purpose/routes**	**Example**
Flood risk and flood hazard maps	Static or Live	Communicating areas that are at flood risk. Can differentiate between areas of high-, medium- and low-risk.	Environment Agency: live flood warning information. https://flood-warning-information.service.gov.uk/warnings
Infographics	Static	Used by organisations (e.g. the Environment Agency) to raise flood risk awareness.	DEFRA countryside stewardship to reduce flooding 2016 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/570105/cs-flood-reduction-infographic.pdf
Commercial applications of flood risk data	Static or Live	Displayed on websites or mobile applications. E.g. 'Flood warnings app'	Flood Assist Mobile App https://floodassist.co.uk/home/flood-assist-app
Real-time water level information.	Live	Monitoring of river levels, allowing locals to monitor and respond to flood risk.	GOV.UK river and sea levels in England https://flood-warning-information.service.gov.uk/river-and-sea-levels?_ga=2.105410883.1917226606.1605436155-1140173632.1600065917

Broadcasted video content	Static or Live	TV broadcasts, YouTube, Twitter alerts etc. There's not always a guarantee the content will be watched.	'EnvironmentAgencyTV' informative Youtube channel https://www.youtube.com/user/EnvironmentAgencyTV
Educational Activities	Static	Participation methods, online campaigns, Youth websites etc.	Projection Augmented Relief Model demonstrations https://www.jbatrust.org/how-we-help/physical-models/parm/
Innovative activities	Static	Participation methods, online campaigns and websites.	Sustainable Flood Memory Project https://esrcfloodmemories.wordpress.com/
Games	Static	Flood websites, online blogs. These require a lot of time, resources and a willing audience.	Gaming for the Earth 'Rising Tide' https://seriousgeo.games/

2.3.1 Challenges of Flood Risk Communication (FRC)

The principal challenge of flood risk communication is to present an up-to-date understanding of current scientific knowledge, motivating audiences to make behavioural changes to reduce their individual flood risk. Previous studies have reported that the existing model of flood risk communication is failing to meet user needs, critiquing earlier methods of FRC approaches of prioritising simple threat messages and missing important participatory approaches (Environment Agency, 2010; Meyer *et al*. 2012; Environment Agency 2015). This has led to some authors calling for more theoretical and empirical studies on flood risk communication (Zaalberg *et al*., 2009; Kellens *et al*., 2012). The high complexity of risk communication is furthered in that the concept deals with 'uncertain outcomes', as it is more difficult to communicate risk when the likelihood of events occurring is not certain. Although technology has advanced enough to make flood event estimations and river monitoring more accurate, the uncertainty associated with this natural hazard still acts as a barrier to communication, especially when flood defences are overwhelmed by unprecedented storm events – such as the Keswick floods in 2015.

It is generally difficult to communicate with residents about flood risk (Grothmann and Reusswig, 2006: Harvatt *et al*., 2011; Brody *et al*., 2008; Whitmarsh, 2008), especially in areas where the perceived chance of flooding appears low. In O'Sullivan *et al*.'s study (2012), the impact of flood risk communications across Europe was assessed. Common themes identified included poor information penetration and personal preparedness, and distrust in management organisations. Management organisations like the Environment Agency are challenged by the need to generate trusting, long-term relationships with at risk communities (Twigger-Ross *et al*., 2011). Alternatively, Samuels *et al*., (2010) documents that many people remain reluctant to accept their own role in risk management, delegating responsibility to public authorities which is a further challenge for flood risk communicators and flood risk management as successful FRM is dependent on participation at all scales. Ineffective flood risk communication is dangerous and problematic and it has been shown to lead to poorly informed public audience decisions and a skewed perception of flood risk (Rollason et al., 2018; Pidgeon and Fischhoff, 2011; Han *et al*., 2011; Politi *et al*., 2007; Spiegelhalter *et al*., 2011). To address these challenges, flood risk communication has been systematically incorporated into policy frameworks of European Member states for several decades, to ensure continual revision and standard of methods (Nunes Correria *et al*., 1998).

2.3.2 Flood Risk Communication in policy

Public dialogues on flood risk communication are prevalent across the world, with different regions prioritising different aspects of communication depending on their flood risk scenarios (Lumbroso, 2009; Kia *et al*., 2012). The literature on global techniques for flood risk communication is vast, however this review aims to focus specifically on addressing communication policy techniques applied in the UK. The need to create meaningful flood risk communications to enable societal resilience is clear and has been a key pillar in the government strategy of 'making space for water' since 2005 (DEFRA, 2004). Flood risk communication has also remained an important element of the implementation of the EU Water Framework Directive, which has utilised in particular, flood hazard and risk maps to provide a basis for further spatial planning and communication of the local hazard situations (Hagemeier-Klose and Wagner, 2009).

2.3.3 Flood Risk Communication in the UK

In spring 2020 the Environment Agency published a revised National Flood and Coastal Erosion Risk Management Strategy (FCERM Strategy) with the overarching vision to create "a nation ready for, and resilient to, flooding and coastal change – today, tomorrow and to the year 2100" (Environment Agency, 2020a). Several strategic objectives have been devised to help deliver the overall ambition of the strategy, objective 3.1 states that:

> "Between now and 2050, people will understand the potential impact of flooding and coastal change on their lives and livelihoods and will take action to reduce that impact"

The planned measures to achieve the objective include:

> "Measure 3.1.1: From 2020 the Environment Agency will continue to invest in developing and transforming customer-driven digital services to better communicate risk from flooding and coastal change."
>
> "Measure 3.1.2: From 2021 risk management authorities will encourage the development of the engagement skills and capabilities they need to better support communities to manage and adapt to future flooding and coastal change."
>
> "Measure 3.1.3: By 2021 the Environment Agency will share learning and best practice with other risk management authorities on working with communities to manage and adapt to future flooding and coastal change."

The achievement of objective 3.1 is thus underpinned by effective communication of the risks and consequences of flooding. All three related measures show the established significance of flood risk communication, that has been continually called for over the last 10 years

(Lorenz *et al*., 2015). The planned measures all relate to the use of education to involve the public early on in flood risk management, utilising digital tools to achieve this. Digital services have been transforming how flood management authorities are able to inform the public about flood risk, and to produce innovative methods of community engagement. 75% of visits to the Environment Agency's web page are related to flooding, and it is estimated that 1-in-10 adults in England now use the Environment Agency's digital services, primarily its flood warning systems (Environment Agency, 2020a). Digital information can be more easily tailored to user needs and therefore has provided a new opportunity for unique, reliable and engaging ways of presenting flood risk information.

2.4 Visual communication

Traditionally, 'visualisation' refers to the **"**representation of an object, situation, or set of information**"**, providing a common language that can aid understanding through presentation and exploration (Sheppard, 2006; Kosara, 2013; Bishop *et al*., 2013). Visual communication has a long history within environmental management, being particularly present in fields such as landscape architecture and planning (Lovett *et al*., 2015). As previously discussed, environmental scientists are confronted with the need to interact with non-scientific audiences. The process of 'visualising' is crucial to assist environmental scientists in the communication of complex information, easing interpretation of environmental data for users and promoting interdisciplinary communication (Cheshmehzangi *et al*., 2017; Molines *et al*., 2006; Saran *et al*, 2018; Rink *et al*., 2014). The greater scale and variety of available data has also made it easier to create ever more complex data visualisations (Meloncon and Warner, 2017), which have now become ubiquitous in the modern day (Bishop *et al*., 2013). Literature defines three widely accepted criteria that need to be met for a visualisation to be effective; it must (1) be understood by people, (2) convincing to people**,** and (3) unbiased (Cash *et al*., 2003).

2.4.1 Environmental Visualisation

Environmental visualisation (EV) is classed as a form of 'technical visualisation' (Figure 4). It is an established, multidisciplinary field, used for environmental management, decision making and communication (Bohman *et al*., 2015, Bishop *et al*, 2013; MacEachren *et al*., 2011). This form of visualisation is now applied to geological, climate change, sustainability**,** and landscape planning contexts (Ballantyne *et al*., 2015; Sheppard, 2012; Wilbeck *et al*., 2013). Any landscape visualisation is an abstraction of reality; therefore it is important to consider which elements of the visualised landscape are chosen to be represented and how they are done so. Maps are a common form of static spatial representation within environmental visualisation and are fully dependent on designer intuition and decision making (Grainger *et al*., 2015; Wästberg *et al*., 2020). Environmental data for visualisations often includes temporal data (time-series graphs) and spatio-temporal datasets that present changes in time and space (McInerny *et al*., 2014; Muller and Schumann, 2003). Beven *et al*., (2015) explains that an inherent challenge within EV is visualising environmental uncertainty. For example, flood inundation maps are a traditional example of EV and are commonly used in flood risk communications (Figure 5), and although the modelled data may be highly accurate, uncertainties may still exist in the data. Yet, these models remain the best method available for understanding potential spatial planning implications and associated uncertainties with flood risk. Additionally, some authors have remarked that by visualising forecast uncertainties, this can increase user trust, establishing a comprehension of associated probabilities of data uncertainty (Joslyn and LeClerc, 2012; Roulston *et al*., 2006).

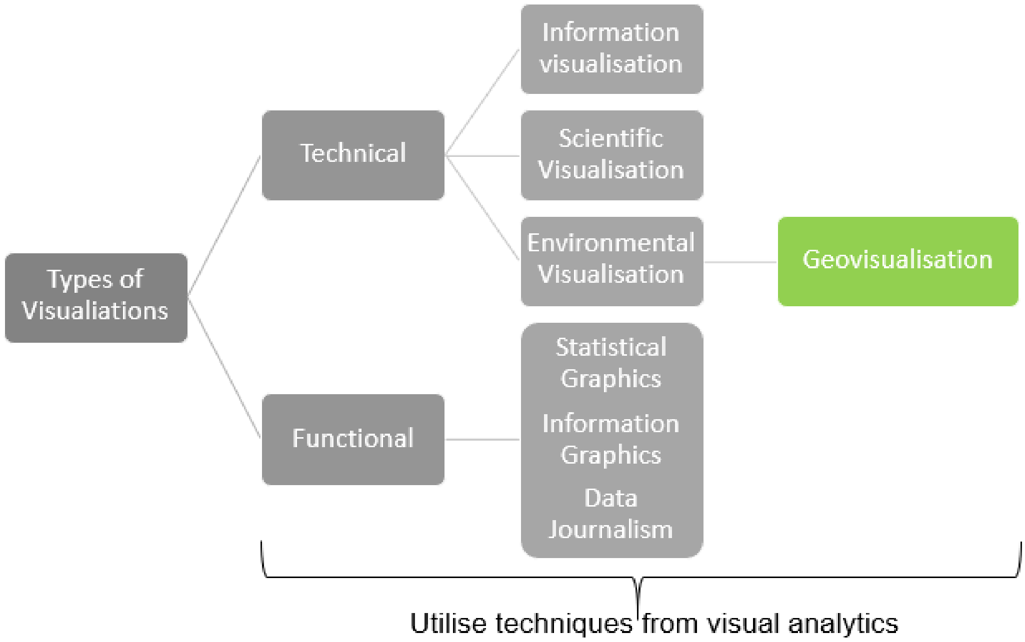
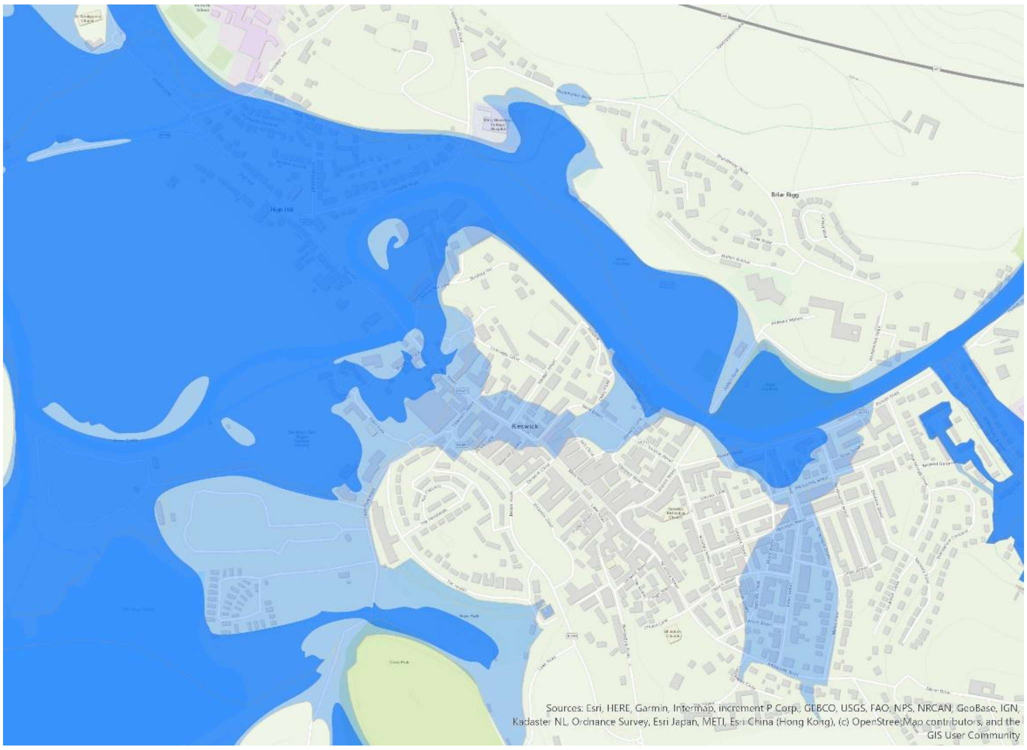
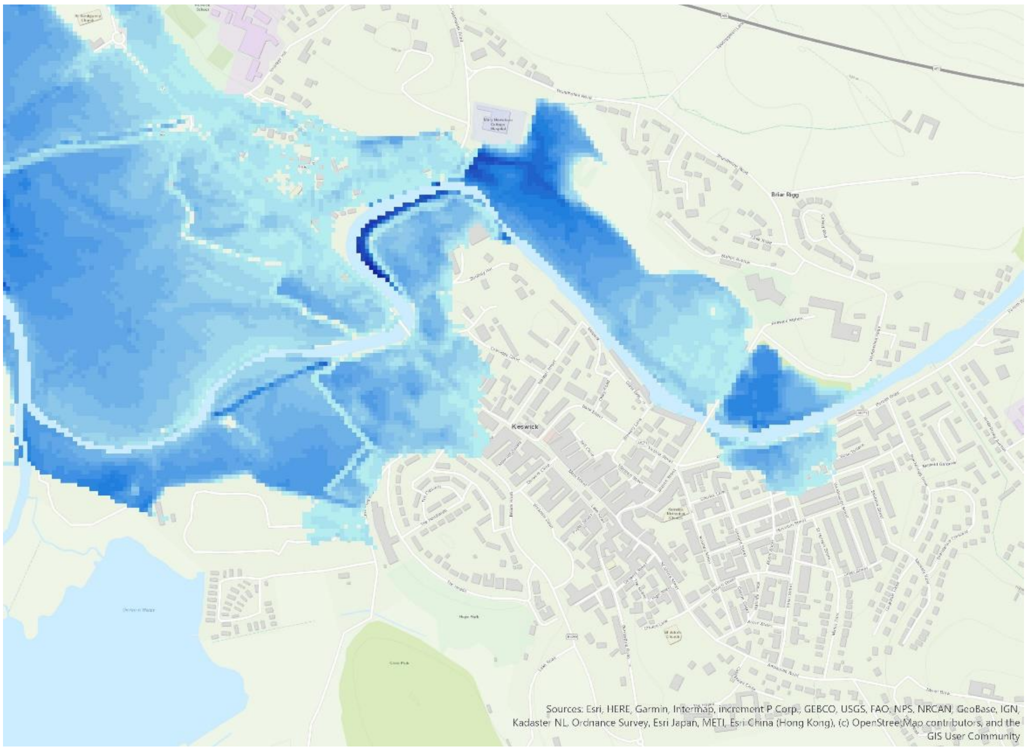


Figure 4. Graphic explanation of visualisation by type. Technical visualisations tend to focus on the development of innovative techniques for exploratory visualisations and require user interaction. Functional visualisations are typically designed for analytical reasoning and often require users to have some prior understanding of the data, and to spend longer examining it (Kosara, 2013).



a) Traditional flood map showing flood inundation, Keswick (Environment Agency, 2020b)



b) Example of a maximum extent flood extent projection map, Keswick (JBA, 2020a)

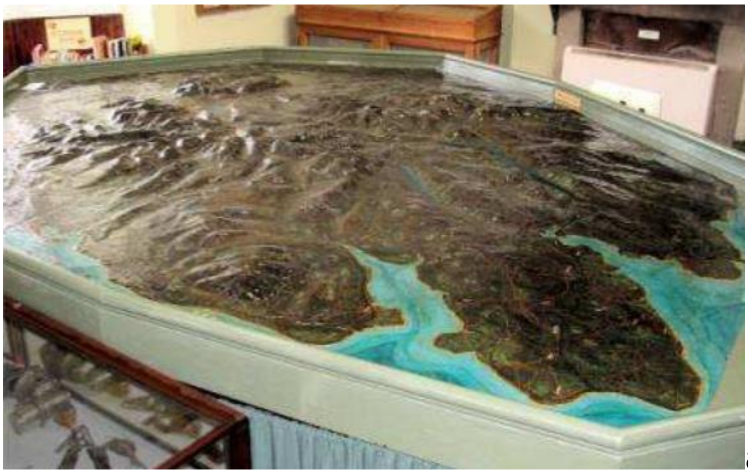
Figure 5. Examples of traditional flood visualisation maps.

2.4.2 Geographic Visualisation (Geovisualisation)

Geovisualisation is defined as “the set of visualization tools that allow interactive exploration of geolocated data in order to build knowledge without assumptions a priori” (MacEachren and Kraak, 1997) and has emerged as a subcategory of EV. In the early 1990s, geovisualisation research focused on how to combine traditional cartography with more effective communication, using exploratory methods and tools (Nollenburg, 2006). Geovisualisation tools take different forms; while some are entirely screen-based, others employ physical elements that are supplemented with digital information. In the context of flood risk communication, the need for effective communication has previously been outlined in Section 2.3, and geovisualisation techniques have been more commonly employed to communicate the geo-spatial information relating to flood risk (Dykes *et al*., 2005).

2.4.3 Physical Relief Models

Physical models offer an option for landscape visualisation. Historically, they have been used in military training contexts (Pearson, 2002) but are now more commonly used to support orientation in visitor centres (Figure 6). Research has demonstrated that physical models offer advanced engagement through kinaesthetic interaction, and an improved sense of landscape features than monitor based visualisation techniques or compared to 2D paper maps (Mitsova *et al*., 2006). Here, engagement is ‘the act of participating’ where users offer ideas, critiques, queries**,** and expression of approval/limitation in relation to the visualisation tool they have been interacting with. The sense of ‘realism’ created from physical relief models is crucial to create familiarity for the user, which also enhances the credibility, orientation and engagement with the model (Lovett *et al*., 2015). Hoare *et al*. (2001) report on the use of three-dimensional topographic models used for land use planning and boundary negotiations in a participatory watershed management project in northern Thailand. Local farm owners were able to help managers to identify the most appropriate areas for reforestation within the upland agricultural fields. Presently, digital terrain data is more freely available, and 3D fabrication technology more prevalent, meaning that the production of physical relief models has become much easier. Contemporary physical relief models are now being augmented with digital textures, for example using projected maps, images and lighting effects to create engaging visitor experiences (Priestnall and Cheverst, 2019).


a


b

Figure 6. Landscape models in visitor centres: a) Flintoft Model, Keswick Museum, Cumbria, UK and b) Mt St Helens Visitor Centre, Washington, USA (Priestnall and Cheverst, 2019; Visit Mt St Helens, 2020).

2.4.4 Digital Landscape Visualisations

Modern visualisations are now ‘fully engineered tools’ that are shaped by advances in computer graphics, data availability and advances in information and communications technology (ICT) (Spiegelhalter *et al.,* 2011). Within ‘Geovisualisation’ the integration of computational and visual approaches for knowledge discovery has been recently prioritised (MacEachren and Kraak 2001). Digital techniques for landscape representation came to the fore in the 1990s (Lovett *et al*., 2015) as the decreasing cost of projection technology meant the rise in potential to create digital displays suitable for larger audiences. Higher levels of feature detail and improvements of visualisation is conducive to more beneficial communication mechanisms (Wissen Hayek, 2011) and a clear user preference towards immersive 3D visualisation has been shown (Gill *et al*., 2013). The rise of 3D cartographic visualisations through immersive 3D displays has been documented, an early example being the Cave Automatic Virtual Environments (CAVEs) virtual reality system (Cruz-Neira, 1993) (Figure 7).

Figure 7. Example of a 4-wall CAVE at the Desert Research Institute in Reno, Nevada (Cabral *et al*., 2005).

Multi-touch immersive displays have slowly been moving out of the research lab setting and into public spaces (Hornecker, 2008). The rise in the commodification of these technologies offers greater opportunities to support group participation with digital medial in public venues including hotels, bars, museums, large scale sport and cultural events (Antle *et al*., 2011). A growing literature on these public 'situated' displays and associated interactions with them has appeared, with the seminal work conducted by Brignull and Rogers (2003) who investigated how best to encourage users to interact with these displays. Several studies have presented issues regarding engagement with situated displays; the need to firstly entice users to engage with the display (display blindness) and further problems with failing to notice that the display is interactive (interaction blindness) (Muller *et al*., 2009; Memarovic *et al*., 2015). Further research into the engagement with and spatial interaction around displays featuring physical landscape models is required (Horneker and Buur, 2006).

Studies have shown that tabletop displays are useful for education and a common component of visions for the "classroom of the future" (Sluis *et al*., 2004; Muto and Diefenbach, 2008). Piper and Hollan's study (2009) concluded that even a minimalistic tabletop application can benefit educational activities. They therefore suggest further research 'to understand how tabletop displays and other digital technology can best fit with and augment existing educational ecologies'. Engagement with digital landscape visualisations is successful as these tools draw on established principles of learning. Hake (1998) argues that authentic engagement "fosters a deeper conceptual understanding of material by anchoring the more abstract learning material concepts to the more accessible learning scenario". Studies have found that the contextualisation within an 'actual' scenario, such as a virtual landscape, enables learners to access factual knowledge more efficiently because the scenario familiarity increases retrieval cues in the learning process, enhancing the durability of the knowledge base (Hansen, 2008; Smith and Van Doren, 2004).

2.4.5 Virtual (VR) and Augmented Reality (AR)

New technology is consistently offering opportunities to investigate alternative modes of visualisation and interaction for citizen engagement (Montargil and Santos, 2017; O'Grady *et al*., 2016, Degrossi *et al*., 2017). Virtual reality (VR) technology fully immerses users in a synthetic environment, using VR glasses, whereas Augmented Reality (AR) allows users a view of the real world superimposed with virtual objects. Both are increasingly popular technologies that provide a novel context with which to engage users, assisting interpretation of virtual learning environments. Romão *et al.* (2004) developed an early AR environmental management system 'Augmented environments' (ANTS) allowing users to explore their surrounding environment, augmented with synthetic images to reveal environmental characteristics specific to the user's spatial location, such as soil composition and water quality characteristics. The Mobile AR (MAR) flood visualisation app is another example of how AR applications that can be used to understand landscape features (Bishop, 2015). The app was designed to complement existing flood risk management tools, visualising flood inundation of the Snowy River (Australia) at one metre in height to assist emergency services. This application emerged within a series of experimental mobile applications designed to take AR 'into the field' with the intention of linking simulations with on-site experience (Haynes *et al*., 2018; Gill and Lange, 2015) (Figure 8).

A further visualisation is Artistic Information Visualisation (AIVs), novel data-based visualisations**,** where artists modify information in a more creative way (Hahn and Berkers, 2020) (Figure 9). Although AIVs have had minimal application to flood risk communication thus far, they were found to be effective in engaging the general public beyond 'awareness' in relation to climate change issues according to O'Neill and Smith's study (2013) and therefore could be trialled in application to flood risk communications.

Digital games have also been shown to support informal and formal learning (Iavcovides *et al.,* 2012). The development of games with environmentally conscious themes has provided direct access to subject matter or content that may not be readily accessible in the real world (Van Eck, 2006). One example of such game is ‘Futura’ developed to enhance people’s awareness of sustain development planning and its complexity (Antle *et al*., 2011). These examples of once novel approaches are now more regularly used tools for geovisualisation in relation to flood risk communication and other environmental phenomena.

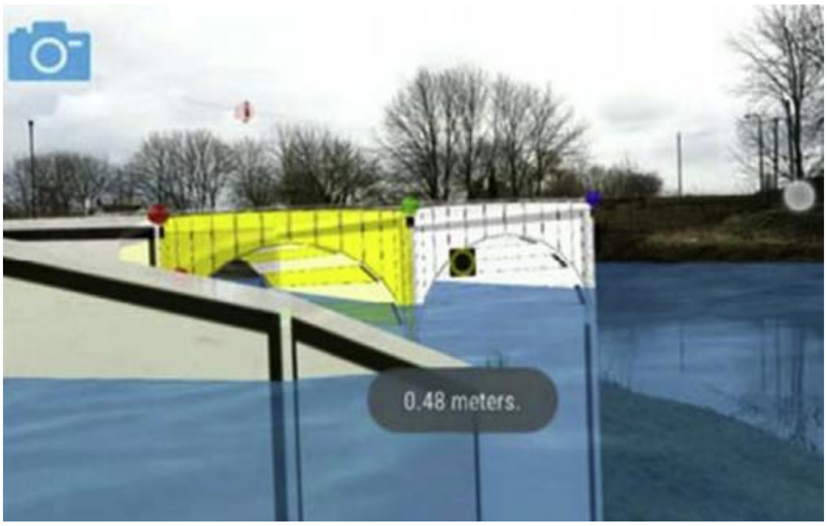


Figure 8. Example from the MAR flood visualisation app showing modelled flooding with attached prototype building geometry (Bishop, 2015).

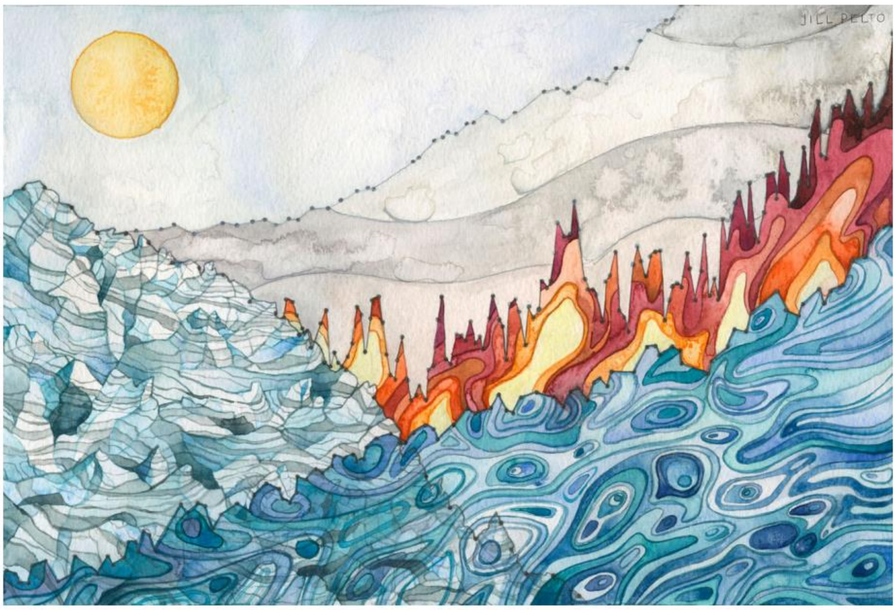


Figure 9. Example of an AIV, entitled Landscape of Change (2016) by Jill Pelto. This visualisation uses data lines of sea level rise, glacier volume decline, increasing global temperatures and fossil fuels (Hahn and Berkers, 2020).

2.4.6 Tangible User Interfaces

Tangible User Interfaces (TUI's) have emerged as geovisualisation tools that combine physical models with AR, allowing users to manipulate objects in space (Mitsova *et al*., 2006). Within these displays lies a direct link between input action and output response, creating an intuitive spatial mapping experience (Sharlin *et al*., 2004). Piper *et al*., (2002) developed the 'Illuminating Clay Project' creating a tangible clay model that could be manipulated by users to create a physical terrain model. This project paved the way for further development of TUIs including the use of sand as a mouldable material. The AR Sandbox is another tangible display that was designed with the aim of teaching concepts embedded within earth science (Figure 10). The display consists of a dynamic topographic map which composes of a box containing sand, a projector, and a Microsoft Kinect 3D camera. The sand can be manipulated by users, who then observe real time changes of the elevation map and the contour lines projected onto the sand. The connect sensor can also detect hands beneath it, creating rainfall and tracking surface flow.

Although this feature is not particularly accurate, it is very engaging and has the educational potential to engage viewers in basic principles of river process, including flooding.

The sandbox tool has been proven to help teach many geographic concepts**,** recreating the real world in urban planning and design**,** hydrology, geoscience and geography (Woods *et al*., 2016). In a study by Petrasova *et al.* (2015), the AR Sandbox was used in a participatory project where participants were asked to evaluate the map of an active transport system and make suggestions for the new location of trail routes. The terrain was easily re-created in the sandbox and the project was successful.

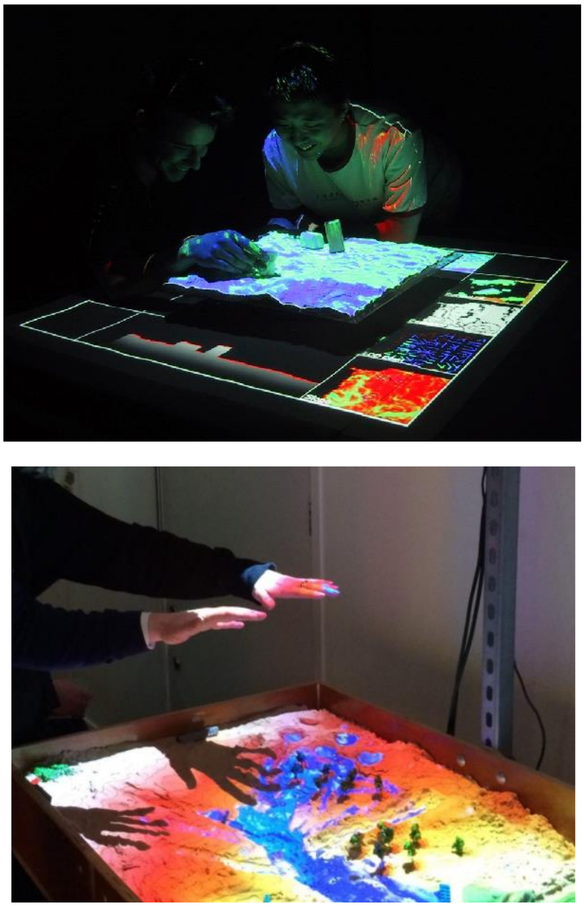


Figure 10. Examples of TUI's being used. Illuminating clay – top (Piper *et al*., 2002) and the AR Sandbox - bottom (JBA, 2020b).

There is a longstanding recognition of the benefit of hands-on activity or manipulation of physical models and an acceptance that physical activity and cognition are more strongly linked than previously thought (Lakoff and Johnson, 1999). Tangible representations of 3D physical forms can be perceived and understood more readily through proprioceptive and haptic perception, than via visual representations alone (Marshall, 2007). Interacting with tangible 'systems' occurs more naturally to users, reducing cognitive effort into understanding how the system works, and encouraging more direct attention to the interface (Sharlin *et al*., 2004). Claes and Vande Moere (2015) describe how "tangible interaction can elicit different forms of engagement and generate more and deeper kinds of insights when compared to traditional public display media". It is therefore unsurprising that tangible user interfaces and other novel visualisation tools are increasing in popularity, use and research studies - such as some of the named examples previously discussed.

2.4.7 Projection Augmented Relief Models (PARMs)

Projection Augmented Relief Models (PARMs) are a relatively new form of tangible display technology that can assist users in orientating themselves within the landscape represented on the model (Priestnall *et al*., 2012). These compelling displays combine physical landscape models and digital surface projection to tell stories and support decision making by using visualisations projected onto a 3D landscape model. The model itself is created using digital terrain data, derived from airborne radar and processed in ArcGIS, followed by a process of CNC milling and 3D printing (Priestnall and Cheverst, 2019). These models are portable and can be set up for demonstrations to support meeting discussions but are also commonly used as static models in-situ. The 'Spots of Time' PARM display was the first museum-based installation, which was used at the Wordsworth Trust, Cumbria to accompany a poetry manuscript exhibition in 2012-13 (Figure 11). There have been multiple PARM commissions since 2012, designed for various users and purposes.

Figure 11. Examples of PARM displays. ‘Spots of Time’ display at the Wordsworth Trust Gallery (top) and the Keswick Flood Risk Demonstrator (bottom).

Like most physical relief models, the aerial view display across a region offers an effective spatial frame of reference which has been shown to engage public audiences (Priestnall and Cheverst, 2019). PARM models deliver information through a passive narrative sequence, related information is displayed on the 3D model and backscreen in tandem (Figure 12). The contents board on the lower rig allows users to navigate through the model at their own pace and in their own time. Unlike the AR Sandbox and Illuminating Clay displays, the PARM is a static relief model that cannot be manipulated by users, however it does enable the representation of real places, and therefore communicate place-specific information. Additional studies to understand the impact of adding either physical or virtual buttons to trigger content sequences, to enhance the immersiveness of the display, may prove useful in testing the capacity of ‘engagement’ for this display.

Figure 12. Annotated PARM display rig.

A study conducted by Priestnall and Cheverst (2019) utilised a PARM of Langdale in a National Trust venue to explore visitor engagement with this new technology. Observation analysis identified that 69% of those who noticed the display transitioned into some form of direct interaction showing that the PARM display was ‘eye-catching’. The study confirmed that in a public setting the PARM was compelling to visitors and successful in encouraging passers-by to interact with or notice the display. The Skipton PARM tells the narrative of the flood risk and management strategy implemented in 2015 in Skipton, Yorkshire. This model was built with the potential for PARM-focused research studies in mind and has provided the focus for this research.

Informal observations and questionnaires taken during a school outreach event, organised by JBA Trust in 2019, began to explore learning comprehension from a presenter-led style of PARM delivery. The comparative study demonstrated how students engaged with different methods of visualising flood risk, comparing the Skipton PARM to 2D paper maps. 92% of students found the PARM the most useful to visualise landmarks, and most students found the PARM easier to understand than 2D maps across all the catchment information stated in the questionnaire. Students also showed preference for the Skipton

PARM over the Keswick PARM display, suggesting that more information can be obtained when the location under investigation is familiar to the users involved.

Orland *et al*., (2001) argues that "technical advances in visualisation technologies can outstrip the knowledge base of how best to use them". Other authors also note that more work is necessary to assess learning with public engagement tools (Fitzpatrick and Sinclair, 2003; Petts, 2007; Owens, 2007). More experimental work is required to investigate how immersive learning styles can be further embraced in flood risk communications. The PARM displays are a promising tangible technology, capable of delivering media-rich information sequences that can address environmental problems across entire landscapes, offering new opportunities for educational and spatial decision support (Priestnall *et al.,* 2017). There is scope to explore the effectiveness of these models more rigorously, with more research required on how PARM displays promote learning and engagement for users during both in-situ experiences and presenter-led discussions. Furthermore, the scope to improve the *ad hoc* design process for these models is promising, in order to find a refined narrative that communicates flood risk and river management options effectively.

This project originally sought to further previous research involving PARM models by carrying out an extensive investigation into PARM user interaction, using focus groups in presenter-led settings, and through in-situ observation analysis. Due to the Covid-19 pandemic, the focus has had to move away from the direct use of a tangible display PARM. However, a pilot study undertaken in January 2020 remains relevant to the development of this project and will be described in the next section.

3. PILOT STUDY

This exploratory study had aimed to compare how different user groups experience the PARM, using focus groups within schools and with members of the public to gain insights into how knowledge acquisition differed between different ages. The project had also aimed to use rigorous methods to test engagement with the PARM, employing detailed observation techniques to monitor interaction. Knowledge acquisition from the PARM model was to be studied using sketch mapping exercises, spatial skills testing and group discussion.

In order to trial the proposed methodologies, a pilot study was conducted. This involved a series of demonstrator-led focus groups, in a school setting. The Skipton PARM demonstration was incorporated into an 'Interactive Geography Day' for 120 Year 8 pupils at Ermysted's Grammar School, in Skipton. Students were split into six groups of 20, permitting six 30-minute focus groups across the day. Consent for student participation in the study was obtained from staff members. In each focus group, interaction with the PARM was observed and documented manually using the following interaction categories: (1) move, (2) point, (3) hover, (4) touch and 5) stroke (Priestnall *et al*., 2017) (Figure 14). Each focus group was observed by a research assistant who noted down any physical interactions with the display, the interaction category (1-5) and a timestamp was recorded. Across all sessions, the 'touch' interaction category was recorded the most frequently, most often by a participant investigating the model to see if it was in fact, 3D. In focus group 1, the total count of individual 'interactions' was 145, whereas in focus group 6 the count was only 29. This result gives an insight into group engagement variation across the day, with the latest afternoon group having the lowest total physical engagement count. From this, future experiments with focus groups should consider 'time of day' as a factor that may impact PARM engagement, especially in younger school groups.

This pilot study revealed that it would not be possible to conduct the observation counts manually, since the demands on the scribe were too high. After the pilot, it was clear that recording each focus group from an aerial view would be a good solution to this, meaning observation data could be collected more accurately, retrospective to the session by using the recording. A further observation of the study was that the groups of 20 participants were too large to efficiently engage all users, as students at the back of each focus group, not able to see the model, appeared to become easily distracted and disengaged. The originally planned research project was therefore redesigned to only conduct focus groups with less than 10 participants, but to incorporate how focus group size may impact engagement and knowledge acquisition as a line of inquiry. The pilot study was useful in understanding how to make key changes to the methods of data collection for this research project, considering the practicality of data collection, focus group size and time of day.

The pilot study used the original content for the Skipton PARM, which consisted of 7 key thematic sections: (1) Development of Skipton, (2) Local Landmarks, (3) What Causes Skipton to Flood, (4) Historic Flooding in Skipton, (5) Flood Risk Management in Skipton, (6) Predicted Flooding and (7) Scenario Animations. In each session, the demonstrator presented and talked through the Skipton PARM sequence, asking for active audience engagement on two separate occasions and taking questions throughout the delivery. Firstly, the demonstrator asked students to point out any local landmarks familiar to them. Across all 6 focus groups, participants offered suggestions of places they recognised from their town, i.e. local landmarks. This section of content elicited successful engagement from the students and showed the PARM's ability to situate a user well within a known landscape. Common landmarks pointed out by the students included the school, sports playing grounds and the train station.

Secondly, the students were asked to complete a sketch-mapping exercise (Figure 13), to see if they had understood and remembered the area’s most at risk to flooding in Skipton. The sketch mapping exercise proved useful in understanding how the PARM visualisations had resonated with the participants as similar, but not wholly identical, common areas ‘at risk’ were identified by the students. Thematic content in section 7 (‘Scenario Animations’) was added to this PARM narrative sequence especially for this pilot study. Here, two comparison animations were shown to students, depicting flood extent across the 3D topographic map, for AEP scenarios with and without the flood defences from the 2015 Skipton Flood Alleviation Scheme. Students reacted positively to this content section, acknowledging its visual appeal audibly, but also using this content as a reference during the sketch mapping activity. It was clear that the addition of the Scenario Animations into the narrative framework was a valuable addition and clearly demonstrated areas ‘at risk’ to flooding to the students and should therefore be kept in the standard narrative of the Skipton PARM.

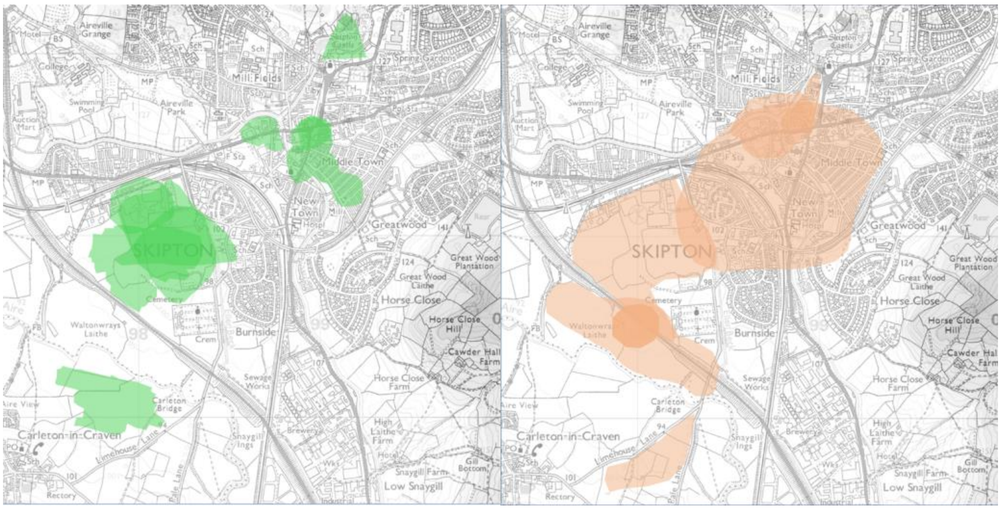


Figure 13. Sketch map examples from focus Group 3 (left) and Group 5 (right). Here a casual sketch mapping exercise was trialled to highlight environmental understanding, following the approach of Blades (1990) whose results demonstrates sketch maps to be a reliable method of data collection. The mapped areas that the students identified as ‘at risk’ have been digitised and overlain to observe the common patterns – expressed as darker shaded areas.

In focus group 3, during group discussion, one student asked if wildfires could be depicted on the 3D model. This comment led into a discussion about what other environmental simulations could be displayed on physical relief models like the PARM. The PARM demonstrator drew connections between wildfires and floods, as both natural disasters are likely to increase in terms of intensity and frequency as a result of climate change. This discussion showed that a PARM can be a useful medium around which to raise the topic of climate change, and perhaps further assess attitudes towards flood risk. The pilot informed the main study as new content on the impact of climate change on future flooding was incorporated into the narrative of the online model.

This pilot study highlighted a need to better assess learning with public engagement tools, as previously identified in relevant literature (Fitzpatrick and Sinclair, 2003; Petts, 2007; Owens, 2007). Despite subsequent changes to the research project, the pilot study provided insights that were translated into the main data study, including new narrative content on climate change and the ‘Scenario Animations’. However, from the methods utilised, it was unclear if the participants understood all the information displayed on the PARM in each thematic section. The sketch mapping exercise only tested knowledge acquisition in relation to spatial understanding of flood risk. This raises the question of whether the information being communicated was enough to not only engage, but help participants understand the whole PARM narrative which explores the causes, management and risk of flooding in Skipton. The pilot study influenced the direction of the research project, highlighting the need to employ more rigorous methods to analyse the structure and content of a PARM narrative sequence, and emphasising the importance of narrative content over the mode of presentation.

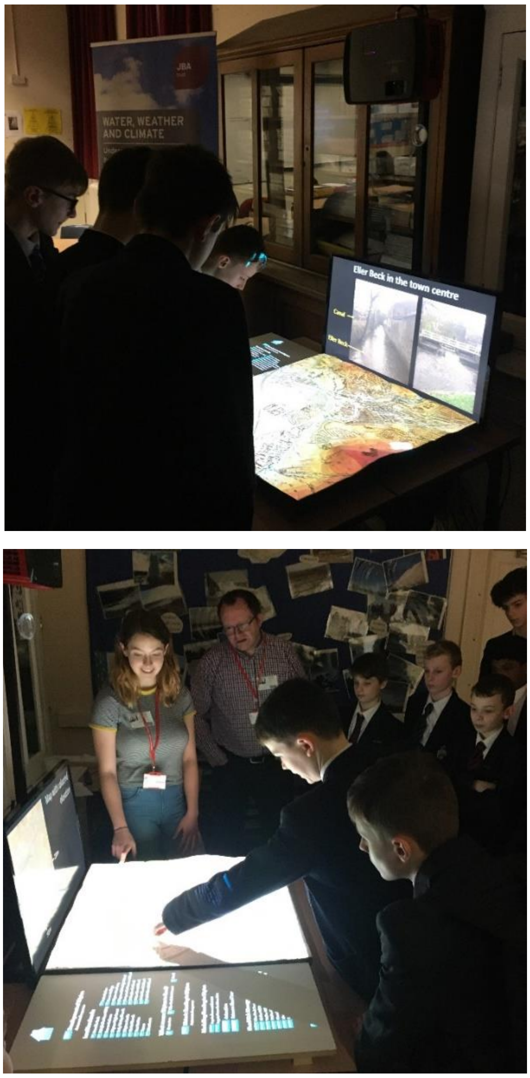


Figure 14. Images taken from the pilot study event in Skipton. Students can be seen physically interacting with the model.

3.1 COVID-19 – Impact and Project Redesign

Since the introduction of social distancing measures in March 2020, the research could not be carried out in the manner originally planned. In-person interaction with the PARM model would not be possible with individuals or with larger groups, such as school classes or in public places. A major adjustment to the project methods, aims and objectives was made since the 3D display could no longer be utilised. Though unfortunate, these unforeseen circumstances offered a new opportunity for a novel online-based investigation. It had become apparent from the use of the Skipton PARM during the pilot study that there was great scope to study the actual information content of the display rather than the particular types of interaction that such displays promote. This could best be done by isolating the content sequences from the 3D portrayal.

This project was therefore re-focused on using an online equivalent of the PARM. The possibility for an entirely online geovisualisation tool could now be explored and tested, in a climate where many stakeholders are looking to make information easily accessible, understandable and engaging through online mediums. This new research focus could be of value to inform the design of content for any future PARM display but may also be of value as an online dissemination and consultation tool.

4. AIMS AND OBJECTIVES

Previous research has demonstrated PARMs to be an engaging form of visualisation which appear to promote interaction and discussion. This research project will aim to focus more on exploring the structure and content of information used in PARM displays rather than PARMs themselves. In order to do this, a 'simulator' will be created which will use the same content as a PARM display but will not attempt to replicate the 3-dimensional perspective of the model. This will enable the isolation of issues related to content rather than the model of display. The aim of this MRes is therefore:

"To investigate how the structure and content of information within an online interactive tool influences public engagement, knowledge and attitudes towards flood risk".

Objectives:

1. To gain insights on user engagement, understanding and attitudes towards flood risk using an online geovisualisation tool (PARM Simulator) through feedback from both professional and non-professional demographics.
2. To assess whether flood location familiarity can influence user experience with the online tool, enabling greater understanding or engagement.
3. To consider people's attitudes towards personal flood risk and current methods of flood risk communication.
4. To explore future implications for the structure and content design of online interactive tools and 3D PARMs with the findings of this research.

Previous PARM displays have been developed in an *ad hoc* format, depending on the purpose of the display and the location of the model. This project will produce recommended guidelines for a base 'narrative' of content, as determined through feedback from participants.

The insights and observations of this research will help uncover how the PARM narrative sequence can be improved for all users, to maximise engagement and knowledge gained, from interaction with PARM models. This research will provide insights into how people understand the basic structure and content of the PARM, with a view to informing future displays like PARM that may be required to operate as stand-alone exhibits, in a town hall or museum for example. This research is justified in its novel approach, employing user-centred testing on an emerging geovisualisation tool within the wider remit of research to enhance flood risk communications.

5. METHODS

As already discussed, studies have shown an overreliance on 'experts' and exclusion of 'users' in the design of risk communications (Rollason *et al*., 2018; Woods *et al*., 2012). MacEachren and Kraak (2001) expressed a need for comprehensive user-centred design (UCD) approaches and usability testing in geovisualisation. A common principle of UCD approaches is a focus on user participation early on, with iterative testing during the whole design process (Karpouzoglou *et al*., 2016; Lorenz *et al.,* 2015). Participatory design is an extension of UCD, requiring 'active involvement of end users and other stakeholders within the co-design process' (McIntosh *et al*., 2011). The empirical research of this project takes a user-centred, mixed-method approach, combining results from a questionnaire and one-on-one interviews. From the interviews, participant interactions with the online simulator were observed and discussions regarding the content were recorded. Data was collected in two separate phases (Figure 15) to obtain in-depth feedback into the design and content of the PARM Simulator.

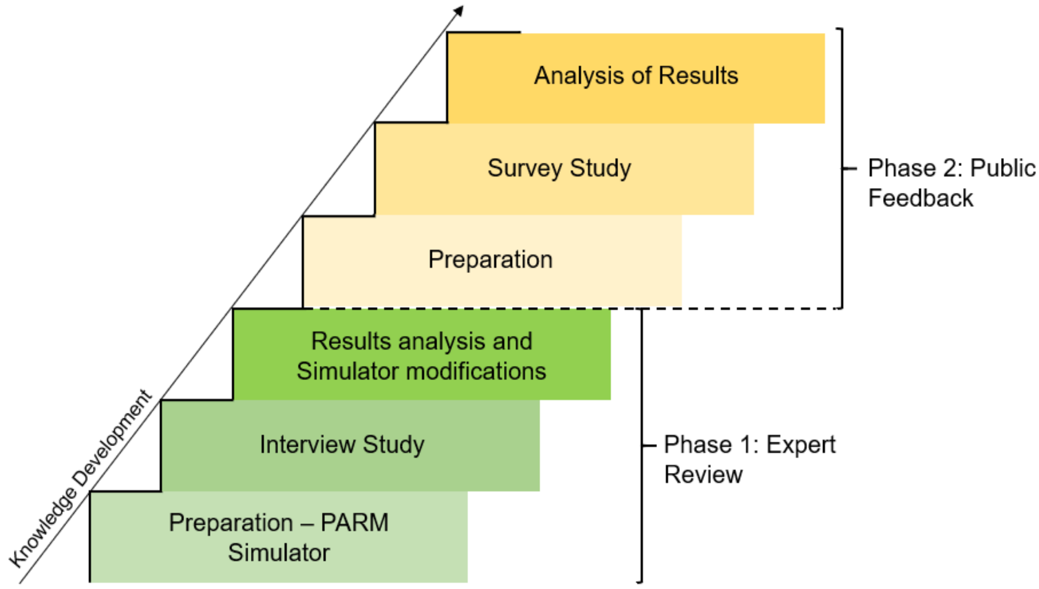


Figure 15. Phases of data collection in the research study, after Wästberg *et al*., 2020.

5.1 Stage 1: Creating the Skipton PARM Simulator

The specific geography and nature of flood hazard in Skipton is shown in Figure 16. The original graphic content and points of interest from the Skipton PARM were transposed to a Microsoft PowerPoint format. To replicate the 'feel' of the PARM, the interactive buttons to trigger content were replicated on the left-hand-side of the screen, while the graphic content was on the right-hand-side, stacked to mimic the arrangement of the 3D model and backscreen (Figure 17).

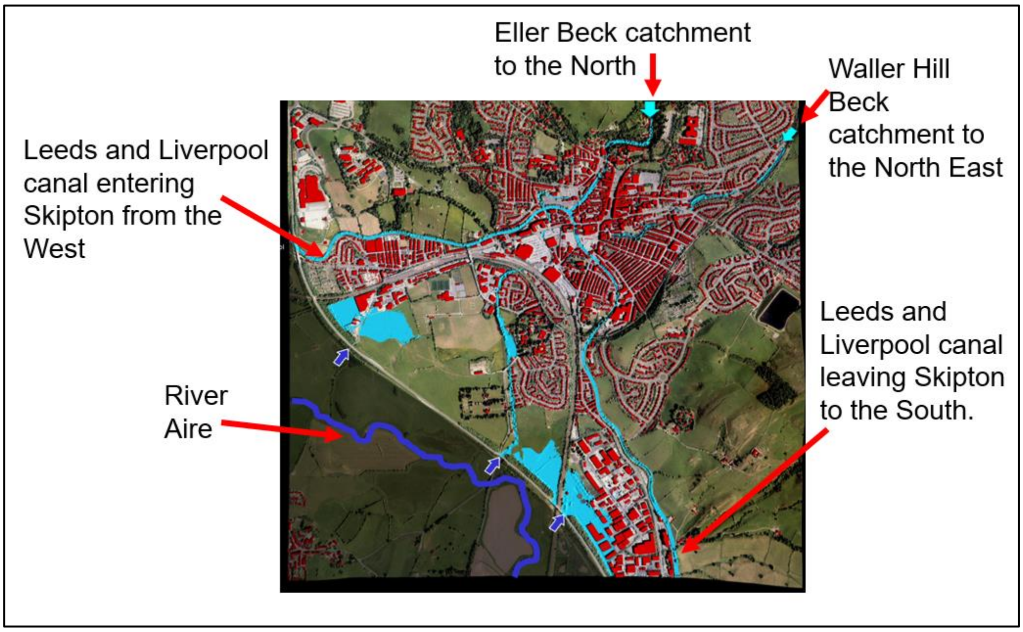


Figure 16. Map of Skipton taken from the PARM Simulator. Infrastructure has been highlighted in red and a flood extent of 20% AEP is modelled. The geography of Skipton and placement within the landscape is pivotal to understanding the nature of flood hazard in the town. Skipton sits at the bottom of two large catchments where two river tributaries converge: the Eller Beck catchment to the north and the Waller Hill Beck catchment to the north east. The Leeds and Liverpool canal enters the town from the west, running through the town centre, alongside the Eller Beck, and out through the south. When the Eller Beck floods, it often overspills into the canal which becomes part of the problem and exacerbates the flood.

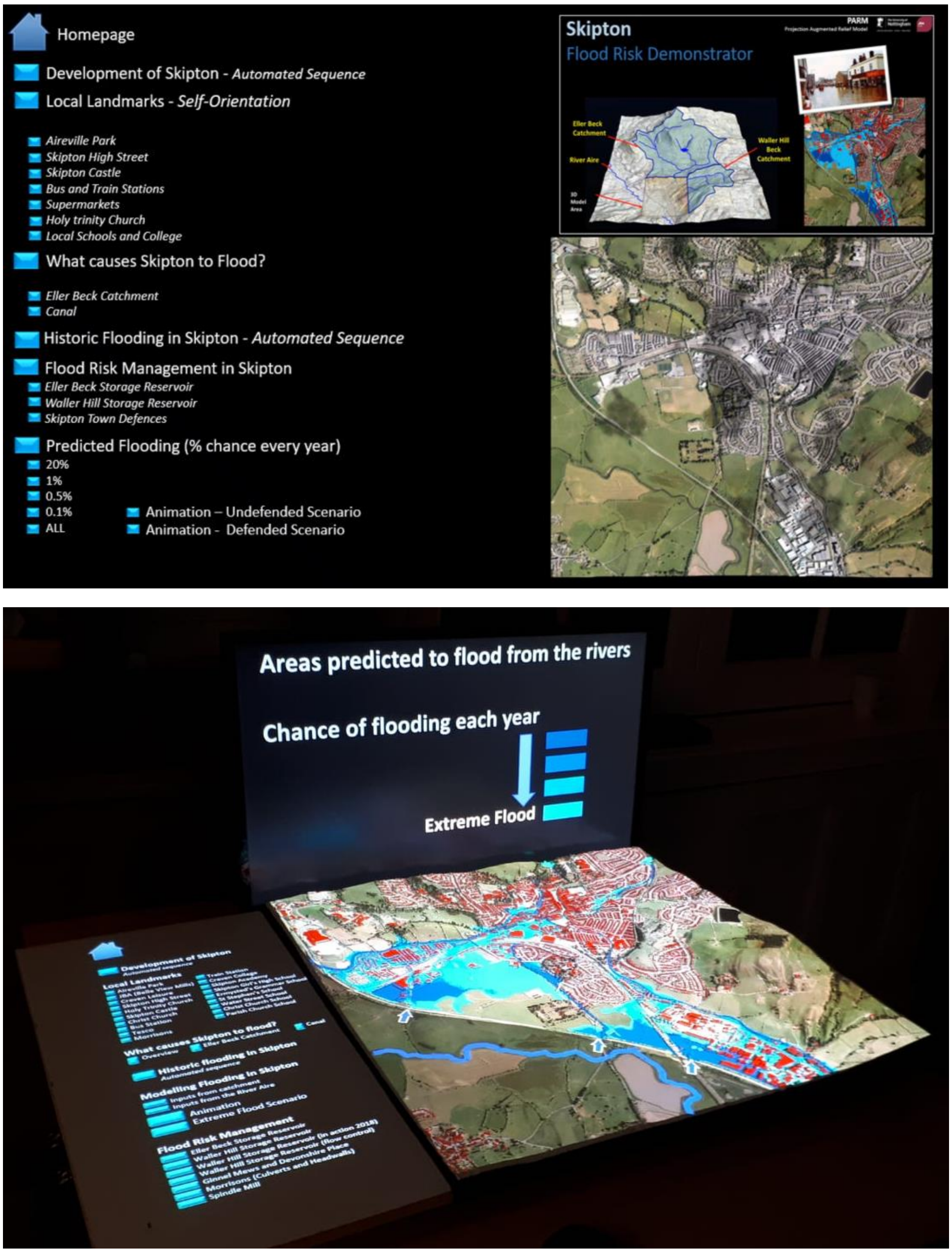


Figure 17. Skipton PARM Simulator (top) compared to the physical 3D Skipton PARM (bottom).

5.2 Stage 1: Interview Methodology

The purpose of the interviews was to gain critical feedback on the PARM Simulator content whilst observing user experience with the online format. Eight one-on-one interviews were conducted remotely. A snowball-sampling technique was employed, where known contacts within a research group are used to find willing participants for the study (Naderifar *et al*., 2017). Time spent at the JBA HQ and attending workshops with the Nottingham Blue-Green Cities research group enabled the sample 'snowballing' to find interview participants.

Participants were recruited by a personalised email from the researcher. Professionals with expertise in flood risk, environmental, or river management were sought to partake in the interviews. Of the eight participants, the associated sectors were as follows: academic (1), independent charity (1), local government (2), consultancy (2), non-governmental organisations (2). All interview participants had some prior knowledge of the PARM, either having seen it previously in-person or simply knowing of its existence. Three participants also had prior knowledge of the local area (Skipton) and the rest did not.

The overall methodology for Stage 1 took inspiration from user-centred design methods (Norman and Draper, 1986; Vredenburg, 1999; Vredenburg *et al*., 2002). The interviews are classified as 'contextual interviews' as they were conducted whilst observing a participant (user) interacting with a 'product'; in this case the PARM simulator. This interview format is common in usability testing (Rubin and Chisnell, 2008). Usually contextual interviews for usability testing involve the observation of a specific set of tasks being performed by the 'user'. In this study, participants were encouraged to follow their natural intuition and navigate through the simulator on their own whilst providing an out-loud narration of what they were reading and seeing. At the start of each interview, participants were told that the purpose of the interview was to gain feedback on the content of the simulator. Since the interviews were conducted remotely via Microsoft Teams, the participants were also asked to share their screen where possible so that their interactions with the PowerPoint could be observed, as well as their feedback commentary.

After the interviewer introduced themselves, the standard introduction for each interview went as follows:
"This masters research project had originally been designed to test engagement with tangible 3D PARMs, however now we have been given the opportunity to change our methods to comply with social distancing. We have created an online interactive tool that simulates the same narrative content of the 3D Skipton PARM, this content was originally deigned for presenter-led demonstrations. In this interview I would like you to self-navigate through the PARM simulator, saying what you see. This project aims to assess the content of information in the simulator so any feedback you can give on the information presented or general interface usability would be very helpful. Since this content was originally designed to be presenter-led there may be some areas that require more explanation, please point these out when you feel the content is unclear or lacking explanation. Please use the contents on the left-hand side of the page to navigate through, this exercise is likely to take around 20-30 minutes. Do you have any questions?"

After the introduction, the participants were also asked their profession, whether they were familiar with 3D PARMs and whether they were familiar with Skipton (and if so, in what way). Since the interviews were conducted remotely via Microsoft Teams, the participants were also asked to share their screen where possible so that their interactions with the PowerPoint could be observed, as well as their feedback commentary. Due to technical issues this was not always possible, therefore in some cases, participants were given control of the interviewers' screen in order to navigate through the PARM simulator. Any dialogue between the interviewer and the participant regarding interface usability was recorded by the interviewer.

Following on from a standard introduction, the interviews were semi-structured, with the simulator itself providing a loose structure for each interview. There were no set questions to ask while participants were self-navigating. However, each time a participant gave feedback on an aspect of the simulator's content or design, they would always be asked to elaborate. For example, "what information do you think is missing here that would enable people to understand that better" or "how do you think the map could be improved". This adapted methodology was chosen with the aim of generating conditions that give rise to direct and genuine feedback from participants, but also to rigorously assess interaction with the simulator in order to identify usability problems with the design and content.

Interviews lasted between 20 and 60 minutes. Participants read a participant information sheet and granted consent prior to completing the interviews. The interviews were recorded and transcribed through Microsoft Stream. Microsoft Stream Transcript VTT File Cleaner was used to remove time stamps from the files which were then reviewed and edited by the researcher, who reviewed the recordings to ensure the transcripts were accurate. The transcripts were anonymized (i.e. P1 = Participant 1) and feedback relating directly to the simulator was coded. A 5-code system was generated through deductive theme analysis which offers a top-down theoretical approach to generate themes within the data to allow code definition (Braun and Clarke, 2006). After becoming familiar with the transcripts, the codes were created (defined in Table 2) and used to categorise feedback. The results of the data analysis are found in section 6.1 and are presented in combination with the discussion.

Table 2. 5-part coding system to define feedback.

Code	Definition
1 – Positive Feedback	User comments that express a liking to aspects of the simulator, identifying areas of effective communication.
2 – Constructive Feedback	User comments that express a disliking to aspects of the simulator, identifying areas for modification.
3 – Suggestive Feedback	When the user offers personal recommendations on how to improve the simulator content.
4 – Functional Feedback	Feedback that indicates the user is having a technical issue or that the interface design in unclear in some way to cause confusion.
5 – Emotive Feedback	User comments that express feelings (positive or negative) towards what the simulator is attempting to convey. This form of feedback typically relates to the wider aims and purpose of the research.

5.3 Simulator Modifications

Modifications to the simulator, based on the categorised interview feedback results, were then carried out. Once the simulator had been modified, a feedback survey was created and linked to the PowerPoint. The survey was made open to the general public and distributed by sharing of an anonymous link: https://drive.google.com/file/d/1YOYEccvnh0I601Fgzl2qsqLFK7k0MfGV/view?usp=sharing.

The modified Skipton PARM simulator is comprised of seven key thematic sections, Figures 18 – 24 give examples from each section and a brief description of content. Screenshots of all content found in the simulator can be found in Appendix 1.

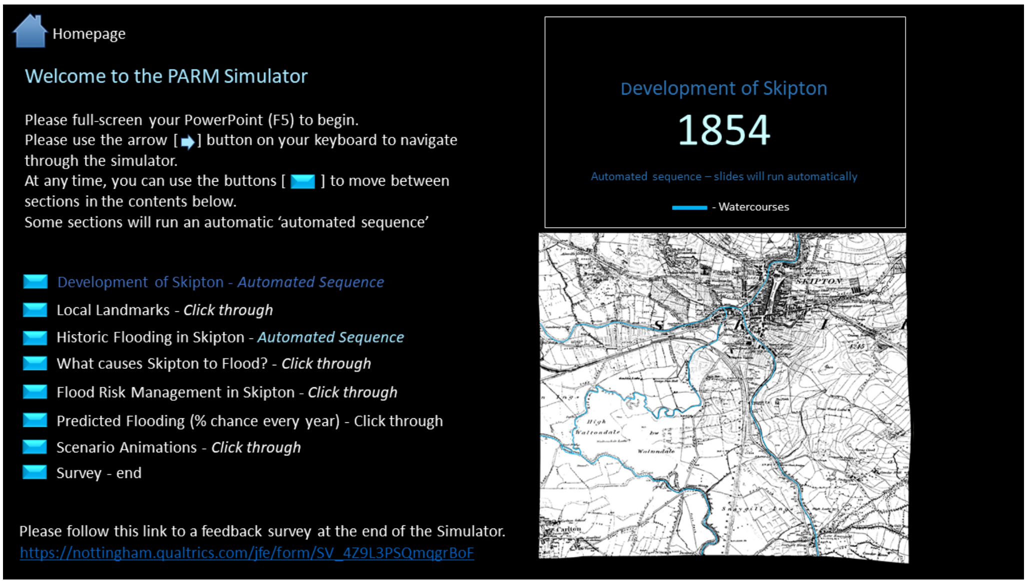


Figure 18. Section 1 – 'Development of Skipton'. This section uses an automated sequence of maps to show how the town has expanded since the 1850s.

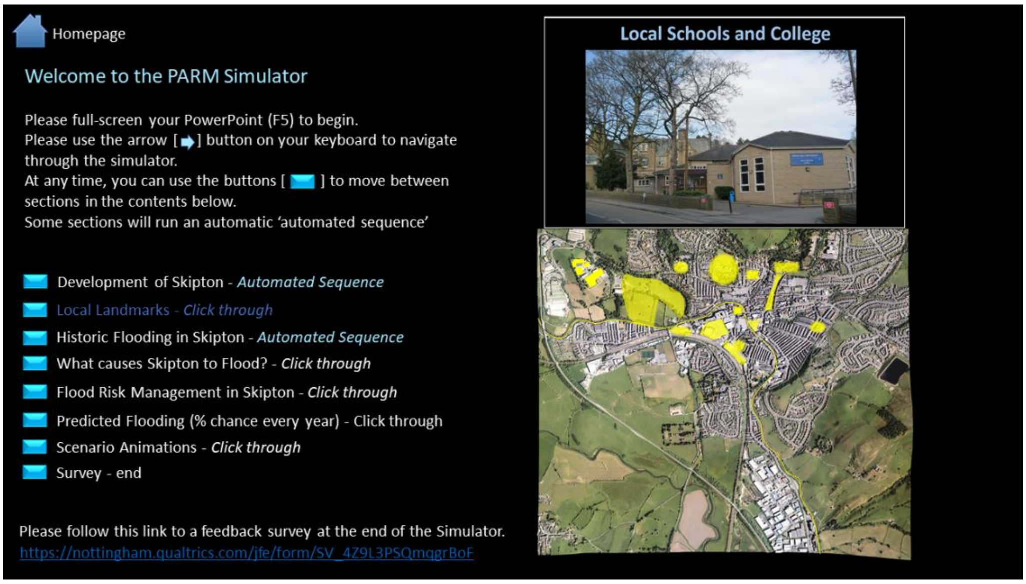


Figure 19. Section 2 – 'Local Landmarks'. This click through section takes the user through the location of seven key landmarks in Skipton to build a frame of reference of the area, landmarks include the Skipton castle and high street.

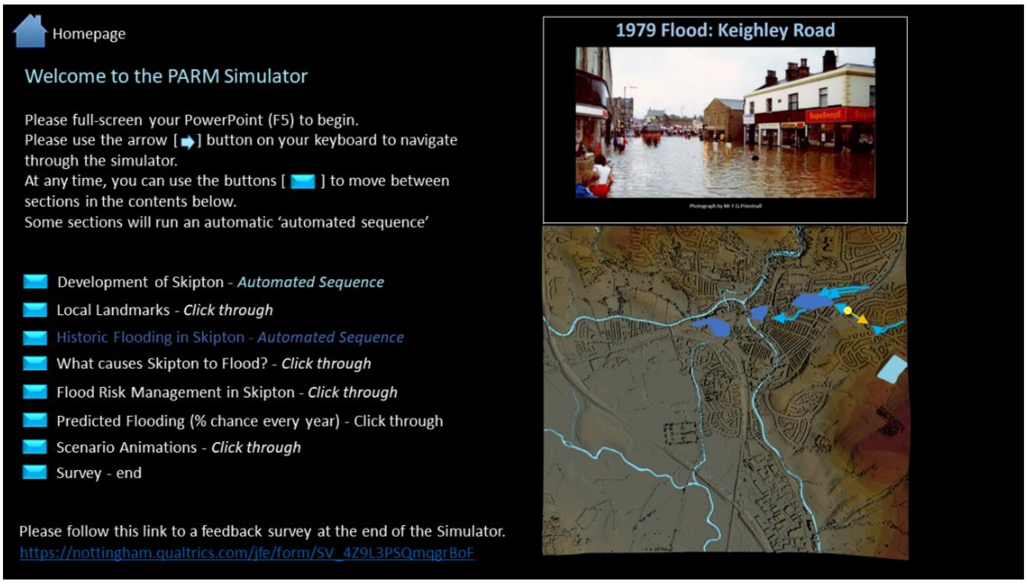


Figure 20. Section 3 – 'Historic Flooding in Skipton'. This section presents a series of images from previous flood events in Skipton, including floods from 1809, 1979 and 2015. The flood extent from each event has been digitised on the lower map for each slide.

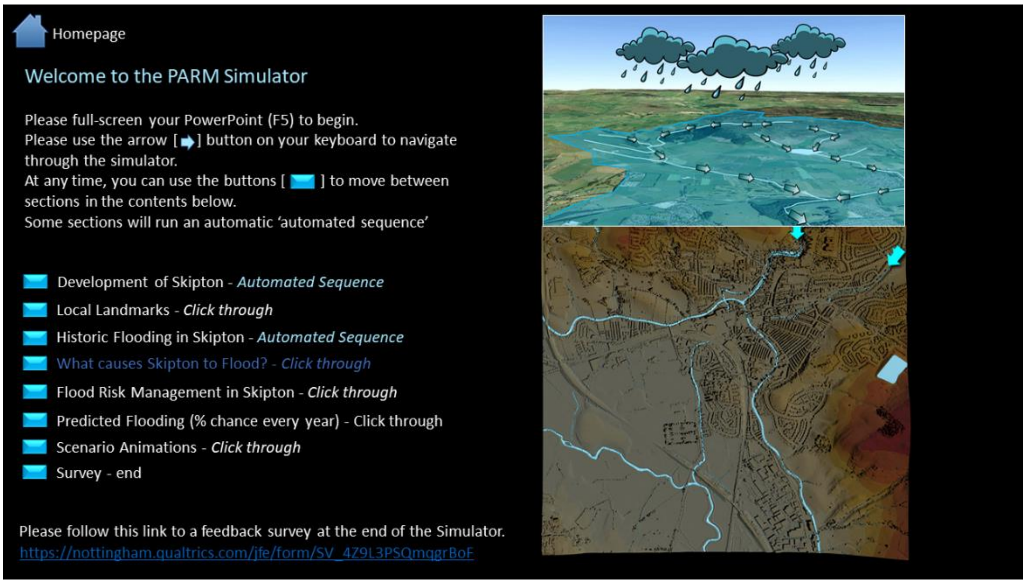


Figure 21. Section 4 – 'What Causes Skipton to Flood?'. Here, the graphics used tell the story of flood risk in Skipton, explaining how the town sits in a classically round catchment, with converging river tributaries and the Leeds-Liverpool canal all contributing to flood risk in the town.

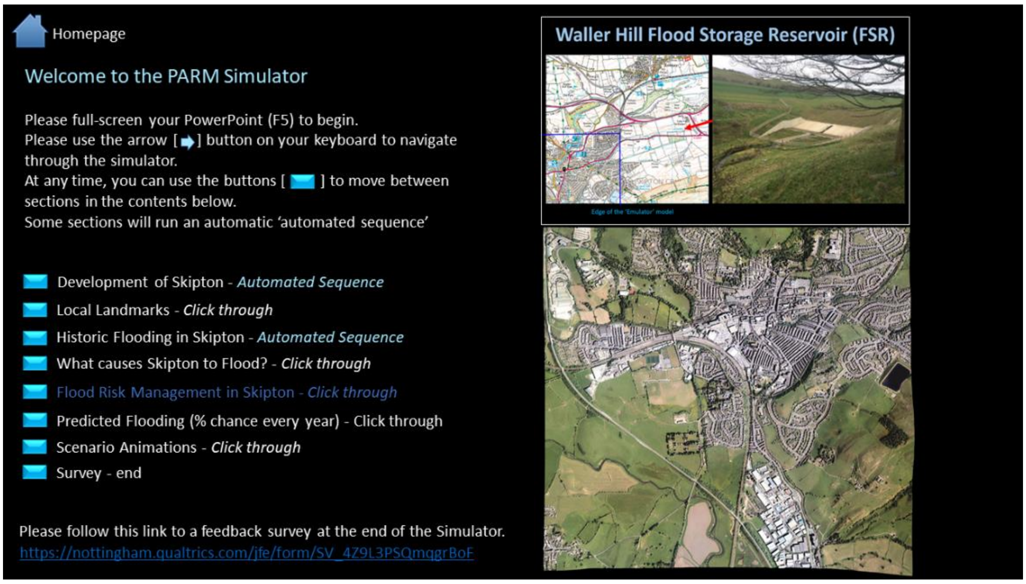


Figure 22. Section 5 – 'Flood Risk Management in Skipton'. This section describes the components of the 2018 Skipton flood alleviation scheme including the two out-of-town flood storage reservoirs and the in-town defences.

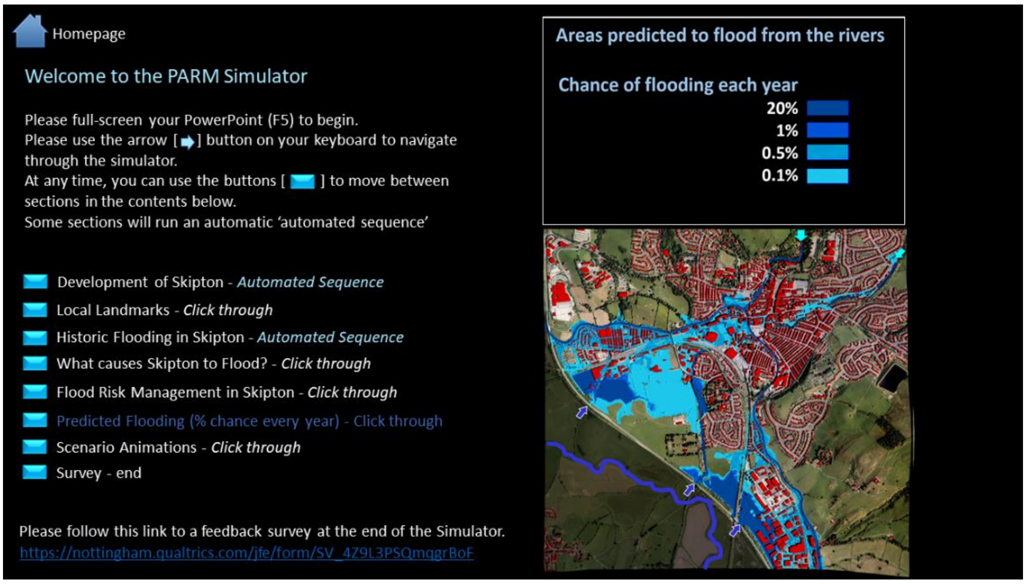


Figure 23. Section 6 – 'Predicted Flooding'. This sequence uses modelled predictions of flood extent for four different magnitudes of flood (0.1% AEP, 0.5% AEP, 1% AEP and 20% AEP).

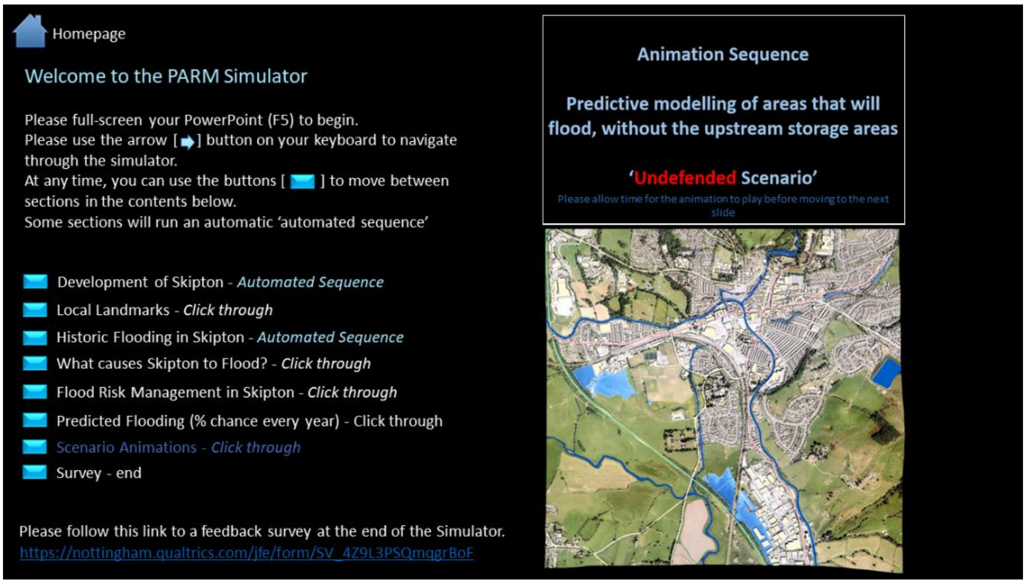


Figure 24. Section 7 – 'Scenario Animations'. The final thematic section uses animated video to compare the extent of flooding with and without the Skipton flood alleviation scheme defences. This was included to show how the alleviation scheme has reduced flood risk.

5.4 Stage 2: Survey Methodology

The purpose of Stage 2 was to critically analyse the acquisition of geographical knowledge and quality of user experience from the modified PARM simulator. This was done using an online survey subdivided into four sections; 1) general information; 2) user experience; 3) learning experience and 4) public engagement (assessing attitudes towards FRM). 22 questions were used in this survey; the range of question types included open questions, multiple choice and ratings (5-point Likert scale) (Appendix 2). The questions were developed using guidelines from Andres (2012).

The survey took approximately 10-15 minutes to complete and was launched online through the Qualtrics XM platform. The survey was open from the start to the end of October 2020. The survey was open to the public and shared on channels including Twitter. Contacts at JBA and the Cravern Museum in Skipton were used to share the survey amongst people who live in and around Skipton. Participants read a participant information sheet, privacy notice and granted consent prior to completing the survey. All survey responses have been anonymised. A total of 37 respondents started the survey, with 35 (94.6%) successfully completing all questions.

5.5 Data and Statistical Analysis

Closed question responses were presented into summary charts and tables using Microsoft Excel. Statistical analysis was performed using Microsoft Excel and SPSS. In order to test for differences between those familiar and those unfamiliar with Skipton, non-parametric tests (Mann-Whitney U) were used for two sample comparisons, to assess if there were statistically significant differences between responses. Additionally, Kruskal-Wallis tests were applied in three other cases to compare categories of information collected from the feedback survey. When a test demonstrated a significant difference, a post-hoc test was used to look for specific differences between groups of data. When a post-hoc test was implemented, the Bonferroni adjustment was applied to the alpha values to control for type 1 errors. Normality testing was not required for these analyses as the data collected from the survey responses was ordinal.

Open question responses were synthesised into thematic ‘nodes’ using qualitative research software (NVivo 11 Pro). Nodes with shared relationships were then grouped into ‘clusters’ for data presentation, where each ‘cluster’ groups question responses by shared themes. A grounded theory approach (Glaser and Strauss 2010) was adopted in this analysis, allowing key themes to emerge directly from the data, reducing the impact of preconceptions (Timonen *et al*., 2018).

5.6 Limitations

Social distancing regulations eliminated the possibility of working with the 3D PARM model. This was accounted for through project redesign and the research was completed online to the best level possible. In the time the survey was open, 37 responses were collected, and a higher completion rate would have been preferred. However, the nature of this research places larger demands on the user than a typical online survey as users were not only required to answer the questions but familiarise themselves with and interact with the PARM simulator. Considering the rich level of data obtained from those 37 responses, it was considered to be a sample fit for purpose in addressing the research objectives.

6. RESULTS AND DISCUSSION

Findings from both research stages will be presented and summarised separately.

6.1 STAGE 1: RESULTS AND DISCUSSION

6.1.1 Development of Skipton (Table 3)

The ‘Development of Skipton’ section sought to introduce the user to the area through a series of animated historic and modern maps. As the first section in the simulator, some participants found the initial interface confusing, asking the interviewer how best to begin navigating the slideshow.

“So that’s come up with a home page and then yeah, and then you just click to move on. Is that right?.” (P1)

“So, should these things be clickable? Or is this about? So, I want to learn about the development of Skipton I want to go to an automated sequence.” (P4)

It was obvious from the feedback that the simulator contents and homepage needed to be adjusted to ensure greater clarity over which sections ran automatically on the simulator. The feedback from this section was mainly positive, with participants commenting on the effective use of maps in animation to tell a sequential story.

“It's interesting to see the growth of the population and where that is and where the housing appears.” (P1)

Land use change such as urbanisation has long been documented as having a role to play in modifying channel conditions, resulting in flood magnitude and frequency increases (Wolman, 1967; Knox, 1977; Schueler, 1992; Suriya and Mudgal, 2012). This section was designed with the original intention to show how urbanisation and expansion in Skipton since the 1850s had led to the encroachment of infrastructure across the Eller Beck floodplain. It was reassuring that participants noticed how the growth of population and housing was displayed through this animation sequence. Participants also found the elevation map useful in conveying the catchment topography without the use of the 3D model (Appendix 1, Slide 6)

“You show the elevation map as well, I think it's hard for people to tell water catchment is really like when it's when it's a map like a normal map. Uhm, so it's just good you have got that on there.” (P3)

The constructive feedback given indicated an interest in more ‘social’ aspects to be mapped, such as greater detail on the highlighted infrastructure.

“One thing that the maps don't show you really clearly is, Uhm, you know what's growth in housing and maybe what's growth in industry.” (P1)

It was also suggested that making the river channel and canal clearer, especially on the historic maps, may be beneficial as both were difficult to locate.

A few participants commented that they would have preferred the section to be ‘click-through’ and made suggestions to include different types of mapping in this section in order to make the visuals more inclusive of the ‘general public’

“We're used to looking at maps as geographers, but wondering the, some of the general public might not be as much. I wonder if there's something just very simply you could do for Skipton and you know just thinking about Google Maps.” (P4)

The cartographic revolution in recent decades has familiarised the general public with maps being both digital and intangible (Bolick, 2006), the simulator assumes a basic comprehension for map reading. It is therefore expected that users in Stage 2 will in fact be able to engage with these maps effectively and that they will not be a barrier to knowledge acquisition.

The novelty of considering historic development was a praised aspect of content.

“You can see how there's more pressure on our environment, which I think is good, it tells a story in itself, and it's something we don't tend to really consider.” (P7)

The series of maps were able to convey environmental pressure which is the first key step in understanding how flood risk can be managed.

Table 3. Summarised feedback for the 'Development of Skipton' section.

Code 1 **Positive**	• Interesting to see increasing population density (P1). • Really interesting (P2). • Elevation map is useful to show the catchment (P3). • Liked use of maps (P7). • Great use of animation to tell sequential story (P8).
Code 2 **Constructive**	• Maps don't clearly show growth of housing or where key businesses are (P1). • Would prefer to click-through to digest all the information from each map (P4). • Too much text on Slide 1 (P6). • Difficult to get maps to line up, cannot remember the first maps (P8).
Code 3 **Suggestive**	• Could include different types of mapping such as Google Street View (P4). • Could combine/remove some of these slides (P6). • Make diagram of river floodplain and add onto maps (P6). • Could add scroll bar for user (P8).
Code 4 **Functional**	• Initial confusion if this was the homepage (P1). • Unsure when the animation sequence had finished (P3). • Should this be clickable? (P4).
Code 5 **Emotive**	• Believes we often neglect the history of an area, so it is good to include this sequence. The maps show increasing pressure on the environment which creates a story in itself (P7).

6.1.2 Local Landmarks (Table 4)

Generally, this section was found useful, as users were able to practice using the simulator and find their bearings within the virtual Skipton.

"The fact that they highlight when you click on them, it just makes it very quick to orientate yourself. Around so that yeah, so that's sort of a chance to play and interact with it is a really, really useful one." (P2)

The meaningfulness of the landmark orientation was debated, with one user questioning how useful this exercise would be to people who did know the area. This shall be explored in Stage 2 through data comparisons between those who are familiar with Skipton and those who are not.

"If I'm local and I know where the Castle is. I know where the Castle is, you don't have to tell me that. I've got my own sort of geographical frame

of reference of what I understand next to the castle and my sort of mental map in my head. What's it got to do with the river?" (P6)

The original rationale for the incorporation of landmarks into the PARM design was to help people create a frame of reference for Skipton that would enable better mental contextualisation of flood risk. Perhaps, an overview reference frame should be presented instead, with only a few key landmarks directly relevant to areas that flood, that are likely to feature later in the PARM narration, such as the high street. Other landmarks could also be included for optional reference, as these may still be of use to those who did not know the area. One user commented that this information was especially useful in setting the scene of the simulator, as someone who had no prior knowledge of the area

"I quite like this with the landmarks particularly if you're someone who doesn't know the town." (P4)

It was suggested that the canal should be marked as a key landmark of Skipton to tell the story of its importance to the overall flood risk of the town. Further interview discussion also generated considerations for PARM design in the future, such as considering changing the landscape elements for different user groups.

"It's a degree to which you want to tailor this to different user groups, because plainly a child is going to have different frames of references you know the parks can be much more important to them." (P6)

Young children as well as adults can use reference cues to recall locations; individual differences including age and visual experience can however alter mental spatial frames of reference (Ungar *et al*., 1997). The 'Local Landmarks' content provides an allocentric representation of Skipton with respect to an external frame of reference through the combination of visualised landmarks (Nardini *et al*., 2005). Since the frames of reference used may influence user performance and learning (Millar and Al-Attar, 2004) further work should be done to compare the optimal frames of reference for both adults and young children, to adapt the PARM sequence accordingly. In this case, the local landmarks chosen to build a frame of reference were deemed appropriate and useful for the user group.

Table 4. Summarised feedback for the ‘Local Landmarks’ section.

Code 1 **Positive**	• Useful to interact with this section, very quick to orientate yourself (P2, P7). • Helps people get bearings – especially if they are from the area (P3, P5). • Useful to get a picture of the area for someone who does not know it (P4).
Code 2 **Constructive**	• Introduction slide to ‘Local Landmarks’ – confusing with all buildings in red (P6). • Locals will know where the landmarks are (e.g. the castle) so why is it important, and what does it have to do with the river? (P6). • Enlarge imagery (P8).
Code 3 **Suggestive**	• Include canal and all landmarks mentioned in the backscreen images (P1). • Consider user groups, a child has different frames of reference to an adult (P6). • Try mapping more ‘social’ elements – e.g. areas of deprivation. Bring out the ‘human side’ (P7).
Code 4 **Functional**	• Presumed this section was a slideshow (P1).
Code 5 **Emotive**	• Useful to get used to the PARM simulator and what it is showing you (P3). • “It’s bringing back memories, it rains a lot there doesn’t it” (P7).

6.1.3 What Causes Skipton to Flood? (Table 5)

This section aims to provide the user with a good comprehension of the specific causes of flooding in Skipton. It was suggested that definitions of “jargon-y” terms were needed to provide clearer explanations. ‘Jargon’ refers to specialised vocabulary terms associated with a situational context or purpose, in this case ‘headwall’ and ‘culvert’ were considered too technical, it is usually recommended to reduce jargon where possible in scientific communication (Baron, 2010; Dean, 2009; Sharon and Baram-Tsabari, 2014).

It was clear from the participant feedback that this section lacked context, especially without a demonstrator to lead through the content in a ‘presenter-led’ style focus group.

“It is undersold without the presenter.” (P2)

“I wonder whether there's just a few more arrows needed, sort of an annotation of what's happening.” (P8)

This was an interesting observation, the feedback here suggested that the content would not be effective as a stand-alone display. This highlights the need to modify the simulator narrative in order to produce a tool that is not dependent on a ‘presenter’.

A key comment was that the link between the canal and its impact on the Eller Beck was “hugely undersold”. The importance of this imagery was missed and needed a clearer narrative.

“The one about the importance of the interface between the canal and Eller Beck. It’s, it’s almost, that certainly needs a story around it.” (P2)

The canal-Eller Beck interface is crucial in this instance as this acted as the focal point for the Skipton Flood Alleviation scheme, the water level here was the controlling point which set the size of the storage reservoirs.

This feedback highlighted the challenge of modifying the PARM content into an online format.

“Sense of losing the compelling nature of the physical model.” (P4)

The content seemed insubstantial and needed to be updated with greater detail, in discussions the use of a voice-over narrative for the online simulator was mentioned as a possible solution to this. The users also commented on the difficulty of conveying the catchment completely on a screen compared to the visual success of the 3D model itself, indicating the loss of immersiveness of the PARM through the transition to an online medium. Since all participants had seen physical PARM before, this may have encouraged their comments about the use of 3D, holding an unconscious bias towards the 3D model they remember.

Table 5. Summarised feedback for the 'What Causes Skipton to Flood?' section.

Code 1 Positive	• Slide 17 is very clear and interesting (P6).
Code 2 Constructive	• Interface between the canal and Eller Beck needs more narrative as its importance is undersold without a presenter (P1, P2). • Some terms too 'jargon-y', e.g. culvert and headwall (P4). • Struggled to relate the top image to bottom map (P6).
Code 3 Suggestive	• Show where Eller Beck meets the canal more clearly (P1). • Show images of flooding fist, to provoke an emotional response, then 'What causes?' (P4). • Make slide transitions longer (P4). • Add explanations for key terms (P4). • More arrows/explanation needed (P8).
Code 4 Functional	• Arrow indicating Waller Beck does not show up well (P1). • Mixture of animated/clickable is confusing (P1). • Was unsure if top panel was part of original model (P4). • Did not notice catchment outline (P5).
Code 5 Emotive	• Difficulty of conveying the catchment completely on screen. Sense of losing the compelling nature of the physical model (P4).

6.1.4 Historic Flooding in Skipton (Table 6)

Participants agreed the imagery used in this section was emotive and successful to engage users in both the message of extreme destruction and personal stories of loss caused by previous flood events.

"I do like photographic evidence and, well, that was quite frightening. Some of it." (P7)

"So, I love your photos and I think loads of people do." (P8)

"If you've got a personal angle to it. You've got them. They'll remember that picture." (P6)

Public consultation meetings could be harnessed as a method of collecting local, volunteered information to be included in PARM narratives, such as photos of flooding or even oral historic accounts of flooding. The use of impact visuals such as images of flooding is not uncommon. In the past, extreme weather events have been used to convince the public of the reality and risk posed by climate change (Bronnimann, 2002). Critical studies of media reporting have suggested that emotional imagery is the most effective way 'to capturing media consumers attention and mobilising public action' (Solman and Henderson, 2019). Studies have also shown this imagery to also foster forms of engagement (Joye, 2015; Pantti *et al.*, 2012), explaining the success of the imagery used in the PARM simulator.

One comment was to rethink the chronology of the presentation, to monopolise on the emotional impact that the 'Historic Flooding' had on the users. It was suggested to order it prior to 'What causes Skipton to Flood?' in the overall narrative and to include more imagery if possible.
"It might be useful to have a wider range of images of the different floods so that you get more of a sense of where it flooded at the different times." (P1)

While interacting with the simulator, during these slides one user who lives in Skipton, commented on resident's perceived flood memory within Skipton:
"I think people do remember. And the other thing is like obviously with all the improvements, I think people are kind of hoping that it doesn't. You know, it's not going to make it, or cause as much damage if it happens again." (P1)
The possibility of the PARM to assist in producing sustainable flood memories warrants further investigation. Sustainable flood memory is a community focused communication to encourage system learning to help decision making for the future (McEwen *et al.,* 2016; Bhattacharya and Lamond, 2014). Research has indicated that local flood risk agencies in the UK have made limited attempts to engage with and enhance knowledges drawn from flood memories to facilitate social learning. (Garde *et al*., 2017; Krause *et al*., 2012). Strategies such as use of the PARM simulator could engage different aspects of recovery and renewal of the memory system, and therefore contribute to enhancing community flood memories (Berkes *et al*., 2003), leaving an interesting research topic for the future.

Table 6. Summarised feedback for the 'Historic Flooding in Skipton' section.

Code 1 Positive	• Liked this section, thought the photographic evidence was used well and is quite 'frightening' (P5, P7). • Photo orientation is clear (P3, P5). • Peter Clark's Garage slide – great. A personal angle hooks people and they will remember the picture (P6).
Code 2 Constructive	• Needs more commentary. Where is the photo being taken from, where is the water going etc. (P2). • Enlarge photos on the screen (P8).
Code 3 Suggestive	• Indicate on slide when an animated sequence has ended (P1). • Include wider range of flooding images – especially 2015 as it is the most recent in people's memories (P1). • Add image of flood peak plaque in Skipton if there is one (P8).
Code 4 Functional	• Participant asked if this section was animated (P1).
Code 5 Emotive	• "I think a lot of people kind of, you know, get quite anxious about because it obviously affects a lot of businesses in the town. So yeah, I think people do remember" (P1). • "God it has flooded a lot" (P3). • "I love your photos I think loads of people do" (P8).

6.1.5 Flood Risk Management (Table 7)

This section aimed to deliver a clear explanation of how flood risk has been managed in Skipton, with a focus on the specific measures implemented as part of the 2015 Flood Alleviation Scheme. Participants commented that a stronger explanation was required here, similar to comments in the 'What Causes Skipton to Flood? 'section, for users to understand how flooding infrastructure has reduced the risk of flooding. For example:

"And then maybe like link that kind of back to the flood routing that's in the causes bit, to again, to make it clearer for people why they work and how they work and why capturing that water there makes a difference." (P3)

Spatially it was easier to represent the in-town defences as these can be displayed on the lower map in the simulator, therefore these were more easily identified and understood.

"The town defences are, so that so you can see those ones quite easily." (P5)

Since the FSRs are located out of town, they cannot be displayed on the original 3D model nor the simulator, creating difficulties in conveying their location. One participant commented:

“Eller beck flood storage reservoir. So personally, I'm struggling to see where it is.” (P8)

This issue relates to the overall challenge of visualising the relative location of anything off the 3-dimensional model. Even though the FSR locations were unclear in the simulator, it is vital to include them in the Skipton PARM narrative as they comprise an important aspect of the flood alleviation scheme.

Although there was some confusion as to the FSRs’ location, the drone images of the FSRs from above provided useful contextual imagery so that the users could still see what the structure look like in-person. A line of investigation in the Stage 2 survey will be to consider public knowledge of specialist techniques such as FSRs.

“I kind of knew about the storage reservoirs out of town but I didn't know much about them so it's quite interesting to see them.” (P1)

Flood storage can be defined as the temporary detention of flood water, capturing peak flow to reduce the likelihood of extreme volumes of water passing downstream and causing rapid inundation in the lower catchment. Flood storage approaches have increasingly been adopted in England as part of more holistic and integrated approaches to manage water environments (Watson and Howe, 2006). Tools like the PARM simulator can be used to address the ‘social dislocation’ problem, often associated with flood storage techniques (McCarthy *et al.,* 2018). Conflicting interests occur as the upstream landowners are forced to make sacrifices to benefit downstream communities, and the downstream communities can be unaware of how these preventative measures work (Haupter *et al.,* 2005; Thaler, 2014). Public consultation exercises could widely utilise the PARM simulator tool to assist cooperation between stakeholders and promote understanding of how catchment management techniques such as FSRs work.

Table 7. Summarised feedback for the 'Flood Risk Management section.

Code 1 **Positive**	• Knew of the reservoirs but it is nice to be able to see them (P1). • Clear drone image (P2). • Can see the in-town defences easily on the map (P5). • Bullet text (slide 28) is the right amount (P8).
Code 2 **Constructive**	• Further explanation needed if this was to be a stand-alone public display (P2, P4). Need to make clear why capturing water makes a difference (P3). • Storage reservoirs could be clearer on the bottom map (P3). • Slide 31 – not necessary. • Slide 28 – too much text. (P6).
Code 3 **Suggestive**	• Would be interesting to see a time sequence to show the reservoir impact (P1, P2). • Try and avoid acronyms or abbreviations (e.g. FSR) (P6). • Add scale, e.g. '50 miles away' (P8).
Code 4 **Functional**	• "Is it supposed to show me on the 3D model where those defences are?" (P5). • Cannot see where reservoirs are (P8).

6.1.6. Predicted Flooding (0.1% AEP etc) (Table 8)

Here, a series of modelled flood scenarios were used to visually demonstrate flooding extent at different scales across Skipton. Participants found these slides visually "interesting". One of the most commonly discussed points was the use of technical language. Most participants agreed that the use of Annual Exceedance Probability (AEP) would be the best route to communicate flood magnitude. Even though AEP is more commonly used than return period language (Beven *et al.,* 2015), some participants suggested that both could be incorporated or that perhaps return periods (1 in 100-year flood) would be a more understandable alternative.

"The general public don't seem grasp terms like 1 in 100-year event. Annual exceedance probabilities are a bit easier to grasp." (P3)

"Saying 1 in 100 years is a good way of maybe making it more understandable, but it doesn't stop you thinking it might only occur once." (P1

"All our documents are AEP now; you almost need both there." (P2)

It will be interesting to see how feedback on language used in the simulator may differ in Stage 2. Standalone PARM systems such as the simulator or a stand-alone display may need to incorporate a brief section where predictive terms like AEP and return periods are explained explicitly to ensure they have been understood.

Two participants suggested that there would be benefit in connecting this content back to the previously identified 'Local Landmarks' for consistency, helping users re-orientate as well as connect these landmarks to the areas now 'at risk' in each shown scenario.

"Can you connect it back to the landmarks you have already defined?" (P1)

The participants also remarked that this section would be ideal to incorporate more specific socio-economic information, such as the value of areas at risk or the estimated cost to rebuild after each flood scenario. Reasoning here was that the general public prefer the use of 'cost' to help understand impact and heighten flood risk perception.

"People understand costs." (P6)

It was also suggested to incorporate an example of a 'comparison event' using one of the examples from the 'Historic Flooding' to then show exactly which areas were flooded at that point in time. Another comment was made suggesting the addition of a new section, subsequent to this one that explains what someone could do to reduce their own personal flood risk. For every PARM simulator location, more local information regarding risk preparedness could be included.

Add "Okay now you're aware of the risk what are you gonna do about it, here are the options. Here are the things you can do." (P3)

From a design perspective, the blue-scale colour scheme used for the flood inundation was critiqued as it was 'unclear'. Blue is the universally adopted colour used to depict water in maps (Tyner, 2010) and the 'Predicted Flooding' colour scheme has been made using maximum colour contrast as recommended by Levkowitz and Herman (1992).

However, problems in colour differentiation could be addressed using hatching or patterns within each AEP model to make distinguishing between each data set easier. As the PARM's popularity and adoption grows, it would be worthwhile to have alternative content presentation, where maps are coloured inclusively to account for multiple colour-blindness conditions, such as tritanomaly (a reduced sensitivity to blue light). A potential alternative to the blue-scale colour scheme could be yellow-orange-red, as this would still convey flood hazard, and has been used previously in the Keswick PARM.

"It's really hard to differentiate between the blues." (P5)

Table 8. Summarised feedback for the 'Predicted Flooding' section.

Code 1 **Positive**	• Saying 1 in 100 years is a good way of maybe making it more understandable, but it doesn't stop you thinking it might only occur once. (P1). • "All our documents are AEP now, you almost need both there" (P2). • AEP is "a really nice way to put it" (P4). • Very clear what is being shown and what areas are at risk (P3, P4). • The general public don't seem grasp terms like 1 in 100-year event. Annual exceedance probabilities are a bit easier to grasp." (P3). • Very visually interesting (P8). • Be mindful of return period language, some people prefer both (P7).
Code 2 **Constructive**	• Downstream Boundary Conditions' – again to 'jargon-y. Is this necessary? (P4). • Diagrams would be clearer than aerial photos (P6).
Code 3 **Suggestive**	• Would be helpful to bring back some of the landmarks from the beginning – to give consistency/know where you are on each map (P1). • Give an example of a comparison event (P1). • Can you connect it back to the landmarks you have already defined, say how 'under threat' each area is. (P4). • Add a key for 'red' and 'blue'. (P4). • Think of a different colour rather than 4 blues? (P4). • Slide 40 – stick with the same shades of blue on the previous maps to make it clearer (P6). • Explain value/economic importance of the areas being flooded. People understand costs (P6).
Code 4 **Functional**	• "Is this automatic?" (P1). • "It's really hard to differentiate between the blues" (P5).

Code 5 **Emotive**	• "It's good to make people understand that it cannot be completely fixed, there is a residual chance of things happening. If the public see we are doing flood works they think it's never going to happen again" (P3). • Add "Okay now you're aware of the risk what are you gonna do about it, here are the options. Here are the things you can do" (P3). • Knowledge about modelling is good, although it has its uncertainties it is the best representation (P7). • "This is the whole purpose of what the work has been about" (P8).

6.1.7 Scenario Animations (Table 9)

The 'Scenario Animations' slides compared the extent of flooding with and without the flood defences in Skipton, the scale of the flood modelled was 0.1% AEP. Initially, participants identified a need to specify which AEP was being modelled on each slide and to include a more formal introduction to the comparison. Participants commented that it "works really well" as a way of capturing the public's imagination.

"It's very visual, people will understand it." (P8)

Functional issues with the PARM simulator were identified. In some cases, participants were confused by the automatic running of the animations themselves and did not know if they should be expecting sound from the videos. Here, discussions once again arose over the use of audio across the simulator. Audio narration has been using in digital storytelling (DST) to enhance user experience for decades; in narrated virtual exhibits in museums for example (Pantile *et al*., 2016; Rizvic *et al*., 2012). The PARM simulator is a story that 'informs and instructs' according to Robin's (2006) classification and could be used to support the educational use of DST. The implementation of audio is beyond the scope of this research project but would be an interesting line of investigation for future work to enhance the 'story-telling' nature of an online PARM simulator. In particular, the use of audio would likely benefit any completely standalone version of a PARM model.

Generally, the visual aspects in this section were received positively.

"It brings it all into context, it's a really big problem you've got to solve. Visualization is brilliant in education for the public." (P7)

It was suggested that, if possible, an overlay of both maximum flood extents should be included at the end of this section for clarity.

Table 9. Summarised feedback for the 'Scenario Animations' section.

Code 1 **Positive**	• The comparison between no defences and defences works really well (P1). • Video length is fine – would give a presenter enough time to talk through it (P5). • The animations are good, they capture the public's imagination (P7).
Code 2 **Constructive**	• Difficult to work on where on the map you are (P1). • There is no introduction to the fact that you are presenting a comparison (P4). • "Is this for a particular AEP?" (P4). • The general public might need a bit more information (P5). • Does that mean with additional defence? Which % scenario? (P8).
Code 3 **Suggestive**	• Pose a new introductory question 'So what difference do the FSR's make?' (P4). • Change colour of text to make comparison clearer, red for undefended and green for defended (P4). • Overlay the colours at the end to show which areas have the most benefit (P5). • Put this after flood management section (P8).
Code 4 **Functional**	• "How do I make the animations go?" (P4). • "Should there be any sound?" (P5).
Code 5 **Emotive**	• "It's trying to get that education across. They're designed to a certain standard and they could be superseded, and you could still flood" (P7). • "It brings it all into context, it's a really big problem you've got to solve. Visualization is brilliant in education for the public" (P7). • "It's very visual, people will understand it" (P8).

6.1.8 General Comments (Table 10) and Recommendations

Discussion regarding the overall usability and impact of the PARM simulator emerged naturally through the interviews. Common usability issues that arose through this expert review included changing the maps into 3D, altering visual colouration and adding a more detailed explanatory narrative.

"In its current state it needs someone to present it, give context to everything." (P2)

Expert comments reconfirmed the impact potential this communication tool possesses, with one participant originally involved with the Skipton flood alleviation scheme commenting:

"This would have been useful at the time for consultation with locals." (P2)

Others commented on the importance on public engagement and the wider potential to use this online format.

"Educating the public and public engagement is really important, and something that visually captures their imagination as well is great." (P7)

"Get this online as well as the 3D models, that would be something quite new, and something that you could then disseminate a lot wider." (P5)

"A better application for it would be a website." (P8)

The PARM online format, as mentioned in P5's comment, would be more easily disseminated than the physical PARM, for example to community members who were unable to access in-person public consultation events. PowerPoint was chosen as a simple method to transfer the original PARM content online, P8 commented that it could be applied fully to a website format instead. The COVID-19 pandemic has been unpredictable in many ways, forcing educational institutions to alter existing practices and move to online teaching (Bryson *et al*., 2020; Horton, 2020). In a climate where the 'switch to online' is dominating communication pathways, this offers a challenging but exciting opportunity to develop highly effective online resources. Public consultation as part flood risk management does not need to suffer as a result of the pandemic; online tools such as the PARM could offer a chance to ensure these kinds of stakeholder engagement exercises can continue.

Table 10. Summarised feedback for the 'General Comments' on user experience.

Code 1 **Positive**	• This would have been useful at the time for consultation with locals (P2). • "It seems to run through nicely and logically" (P4). • "I think education and educating the public and public engagement is really important, and something that visually captures their imagination as well is great. Every opportunity to make somebody thing about climate change is a good thing" (P7). • Have chaptered it well (P8).
Code 2 **Constructive**	• The screen version is very different to the model (P2). • "In its current state it needs someone to present it, give context to everything" (P2). • "The colouration needs a tweak, but someone approaching it would understand that" (P5). • Anything over 5 minutes for children is too much (P6). • 42 slides is a lot (P6). • At the moment it's not a story (P6). • Using PowerPoint – expected the whole thing to be scrolling through sequentially (P8).
Code 3 **Suggestive**	• Adding links to sign up for flood alerts would be great (P2). • It would help to bring back the 3D element to it (P3). • Need to cater for technical/non-technical audiences (P4). • The introduction slide is critical (P6). • Modify all maps into 3D – this will achieve a higher level of engagement. (P6). • Ensure the graphic focus is in the slide centre (P6). • Make it short/engaging/fun (P6). • Should flood risk management come after predicted flooding? (P8). • A better application for it would be a website (P8).
Code 4 **Functional**	• "Would they just play it through themselves?" (P6).
Code 5 **Emotive**	• People are always really interested in the 3D models so they can see how flooding works in their local area (P5). • It is important to talk to the public – they have information they can tell you (P5). • "It's a great idea, for a lot of the projects we do we don't have anything like this" (P3). • "Get this online as well as the 3D models, that would be something quite new, and something that you could then disseminate a lot wider" (P5). • Contents page feels like a website map (P8). • Seeing the pictures of flooding and how catastrophic it can be – the most important thing (P8).

The Stage 1 interviews were successful in providing a range of feedback to be implemented into the simulator prior to Stage 2. The ‘experts’ who participated have made several suggestions on how to modify the content and narrative of the PARM simulator for a non-technical audience. Table 12 explains the recommended changes, and which were possible to implement for Stage 2. Changes that involved existing simulator content were prioritised. Recommended changes in red required either additional model data or more substantial changes that were considered beyond the scope of this project but will be factored into the recommendations for future PARM display content.

Table 11. Recommended alterations to PARM simulator from Stage 1 expert review. This table shows which points were possible to change (green) and which were not (red).

Development of Skipton	• Elongate transition time gap to 7 seconds • Declutter slide 1 • Digitise rivers on all historic maps • Explain this sequence is self-animated.	
Local Landmarks	• Add 'canal' as local landmark • Keep each landmark on screen as user moves to the next • Add key for infrastructure	
What Causes Skipton to Flood	• More explanations onto all slides • Emphasise importance of the Eller Beck – canal convergence. • Increase size of arrow indicating the Waller Beck tributary • Make whole section click through for consistency.	
Historic Flooding	• Move this section to before 'What causes' • Add more images of 2015 flood event • Explain this sequence is self-animated.	
Flood Risk Management	• Reduce text on slide 28 • Add slide to explain how FSRs work with hydrograph. • Add definitions for key terms, e.g. culvert and headwall. • Explain that these defences may still be superseded	• Explain that these defences may still be superseded
Predicted Flooding	• Re-visit the local landmarks • Add key for 'red' and 'blue' • Add slide talking about climate change – the relevance of increasing risk.	• Give comparison event. • Alter colouration (blues) • Quote economic value of areas at risk
Scenario Animation	• Use introductory question and slides to highlight the comparison. • Alter text colour heads for 'defended' and 'undefended'	• Overlay the end results of the animations to show the difference
Overall	• Overall more narration is needed. • Add final slide giving users the opportunity to sign up to their local flood alert scheme.	• Change all maps to a 3D representation

6.2 STAGE 2: RESULTS AND DISCUSSION

The survey was used in Stage 2 to critically analyse the acquisition of geographical knowledge and quality of user experience from the modified PARM simulator. It was expected for the results in Stage 2 to differ somewhat from Stage 1 as a greater sample size was used, and those who participated in the survey were not anticipated to be technical experts or have any prior knowledge of environmental management.

6.2.1. General Information and respondent profiles

The survey received 37 total responses. Respondents had a mixed profile (Table 12), with a nearly even proportion of ages, most respondents were between the ages of 40 – 60 (30%). 35 respondents gave their 'occupation' classification, around one third of respondents were students and over 50% of respondents were either in full or part-time employment.

39% of total responses (14 respondents) said that the respective participants were familiar with Skipton in some way (Table 13), the other 61% of responses said they were not. 43% (6) of those 'familiar' with Skipton also said that they had 'personally experienced a flood event in Skipton'. Meaning 16% of total survey respondents had personally experienced a Skipton flood first-hand. Statistical tests have been applied to the results of some questions in order to investigate if there are significant differences in the user experience between those 'familiar' with Skipton and those who were not.

Table 12. Respondent profile from survey.

Variables	Response count	Percent
Age		
18 – 24	10	27
25 – 39	9	24
40 – 60	11	30
60+	7	19
Occupation		
Full-time employed	14	40
Part-time employed	6	17
Not employed for pay	2	6
Full-time Student	10	28
Other	3	9

Table 13. Respondents familiarity to Skipton.

Familiarity to Skipton	Response Count	Percent (all survey responses)
I live there	3	8
I have lived there	2	5
I live in the nearby area	2	5
I have visited Skipton before	5	14
I have never visited Skipton before	2	5

6.2.2 Likert and rating survey responses in relation to user-experience

Respondents were asked to what extent they agreed or disagreed with a series of statements in relation to their overall PARM simulator experience; to gain a snapshot of overall usability. As seen in Figure 25, evidence of an overall positive user experience was found. 94% of respondents either agreed or strongly agreed that they were able to understand all language used in the simulator. 91% also agreed that the explanations on each slide were easy to understand. 97% strongly agreed or agreed that the order of contents in the simulator was logical, with the other 3% of respondents neither agreeing nor disagreeing with the statement, indicating no negative attitudes towards the narrative order of the simulator. In reaction to 'the maps used were clear' statement, only 82% strongly agreed or agreed with this, leaving 18% who neither agreed or disagreed or disagreed somewhat. 9% of respondents disagreed that the 'local landmarks' helped with self-orientation, and 23% of respondents had no significant feelings (neither agreed or disagreed) to the statement 'images of previous flooding events were emotive and made an impact on me.

The 'jargon' terms from the 'What Causes Skipton to Flood?' section were addressed prior to the survey distribution as this was highlighted as an issue by the experts in Stage 1. Therefore, the content needs to be reassessed for complex language. Even though only 3% of respondents disagreed with 'the language was clear', there should be no room for language to act as a barrier to learning from the PARM. These results showed that generally the PARM narrative was logical and easy to understand. The experts may have overpredicted the success and impact of the 'images of previous events' as this statement received the highest proportion (23%) of indifferent (neither agree nor disagree) votes. This could be since the general public are very familiar with this type of imagery and experience flood fatigue, or the responses evoked were not 'emotional' as phrased by the statement.

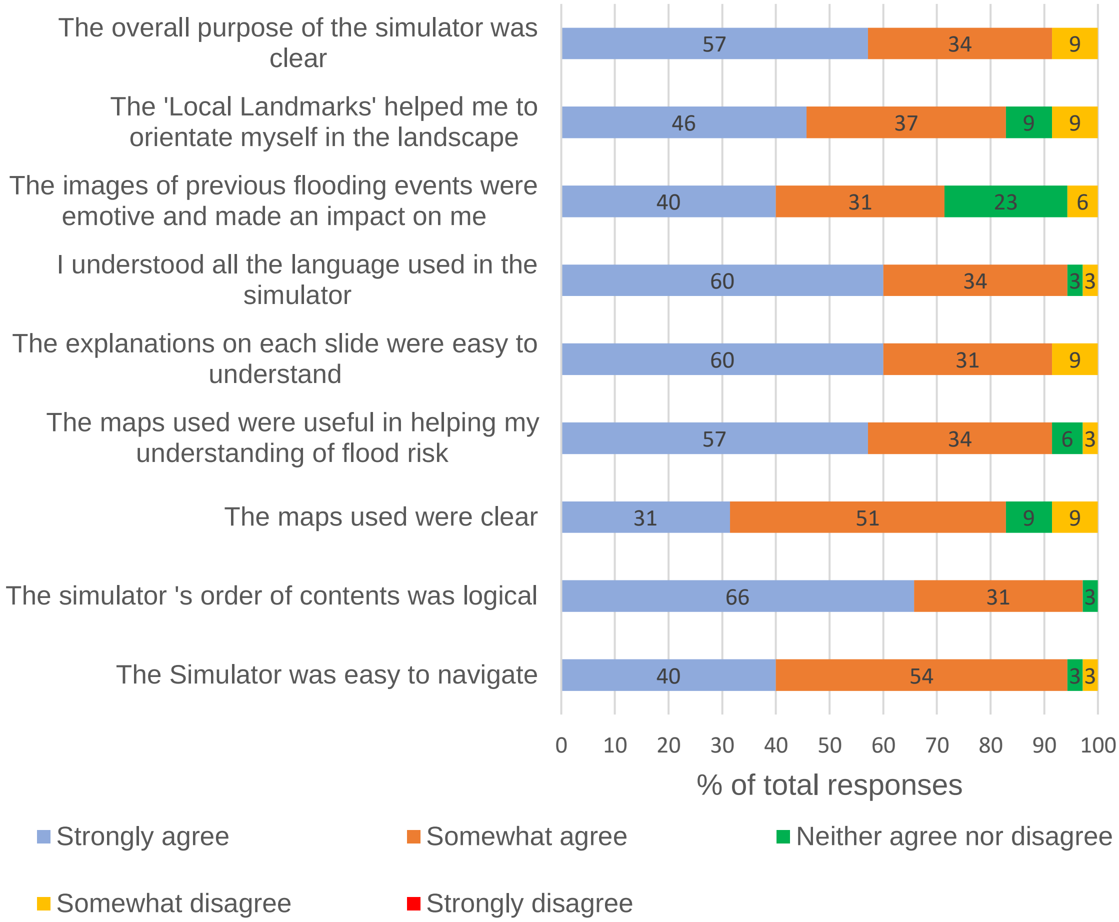


Figure 25. Graph to show % of total responses of agreement for each statement.

Respondents were asked to rate the seven key content areas of the PARM Simulator, according to which section they found the most engaging. Sections were rated where '1' was the most engaging and '7' was the least (Table 14). With a mean rating of 2.94, the 'What Causes Skipton to flood?' can be concluded as the "most engaging", narrowly followed by the 'Historic Flooding' and 'Predicted Flooding' with mean ratings of 3.31 and 3.34 respectively. The highest rated, on average, also had the lowest standard deviation, evidencing that this was consistently rated high by participants. The mean rating for the 'Local Landmarks' (5.29) suggests that overall participants found this section the least engaging. The 'Development of Skipton' was the second least favourable.

Looking at the % of total counts for each rating reveals more about user preference towards each section (Table 15). 25.71% of respondents rated the 'Historic Flooding' as '1', the same with 'Predicted Change'. Although only 17.14% of respondents rated 'What causes Skipton to flood' as '1', this section had high rating percentages for places 1, 2 and 3. 'Flood risk management' was the 4th most 'engaging' section according to the mean rating, it was the only section to get 0% of a '1st' rating. 11.43% of respondents rated 'Development of Skipton' as '1', yet this section's mean rating (6.63) was lower (worse) than 'Flood risk management'.

A Mann-Whitney U test was performed to assess whether mean ratings differed significantly between those familiar with Skipton and those who were not (Table 16). It was expected that lower mean scores would be received from those familiar with the area, meaning that respondents familiar with the area would find all PARM simulator content to be more engaging. In all cases, the p values exceeded the set alpha value of 0.05, indicating that the ratings between the two groups for each thematic section did not differ significantly. This result indicates that those who were not familiar with Skipton were not hindered when interacting with it by their lack of familiarity. This is an interesting outcome as it indicates that the narrative is not particularly biased to those with 'familiarity' and is accessible to a wider audience, not limited to those who know the case study area presented in the online simulation.

In order to compare the individual categories of data from this survey question, a Kruskal-Wallis test was used. The results from this test indicated that there was a significant difference across the groups (Table 17). To look for specific differences between the mean engagement ratings of thematic sections, a post-hoc test was applied (Table 18). In two cases, the p value (Adj. Sig column) indicated that pairings were significantly different. This was the case when comparing the 'Historic Flooding' with 'Local Landmarks' and comparing 'Predicted Flooding' with 'Local Landmarks'. The 'Local Landmarks' section performed the worst in terms of mean engagement rating and was significantly less engaging than the two other content sections mentioned above. The implication of this result for future PARM narratives may be to consider alternative slide design to make this section more engaging, or whether this section is necessary altogether.

Table 14. Table showing the average mean rating of ‘engagement’ for each thematic section of the PARM simulator.

Section	Minimum	Maximum	Mean	Std Deviation (SD)	Variance (σ^2)
Development of Skipton	7.00	1.00	4.63	1.99	3.95
Local Landmarks	7.00	1.00	5.29	1.98	3.92
What causes Skipton to flood	7.00	1.00	2.94	1.42	2.05
Historic flooding in Skipton	7.00	1.00	3.31	1.89	3.59
Flood risk management in Skipton	7.00	2.00	4.14	1.43	2.01
Predicted flooding (% chance)	7.00	1.00	3.34	2.06	4.23
Scenario Animations	7.00	1.00	4.34	2.01	4.05

Table 15. Table showing the % of total counts for each engagement rating (1 – 7).

	% of total counts for each rating						
Section	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Development of Skipton	11.43% (4)	5.71% (2)	11.43 % (4)	17.14 % (6)	11.43 % (4)	20.00 % (7)	22.86 % (8)
Local Landmarks	11.43% (4)	0.00% (0)	8.57% (3)	8.57% (3)	8.56% (3)	25.71 % (9)	37.14 % (13)
What causes Skipton to flood	17.14 % (6)	22.86 % (8)	28.57 % (10)	20.00 % (7)	5.71% (2)	2.86% (1)	2.86% (1)
Historic flooding in Skipton	25.71% (9)	17.14 % (6)	8.57% (3)	17.14 % (6)	14.29 % (5)	14.29 % (5)	2.86% (1)
Flood risk management in Skipton	0.00% (0)	17.14 % (6)	20.00 % (7)	14.29 % (5)	31.42 % (11)	14.29 % (5)	2.86% (1)
Predicted flooding (% chance)	25.71% (9)	20.00 % (7)	11.43 % (4)	11.43 % (4)	8.57% (3)	14.29 % (5)	8.57% (3)
Scenario Animations	8.57% (3)	17.14 % (6)	11.43 % (4)	11.43 % (4)	20.00 % (7)	8.57% (3)	22.86 % (8)

Table 16. Data from Mann-Whitney U tests comparing the mean rating for each thematic section between respondents who were familiar with Skipton and those who were not.

	Thematic Section	Familiar with Skipton	n	Mean	Mann-Whitney U	Wilcoxon W	Asymp. Sig (2 tailed)	Exact Sig [2*(1-tailed Sig.)] (p)
1	Development of Skipton	Yes	13	4.77	130.500	383.500	.665	.674
		No	22	4.54				
2	Local Landmarks	Yes	13	5.70	127.00	380.00	.571	.601
		No	22	5.05				
3	What Causes Skipton to Flood	Yes	13	3.15	128.500	381.500	.612	.625
		No	22	2.82				
5	Historic Flooding	Yes	13	3.80	115.000	368.000	.331	.353
		No	22	3.05				
5	Flood Risk Management	Yes	13	4.40	121.000	374.000	.441	.468
		No	22	4.00				
6	Predicted Flooding	Yes	13	2.70	106.000	197.000	.199	.216
		No	22	3.73				
7	Scenario Animations	Yes	13	3.54	92.000	183.000	.077	.085
		No	22	4.82				

Table 17. Results from Independent-Samples Kruskal-Wallis test.

Total N	245
Test Statistic	36.650[a]
Degree of Freedom (df)	6
Asymptotic Sig (2-sided test)	.000

Table 18. Post hoc pairwise comparison from Kruskal-Wallis test. Each row tests the null hypothesis that distributions in each sample are the same. Asymptotic significances (2-sided tests) are displayed, the significance level is .050.

[a] Significance values have been adjusted by the Bonferroni correction for multiple tests

Comparison Pairings	Test Statistic	Std. Error	Std. test Statistic	Sig.	Adj. Sig[a]
What Causes – Historic	13.000	16.767	.775	.438	1.000
What Causes – Predicted	14.000	16.767	.835	.404	1.000
What Causes – FRM	42.000	16.767	2.505	.012	.257
What Causes - Scenario	49.000	16.767	2.922	.003	.073
What Causes – Development	59.000	16.767	3.519	.000	.009
What Causes –Landmarks	82.000	16.767	4.890	.000	.000
Historic – Predicted	-1.000	16.767	-0.60	.952	1.000
Historic - FRM	29.000	16.767	1.730	.084	1.000
Historic – Scenario	36.000	16.767	-2.147	.032	.668
Historic – Development	46.000	16.767	2.743	.006	.128
Historic – Landmarks	-69.000	16.767	-4.115	.000	.001
Predicted – FRM	28.000	16.767	1.670	.095	1.000
Predicted – Scenario	-35.000	16.767	-2.087	.037	.774
Predicted – Development	45.000	16.767	2.684	.007	.153
Predicted – Landmarks	68.000	16.767	4.055	.000	.001
FRM – Scenario	-7.000	16.767	-.417	.676	1.000
FRM – Development	17.000	16.767	1.014	.311	1.000
FRM – Landmarks	-40.000	16.767	-2.386	.017	3.58
Scenario – Development	10.000	16.767	.596	.551	1.000
Scenario – Landmarks	33.000	16.767	1.968	.049	1.000
Development - Landmarks	-23.000	16.767	-1.372	.170	1.000

Respondents were asked to mark out of 10 how easy it was to understand different representations of catchment information on the simulator (where 1 is very difficult and 10 is very easy). All mean ratings collected were higher than 7.0. Figure 26 demonstrates the mean ratings assigned to each category. Although the 'Local landmarks' was rated poorly in the 'engagement' question, the mean rating of 8.91 here suggests that this section was still effective in conveying spatial information and providing a clear frame of reference as the highest rated feature. 'Where flooding is likely to occur' held the second highest mean rating in this question (8.57), confirming that combined impact of the 'Predicted flooding' and 'Scenario animations' was enough to clearly represent areas 'at risk' from flooding.

The loss of 3D elements in the simulator may explain the lower mean rating (7.97) for 'where water flows'. Without the 3D model itself, the content is restricted to only conveying the lie of the land through 2D imagery (a contour map), therefore the direction of flow may not be as easy to understand. As recommended in Stage 1, a more explicit representation of water flow, designed for 2D, may be required. From this question, 'Land use and infrastructure' were rated as the most difficult to understand (7.71), this is likely a product of missing information and issues with graphic sizing on the simulator.

Table 19 shows the results from a Mann-Whitney U test between those familiar and unfamiliar with Skipton. It was expected to find higher mean scores from those familiar with the area, anticipating that respondents familiar with the area would find PARM information easier to understand. In all cases, statistical analysis shows that there is not a significant difference between the means of those familiar and unfamiliar with Skipton. Although the mean values across the 2 groups were not statistically different, it is worth noting that the mean score for every category of catchment information is higher for the 'familiar' group. This may be due to those familiar with Skipton having a stronger geographical knowledge of the area making it easier to understand how frequently ‘places are likely to flood’ given their frame of reference. A Kruskal-Wallis test was performed to compare categories of data relating to how easy it was to understand the information. Further comparisons using a post-hoc test was not performed because the overall tests did not show significant differences across the category samples (Table 20).

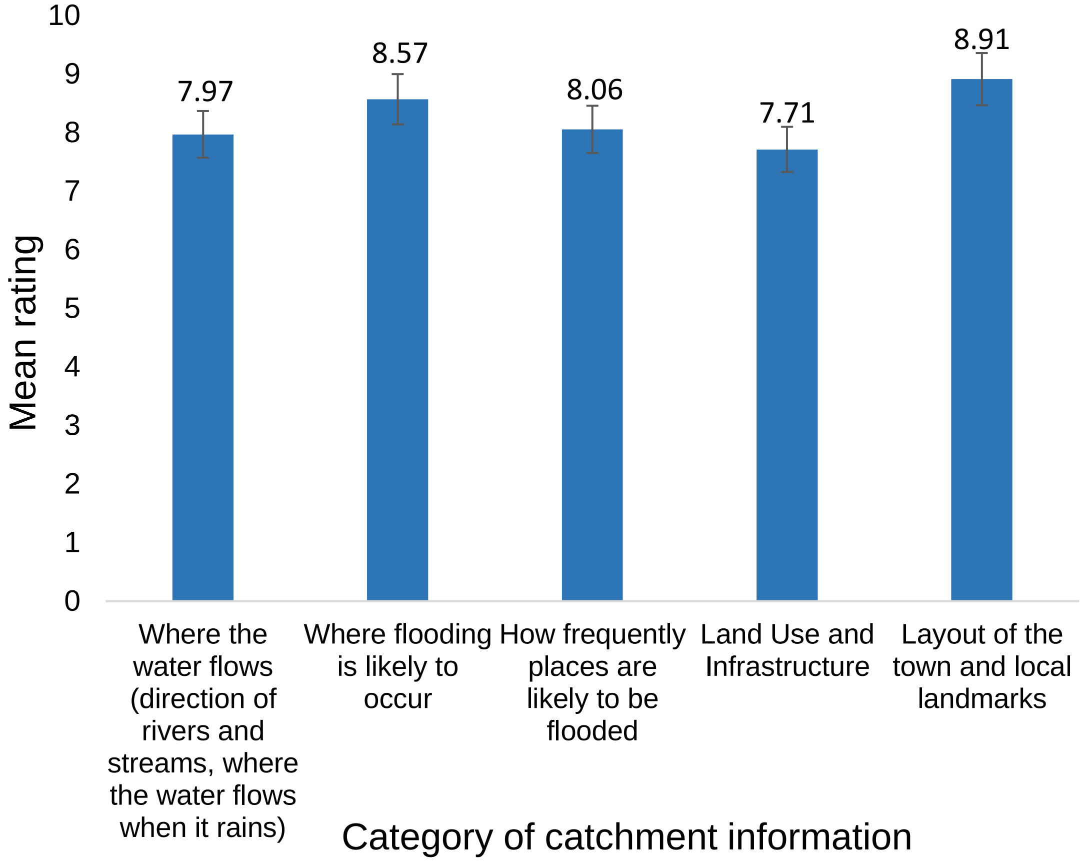


Figure 26. Mean rating out of 10 for all responses on how “easy it was to understand different representations of catchment information” (where 1 is very difficult and 10 is very easy). Error bars showing 95% confidence intervals have been included.

Table 19. Data from Mann-Whitney U test comparing the mean rating for each category of catchment information between respondents who were familiar with Skipton and those who were not.

	Familiar with Skipton	n	Mean	Mann-Whitney U	Wilcoxon W	Asymp. Sig (2 tailed)	Exact Sig [2*(1-tailed Sig.)]
Where the water flows	Yes	13	8.30	121.500	374.500	.449	.468
	No	22	7.77				
Where flooding is likely to occur	Yes	13	8.92	110.000	363.00	.241	.271
	No	22	8.36				
How frequently places are likely to be flooded	Yes	13	8.46	116.000	369.000	.340	.371
	No	22	7.82				
Land use and infrastructure	Yes	13	8.00	106.500	359.500	.203	.216
	No	22	7.45				
Layout of the town and local landmarks	Yes	13	8.80	91.00	344.000	.066	.079
	No	22	8.10				

Table 20. Results from Independent-Samples Kruskal-Wallis test.

Total N	175
Test Statistic	8.238
Degree of Freedom (df)	4
Asymptotic Sig (2-sided test)	.083

The final rating question assessed the simulator content designed to help users understand local flood risk in Skipton (Table 21). Respondents reported that seeing how frequently different flood events are likely to occur was the most helpful in understanding flood risk. This category received the lowest mean (1.74) rating and the highest count of ratings in 1st place (19 counts) (Figure 27). The other two content categories had similar mean ratings, with the models of scenario animations being the highest rated (2.19) and therefore the least useful in understanding flood risk. From these results, it seems that the frequency of flood events (% AEP) information was the most useful in understanding flood risk. These results were expected as flood inundation mapping using AEP is a very common method of risk communication, and therefore respondents may have seen this form of information presentation before. A Kruskal-Wallis test was performed to compare categories of data, but the overall tests did not show significant differences across the categories (Table 22), and therefore further comparisons using a post hoc test were not performed. Even though mean ratings provide some insight into the most important types of information in aiding comprehension of flood risk, it cannot be concluded that one category was statistically significantly more helpful than the others.

Table 21. Mean rating from 1-3 for all responses on which content was most "helpful in understanding flood risk in Skipton" (where 1 = most helpful and 3 = least helpful).

Content	Mean Rating	Std Deviation	Variance	Count
Catchment factors: the catchment shape, river tributaries and direction of rainfall, the canal/Eller beck overspill	2.06	0.80	0.64	31
Seeing how frequently different sized flood events are likely to occur (e.g. 0.1% AEP, 1% AEP, 5% AEP etc)	1.74	0.95	0.90	31
Seeing the modelled animation of both the undefended and defended flood scenarios	2.19	0.59	0.35	31

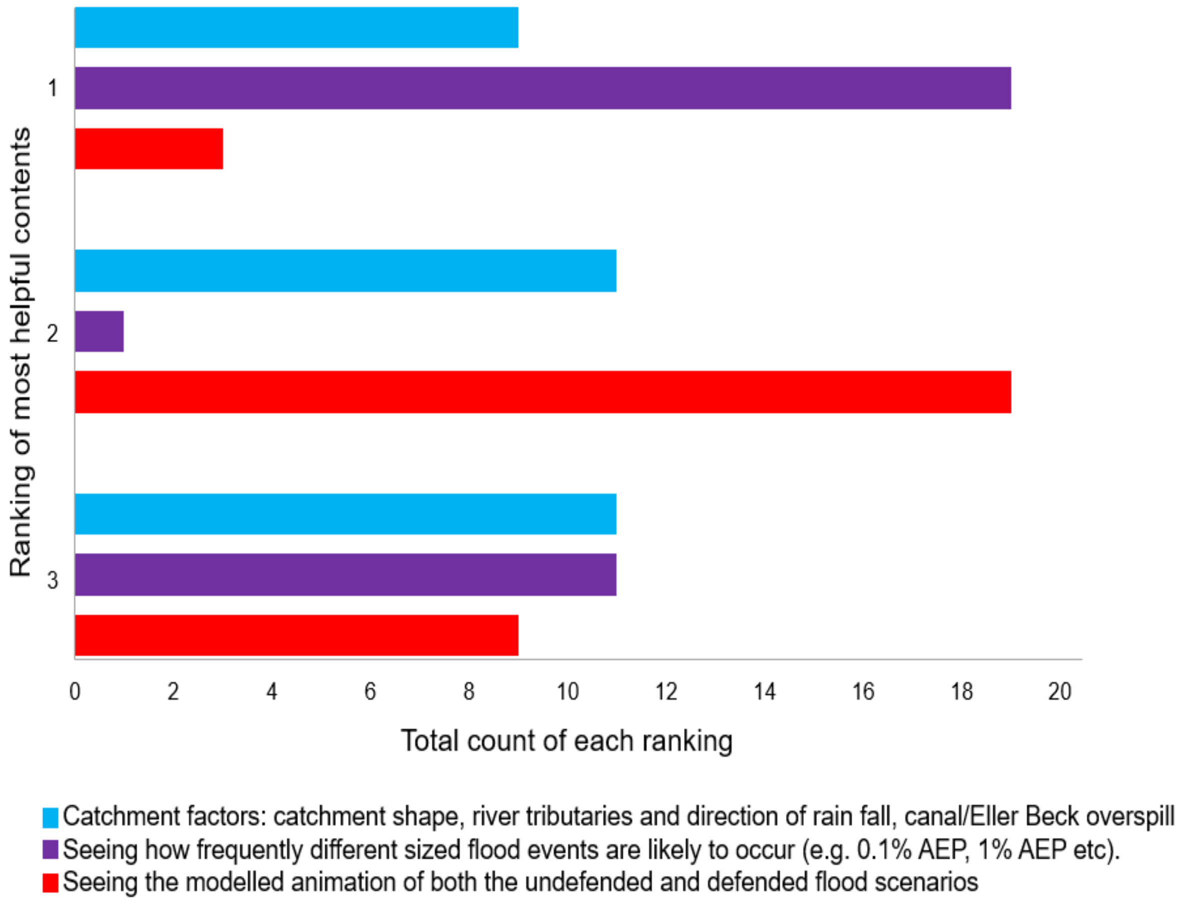


Figure 27. Graph visualising total rating counts of each content section.

Table 22. Results from Independent-Samples Kruskal-Wallis test.

Total N	93
Test Statistic	4.978
Degree of Freedom (df)	2
Asymptotic Sig (2-sided test)	.083

6.2.3 Survey answers to open questions

A series of open questions were incorporated into the survey to gain more specific insights into user experience. The results from each open question have been tabulated and presented in thematic clusters that were determined from node analysis in NVivo. Dominant codes (i.e. codes with the highest number of significant excerpts assigned to a code) have been listed at the top of each retrospective cluster. The first open question was "What was the most interesting or surprising thing you learnt by using the PARM Simulator?" (Table 23)

Overall, responses to this question showed that respondents found information that was Skipton-specific the most interesting or surprising. Five responses claimed that the specific catchment characteristics which lead to flooding were the most interesting. The role of the canal in Skipton was also a popular theme. The importance of the canal-Eller Beck interface has been previously discussed and the simulator content was modified after Stage 1 to covey the importance on the canal more effectively (Section 6.1.3). The fact that respondents have picked up on this as an interesting or surprising feature is a testament to the simulator's capacity to convey information through storytelling, with the most important aspects of Skipton's flood risk scenario not being missed out.

Some respondents highlighted how the imagery and depiction of flood events ('Predicted Flooding' and 'Scenario Animations') were the most interesting aspects learnt from the simulator. These results correspond to the favoured rating of those sections in previous survey questions as discussed in section 6.2.2. Other responses mentioned that learning about flood risk and FRM more generally and in an accessible way was the most interesting/surprising thing learnt from the simulator. 'Accessible' here could relate to either the clarity of information presented or the use of an online medium for dissemination, both are positive. 'Accessibility' is crucial for effective risk communication tools, the feedback from this question suggest that the PARM simulator has been able to foster learning in an easy and engaging way.

Table 23. Thematic cluster analysis of open question answers regarding 'interesting' or 'surprising' features learnt from interaction with the PARM simulator.

Cluster 1: *Skipton PARM specific*	Cluster 2: *PARM graphic content*	Cluster 3: *Broader FRM understanding*
• Skipton catchment characteristics that cause flooding **(5)** • Role of the canal for Skipton **(3)** • Variation of flood extent (% chance) **(3)** • Existence of FSRs **(3)** • Historic flood images **(1)** • How 'image and story combined to bring an issue to life' **(1)**	• Defended vs undefended graphics 'were the most impactful imagery' **(2)** • Interactive potential of PowerPoint **(1)** • Slide 27 **(1)** • Useful to see in 'picture form' **(1)** • Visualisation of flood events **(1)** • Imagery to see how Skipton has developed around flood risk **(1)**	• Learning about flood risk **(3)** • Understanding FRM in an accessible way **(2)** • Flooding remains an issue even after management has been put in place **(2)** • Development of flood risk over time **(1)** • How flood modelling works/its effectiveness **(1)** • Risk to flooding from climate change **(1)**

Respondents were asked "What information was missing (if any) from the simulator that is needed to understand flood risk more generally?" (Table 24). From the results in cluster 1 more detailed data was required to help understand flood impact such as: economic impact, damage to infrastructure, personal data, and average flood depths of previous events. Here it seems respondents were seeking more information about previous events to help make comparisons to the modelled scenarios in the simulator and understand the scale of impact these larger floods could have. Interestingly, 'personal accounts of flood risk' was suggested; the inclusion of personal stories could be used to recount impacts of previous flood events, or as an example of what homeowners may to do reduce personal flood risk. These suggestions can be acted upon as fine details and impact data can be tailored to each PARM simulator if known.

Alongside a few specific missing graphic content points, the concept of clearer colour coding and larger maps on the PowerPoint was raised by survey respondents. Additionally, answers called for an overlay comparison of the maximum extend of each scenario animation. Generally, this feedback on missing graphic content agrees with the suggestions made in Stage 1. These reoccurring feedback points will be incorporated into a final recommendation on how to improve the PARM simulator content in future work.

Interestingly, some answers asked for more explanations on 'how flood risk changes with the time of year' which had not been considered as necessary information until this point. Other points made here included how long FSRs take to reach maximum capacity and what individuals could do to reduce their own risk. The simplified hydrograph featured in the simulator 'Flood Risk Management' could be furthered with specific timings of a flood event reaching peak flow, alongside an animation of the FSRs filling to maximum capacity. These visuals could be useful at emphasising the need for those at risk in a flood event to respond quickly, and how beneficial this can be for reducing overall flood risk, damages and threats to life. A respondent was looking for ways 'individuals can reduce risk', demonstrating that this person was almost 'convinced' by the narrative of risk and was motivated act on it. The PARM simulator can be modified with extra content focused on this idea, but also may be used at events where the PARM raises awareness of flood risk.

Table 24. Thematic cluster analysis of open question answers regarding missing information from the PARM simulator.

Cluster 1: *Missing impact data*	Cluster 2: *Missing graphic content*	Cluster 3: *Explanations needed*
• Economic impact from previous events **(4)**	• Animation comparison **(3)** • 'Better colour coding' **(1)** • Larger maps **(1)**	• How flood risk changes with seasonality **(2)**

• Impact on infrastructure and housing **(2)** • Population data **(2)** • Personal accounts of flood risk **(2)** • Average flood depth at each scenario **(2)** • Environmental impact data **(1)** • Recovery time from events **(1)** • Quantifiable risks (e.g. expected injuries, expected cost at each % chance). **(1)**	• Transport routes **(1)** • Explanation for blue arrows in 'Historic flooding' **(1)** • Animations progress bar **(1)** • Use 'return period' language **(1)**	• How FRM works in this example **(1)** • How long do the FSRs take to fill **(1)** • Link flooding to climate change **(1)** • More evidence to show flood frequency increase in recent years **(1)** • What can 'individuals do to reduce their risk' **(1)** • Flood planning process **(1)**

Respondents were asked if they could "think of any other forms of engagement that you think could be used to help understand flood risk?" (Table 25). This question aimed to get people to think about what forms of risk communication they would like to see used more often. The results from this question showed a very wide range of examples of methods of communication that the respondents believed would be helpful.

Overwhelmingly, responses were dominated by answers calling for more public engagement consultations, in a town hall meeting for example. Other examples of suggested public engagement included information pamphlets for at risk residents and even in-person PARM model demonstrations. These answers show a preference for traditional in-person consultations, where two-way flood communication can occur. Nevertheless, there were also a variety of answers referring to online methods of engagement, which typically only offer one-way communication. This population sample were able to list almost all current methods of online flood risk communication. Even though the preference for in-person communication prevails, the fact that the respondents showed an awareness and desire for alternative online methods of communication suggests that there could be a place for the PARM simulator among them.

Table 25. Thematic cluster analysis of open question answers relating to alternative forms of engagement as proposed by respondents.

Cluster 1: *Web-based platforms*	Cluster 2: *Public engagement*	Cluster 3: *Other forms*
• Narrated videos **(3)** • Other platforms **(2)** • Cartoons and animations **(1)** • Interactive virtual maps **(1)** • Social media **(1)** • Webinars **(1)** • YouTube Videos **(1)**	• Town meetings/public consultation **(7)** • In-person PARM model **(3)** • Newsletters/pamphlets for at – risk residents **(3)** • In schools **(2)** • Localised text notifications **(1)**	• Mobile apps **(1)** • TV **(1)** - flooding documentary **(1)** • 'Quiz – like' flood simulator **(1)** • 'Directly contacting property owners at risk' **(1)**

The final open question in the survey asked participants if they "have any other comments about your user experience with the PARM Simulator?" (Table 26). Thematic clusters 1-3 group answers relating to problems with the simulator, whereas clusters 4-6 relate to more positive feedback and final comments. The PowerPoint slide style and sizing of the maps was clearly a downfall of the simulator and any further work that advances the PARM simulator needs to ensure that map content occupies more space than the contents. The 'scenario animations' not only need to be accompanied by an overlay of the comparative outputs, but also need to start playing sooner, be cut down, and include a visible progress bar. Two respondents also commented that the self-navigation through the simulator did not operate intuitively and that the combination of automated sequences and 'click-through' sections was confusing.

This usability issue can be addressed in future adaptations of the PARM simulator, but ultimately will depend on what platform is used for future commissions; for example, the self-navigation through the simulator will differ on a PowerPoint compared to a website. Since only 5% of respondents found the simulator ‘not intuitive’ it can still be assumed that overall the way users can interact with the simulator was in fact clear and intuitive.

The most common final comment was that overall, user experience with the PARM simulator was positive, useful and that the model was well presented. Further comments acknowledged the simulator as a tool to raise awareness of the risk of flooding within the context of climate change (Evans *et al*., 2004), and crucially, respondents could see the benefit of adapting the simulator content for other areas. This has been a fundamental line of investigation for all PARM use so far, to test how each varied model is applied to different areas with different situational flood risk. The final remarks from respondents reconfirmed the areas of improvement that were highlighted in Stage 1, but also concluded their satisfaction with the simulator along with an acknowledgement of its future potential.

Table 26. Thematic cluster analysis of open question answers regarding any other comments on user experience.

Cluster 1: *Graphic design issues*	Cluster 2: *Troubleshooting animations*	Cluster 3: *Further usability issues*
• The maps and graphics on the right-hand-side were too small **(5)**	• The animations did not work **(3)** • Animations too slow **(2)** • Progress bar needed for animations **(2)** • Need comparison of animation **(1)**	• Automated sequence ran too quickly **(1)** • Self-navigation did not operate intuitively **(1)** • The combination of automated and click-through did not work **(1)**

		• Unable to respond to individual queries **(1)**
Cluster 4: *Positive user-experience*	Cluster 5: *Future applications*	Cluster 6: *Application to climate change*
• Overall a well-presented and useful model **(6)** • Effective and easy to follow design **(4)**	• Can see benefit of adapting this to other areas/at-risk towns **(1)** • 'I would like to see a similar model of where I live' **(1)** • To communicate the risks of building on floodplains **(1)**	• A useful tool to 'raise understanding of flooding' in the context of climate change **(1)**

6.2.4 Survey answers to explore attitudes towards FRM

A sub-set of questions within the survey were used to query respondent's attitudes and concerns about flooding. Participants were asked to pick three options out of 12 that they thought were the 'most significant risk or problem caused by flooding generally' (Figure 28). 35 participants completed this question and therefore 105 selections were made in total. Results shown in Figure 18 show that a large proportion of respondents considered damage to homes and infrastructure as the most significant risk or problem caused by flooding. Safety and economic impacts were the second and third most common choices. Generally, respondents prioritised personal safety and tangible damages as their main concerns.

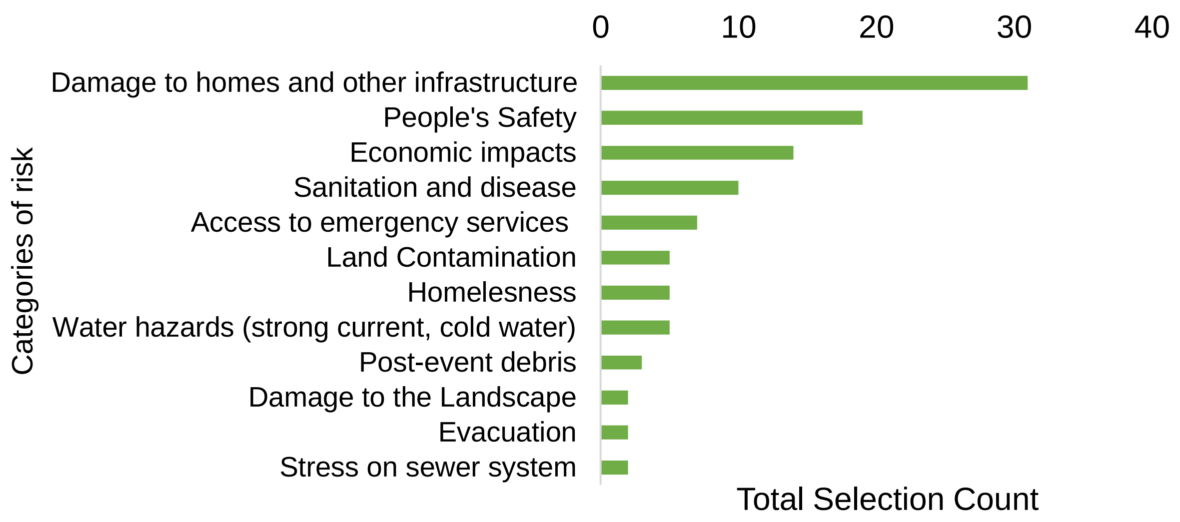


Figure 28. Graph showing counts for each category of risk caused by flooding, showing how the respondent's prioritised problems associated with flooding.

Respondents were asked to choose to what extent they agreed or disagreed with a series of statements, some involving personal flood risk (Figure 29) and some relating to FRM more generally (Figure 30). 100% of respondents either strongly agreed or somewhat agreed that they were concerned about natural hazards increasing due to climate change. Climate change, and its predicted implications for flooding, has been found to be a topic for public deliberation, errors in understanding and distrust in the past (Dessai and Hulme, 2007). Therefore, these results, showing public concern and awareness are a positive sign as this small population sample, across a variety of age categories, showed appreciation of climate risk in the context of flood risk.

Interestingly, there was a wide range of reactions to the second personal statement, with 17% of respondents disagreeing that as a 'homeowner' they would have some responsibility to help manage their own flood risk. This attitude and distortion of risk perception amongst the general public can be problematic, generating on overreliance on management authorities (Botzen *et al*., 2009). A more contemporary standpoint that has arisen through recent flood risk management (FRM) is that citizens should 'accept more personal responsibility for their decisions on where to live' (White *et al*., 2010). Responses to this question highlight a residual need to foster a risk appreciation and awareness for responsibility of risk.

Previous literature has recognised individual households as important stakeholders in the FRM process (Osberghaus, 2017; Haer *et al*., 2016, Bubeck *et al*., 2012 and Zaalberg *et al*., 2009). People are more likely to adopt mitigation behaviours, such as implementing private flood risk reductions (FRRs), if they feel it is their responsibility to do so (Lara *et al*., 2010). Grahn and Jaldell (2019) applied protection motivation theory (PMT) to analyse homeowners flood risk perception and their risk reduction behaviours, finding both insufficient in Swedish households. Self-protective behaviours can help reduce the impacts of flooding, for example in flood-prone urban areas they can reduce monetary flood damages by as much as 80% as shown by Grothman and Reusswig (2006). Poussin *et al.* (2014) noted that in order to initiate private FRR and individual must feel the threat exists and believe in easy to implement measures to reduce the risk. The PARM simulator has the capacity to convey the threat of flooding but also to supplement with information on location specific FRRs, therefore this research recommends exploring the capacity of this tool to help influence risk perception and encouraging adaptive behavious (Haer *et al*., 2016; Terpstra *et al*., 2009).

In response to the statement “flood management schemes are 100% effective at removing the risk of flooding” 74% of respondents claimed that they strongly or somewhat disagreed with the statement, demonstrating an awareness for the realistic effectiveness of FRM. The ‘Scenario Animations’ showed how the Skipton defences can still be overtopped by unprecedent events. It is important to consider that a bad personal experience of flooding may influence people’s perceptions of FRM, and therefore it cannot be automatically assumed that respondents disagreed with this statement based on a good knowledge base for the complexity of FRM. 9% of respondents ‘somewhat agreed’ that FRM schemes are 100% effective at removing risk. Future PARM content needs to ensure that explanations of residual risk are incorporated into narratives, to foster an appreciation for the uncertainty of nature and realistic expectations of FRM strategies.

For the statement “generally the public are well informed about their local flood risk” responses were mostly negative, with 71% of respondents either strongly or somewhat disagreeing. This is furthered with the overwhelming agreement (97%) that “public engagement with local flood risk needs to be improved”. These responses show the sample population did not feel that existing flood risk communications were satisfactory. Additionally, responses to the statement “residents are consulted about new flood management schemes to a good standard” was the only statement to receive answers from all 5 possible categories. Most responses here (51%) neither agreed nor disagreed with the statement, perhaps suggesting some confusion over the responsibility for flood risk managers to communicate about schemes. Public participation in flood risk management is a legal requirement within current UK legislation as explained in Section 2.3.3 and therefore needs to be executed. The wording of the statement “to a good standard” should also be considered, as respondents may believe residents are in fact consulted about FRM, but just not to a satisfactory level, thus explaining the spread of answers.

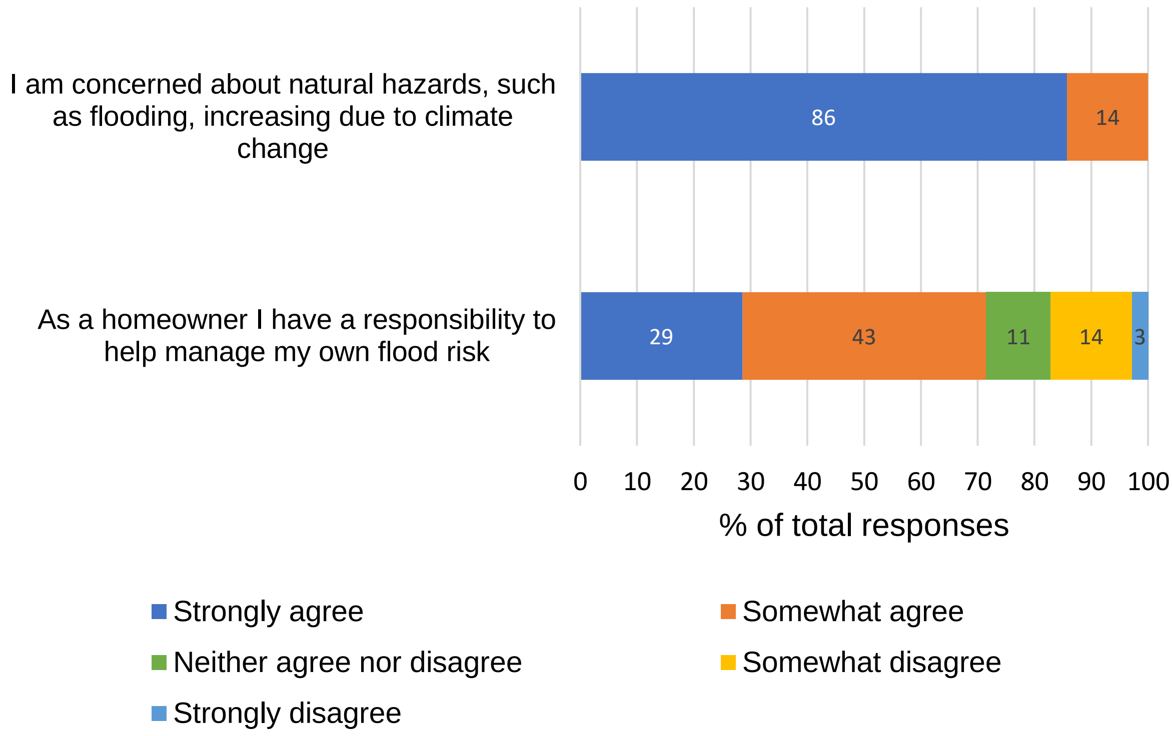


Figure 29. Graph to show % of total responses for each possible agreement category for two statements on personal flood risk perception.

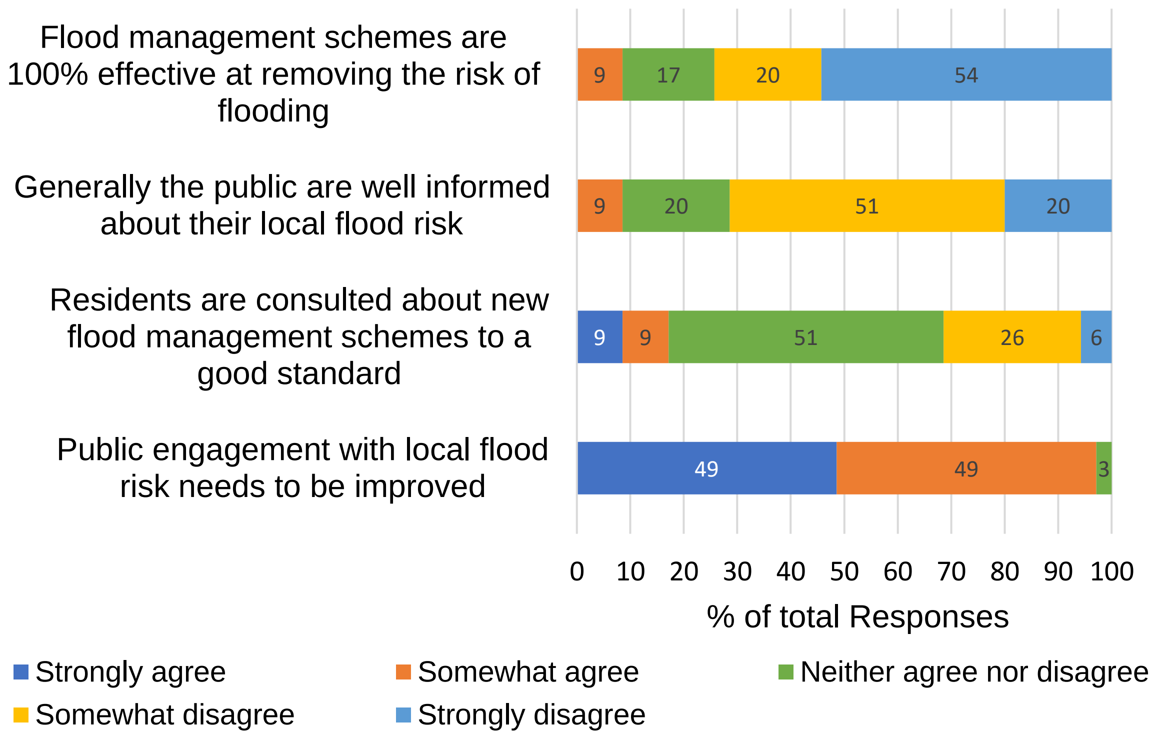


Figure 30. Graph to show % of total responses for each possible agreement category for four statements on attitudes towards FRM and public engagement.

As previously discussed, flood risk communication tools can be used for their potential to evoke a behavioural change in order to reduce an individual's personal risk. 37% of total respondents said that they "did/will sign up for the gov.uk flood alert scheme signposted at the end of the simulator" and 63% of respondents did not. Those who did not sign up for the flood alert scheme were asked why (Table 27), to which 73% of these of answers were because the respondent "did not live in an area at risk to flooding". Nevertheless, as nearly 40% of survey respondents claimed to sign up to the alerts, this result is a clear example that the PARM simulator is a tool that can successfully evoke behavioural change.

Table 27. Reasons why respondents did not sign up to the flood alert scheme.

Response Option	**Response Count**	**Percent**
"I don't live in an area at risk to flooding"	16	73
"I did not see the link on the Simulator"	2	9
"Other"	4	18

6.2.5 Is there value in the Skipton PARM simulator?

Respondents were asked if they thought "there is value in engagement tools such as the PARM Simulator, as a resource for more effective communication of environmental risk?". An overwhelming majority of 97.14% of responses answered 'Yes'. Respondents were also asked if they had "ever seen anything like the PARM simulator before?". 28.57% of the sample population said they had, those who had gave examples of what they had seen that was similar:

"seen the physical model before" (n =3)

"Seen other types of flood risk simulators for different areas" (n = 3)

"Seen 3D printed models with historic maps overlain on them" (n=1)

"I've seen model simulations online like this, not seen anything like the actual PARM simulator (with projections etc.)" (n = 1)

Respondents were asked "Do you believe your interaction with the Skipton PARM simulator improved your understanding of flood risk and flood risk management?". To this question there were 35 responses, with 94.29% of answers saying 'Yes'. 5.71% of answers said 'No'. Those who said 'No' were then asked why they did not believe their interaction improved their understanding. The answers to this were mostly constructive, such as: *"I have a good knowledge of flood risk management already! Although this study increased my knowledge of flood risk in Skipton"* although one respondent did state: *"It needs re-thinking".* However, as they did not elaborate and other open comments were either positive or constructive, it is not possible to further interpret or respond effectively to this comment.

7. CONCLUSIONS

There is a growing need for more effective flood risk communication, as required from UK legislation. Flood risk communication is needed to engage participants and alter their flood risk perceptions, as part of a holistic flood risk management. 97% of survey respondents agreed that public engagement with local flood risk needs to be improved. Among various emerging tools, the PARM simulator offers a unique and interactive user experience to learn about flood risk from a case study location. Two stages of investigation have been employed to meet the overall research aim 'to investigate how the structure and content of information within an online interactive tool influences public engagement, knowledge and attitudes towards flood risk'. By modifying the original Skipton PARM content into an online simulation, this has allowed for the critical analysis of PARM content and structure in the absence of the 3D model. This research project has obtained substantial feedback on the Skipton PARM simulator that translates into several key, future implications for the structure and content design of online interactive tools and 3D PARMs (objective 4).

The Skipton PARM Simulator content is comprised of seven thematic content sections, each offering a different contribution of information to build a narrative of the flood risk story in Skipton, UK. Participants in both stages of research were not directly asked if they believed all seven sections were necessary. Instead, they were asked for feedback on the overall structure of information and what information was missing or should be incorporated to future narratives to improve engagement and understanding. The seven thematic sections should be used as a base narrative from which to build future PARM stories, but there should be consideration that in different case study scenarios, all seven sections may not be necessary. Some reactions to the 'Local Landmarks' theme warrant further investigation as some felt that this was not needed, especially for those with familiarity of the case study area as they did not need to build a frame of reference through landmark exploration. It is recommended that future PARM commissions refer to the list of summarised feedback as a guide supplementary content to be incorporated into future PARM displays (Figure 31), prioritising points raised in the 'Feedback Overlap' category, as these were recommended in both Stage 1 and Stage 2. Modifying the simulator content according to the summarised feedback will enable a narrative that is potentially more engaging, easier to understand and holds more influence to alter perceptions of flood risk.

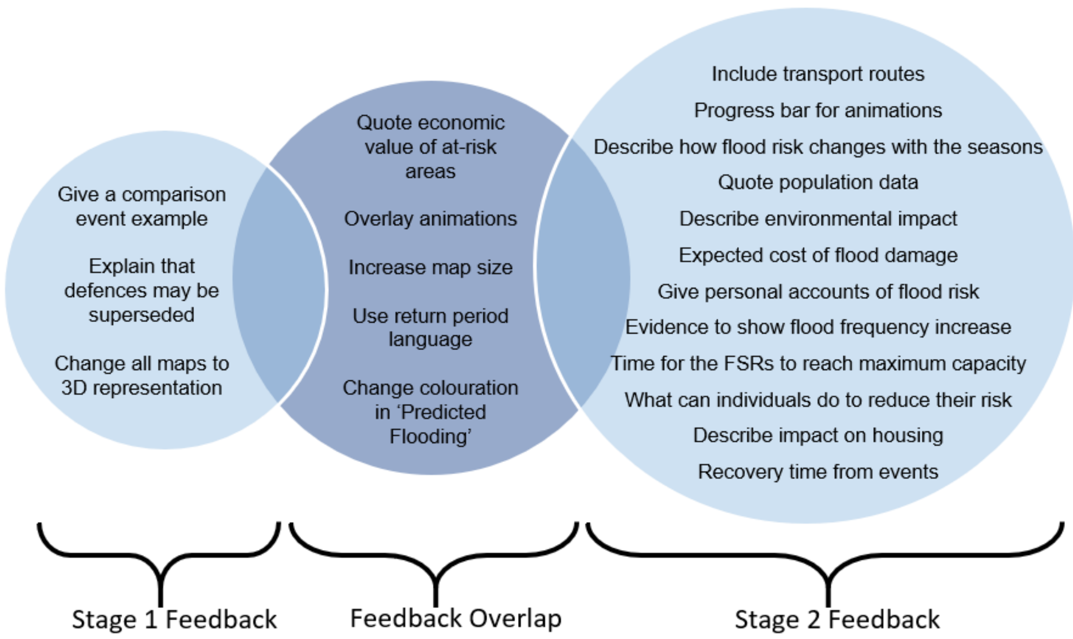


Figure 31. Summary of feedback from user experience with the Skipton PARM simulator. Stage 1 Feedback includes the suggestions made by the experts that were not implemented prior to Stage 2. The feedback overlap combines identical ideas from the experts and general public. Stage 2 feedback was obtained from the open survey questions.

The colour scheme used in the 'Predicted Flooding' section was a design issue noted in the feedback overlap. Future displays should use patterning to distinguish between presented data sets or have the option for an alternative colour scheme. This is crucial as all PARM models or simulations should be inclusive to all users, ensuring there are no barriers to engagement with these tools. The size of the maps used in the simulator was a further design fault addressed in the feedback overlap. By reducing how much space the contents occupied on the screen and increasing the map size, this would drastically benefit user experience. The findings from this study warrant further investigation into a more intuitive online medium for the PARM, where map imagery used could be prioritised over a content navigation bar. A website-based design could be an alternative platform for the simulator, not only providing an opportunity to expand the PARM simulator imagery, but also offering a more accessible tool, negating the need to download any large data files such as the PowerPoint used in this study. Any investigation into alternative online platforms should also consider the incorporation of audio narration into a PARM simulator or to accompany stand-alone PARM displays. Feedback from participants suggested that this would ease explanations and potentially offer a more immersive user experience.

Feedback from both stages agreed that a ‘Animated Scenario’ overlap should be used to make the comparison between the defended and undefended scenario animations abundantly clear. The economic value of ‘at risk’ areas should also be quoted if known, as this will be useful in helping users comprehend the importance of FRM by showing the value of the land and infrastructure at risk. The final overlapped feedback was the incorporation of ‘return period language’. It is recommended that future displays incorporate return period language as well as AEP, and a brief explanation of the language used would also benefit the user, especially when interacting with a stand-alone display.

The graphic representation of different flood events (% AEP) was the most useful in helping users understand flood risk in Skipton. These results may be because flood inundation mapping using AEP is a very common method of risk communication, meaning respondents may have seen this form of information presentation before. The AEP maps displayed in the ‘Predicted Flooding’ section should be incorporated into every future PARM display that relates to flood risk. Overall, 97% of respondents agreed that their interaction with the PARM simulator improved their understanding of flood risk and flood risk management.

Survey respondents agreed that the overall display was easy to understand (91%), presented in a logical order (97%) and used appropriate and understandable language (94%). All suggesting a reasonably effective narrative and positive user experience. The local story of 'What Causes Skipton to Flood?' was deemed, on average, the most engaging thematic section. This section presents the explanation of why flooding occurs in a specific location. Homeowners may feel that even if flood risk is being managed, they may not have had the causes of flood risk explained to them, leaving the public uninformed and perhaps disengaged. Open questions also revealed that Skipton-specific catchment information used in the content was the most commonly listed 'interesting or surprising' content feature. This section content will need change dramatically for each separate PARM display that focuses on a different location. The simulator presents flood risk using an explanation of catchment-scale geography and picking out the specific details of risk, in this case the canal-Eller Beck interface. Future displays should carefully consider how to explain the story of local flood risk using these methods to successfully engage users.

Statistical analyses were used to assess whether flood location familiarity can influence user experience with the online geovisualisation tool, enabling greater understanding of engagement (objective 2). Results from the Mann-Whitney U tests showed that no individual thematic section was statistically proven to be rated, on average, significantly more engaging by those who were familiar with Skipton compared to those who were not. Average ratings also demonstrated that the catchment information presented was easy to understand for both those familiar and unfamiliar to Skipton. The results from this research have not proven that familiarity of the PARM simulator location gives a significant advantage in overall knowledge acquisition as previously expected, demonstrating the effectiveness of content used in the PARM simulator deign as information was clear to both groups. This insight shows that the structure and content of information in the online PARM was accessible to those with and without location familiarity. Future research using 3D PARM models could investigate for a 'familiarity' bias to compare how the use of a 3-dimensional model may positively influence the understanding of a group familiar to the case study area.

Attitudes towards personal flood risk and current methods of flood risk communication (objective 3) were assessed in Stage 2 of the research. 97% of survey respondents agreed that "public engagement with local flood risk needs to be improved". 97% of respondents also agreed that "there is value in engagement tools such as the PARM Simulator as a resource for more effective communication of environmental risk". These results indicate a that the general public sampled in this investigation feel strongly that a lot more needs to be to engage people with local flood risk, but that the simulator and similar tools carry value and potential as a resource to address this engagement issue.

17% of survey respondents disagreed that as a homeowner, they hold some responsibility for managing their own flood risk. An integral part of flood risk management (FRM) is the variety of scales across which it occurs, including personal scales (Schanze *et al*., 2010). If homeowners do not accept a proportion of responsibility in managing their own personal flood risk, this can impact the efficiency of the FRM system. Whilst the vast majority agreed that homeowners hold some responsibility, 17% did not. Indicating that an issue of responsibility remains, bringing to light the importance of communicating individual responsibilities as part of societal FRM. Future PARM models and other methods of flood risk communication should consider incorporating this message into the design of content to help address this lingering issue with public attitude towards personal flood risk.

This study found that the PARM simulator is a tool with the potential to mobilise behavioural change as 37% of respondents signed up to flood risk alerts as a result of their interaction with the simulator. Interaction with the simulator influenced participant's understanding of flood risk and in some cases was able to evoke this minor behavioural change. This result implies that future PARMs should, when appropriate, incorporate guidance on implementing personal protective behaviours. This recommendation on future content could potentially help encourage private flood risk reductions and ultimately contribute to a more holistic FRM system, whilst also increasing the issue of risk responsibility awareness as previously mentioned.

This project has successfully consulted with both professional and non-professional demographics to gain insights on user engagement, understanding and attitudes towards flood risk (objective 1). This research highlighted how the population sampled in Stage 2 felt that current flood risk communication needed to be improved, and an absence of a universal acceptance of responsibility for personal flood risk. The rich content of information possible in a PARM could potentially enable improvement in public attitudes towards flood risk by utilising content that addresses social dislocation issues, enhancing community flood memory and generating behavioural change. User interaction with the Skipton PARM simulator in Stages 1 and 2 has resulted in a series of recommendations for the structure and content of design to improve how users engage with and learn from future narratives. These recommended alterations can be selectively applied to both online geovisualisation tools (Skipton PARM simulator) and 3D PARM models. Overall, the Skipton PARM simulator has proven to be an effective geovisualisation tool to engage the public with flood risk and river management techniques. Effective flood risk communication has the power to reduce the impact of extreme flood events, and tools like the PARM simulator need to be continually exploited to engage users with their local flood risk for the benefit of holistic flood risk management.

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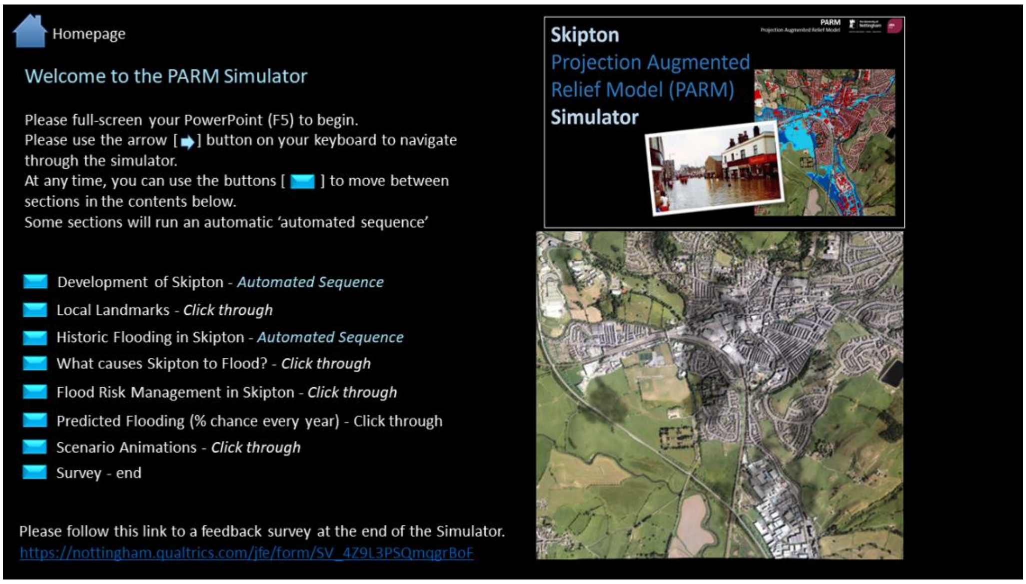
APPENDICIES - ***Appendix 1*** PARM Simulator



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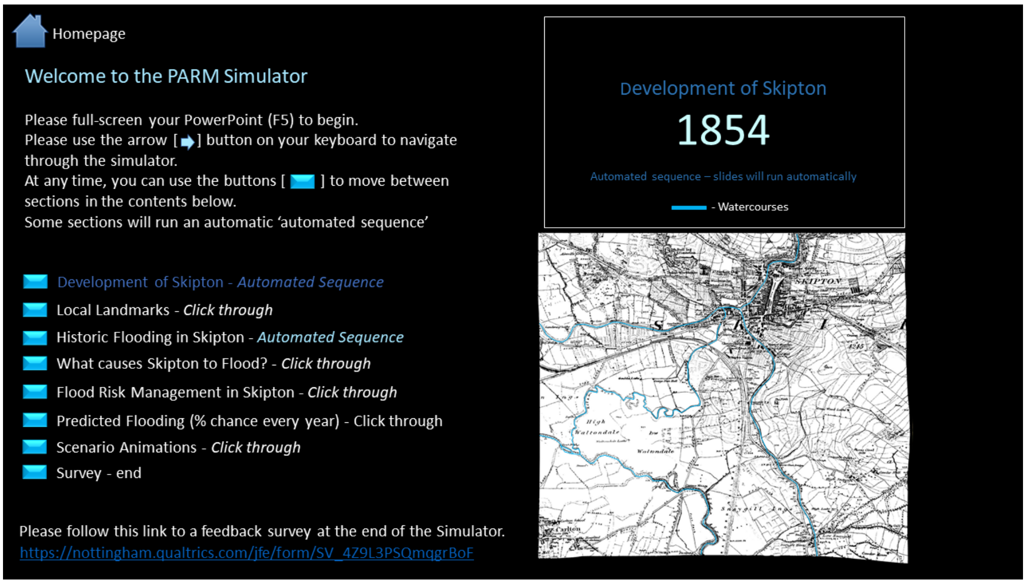

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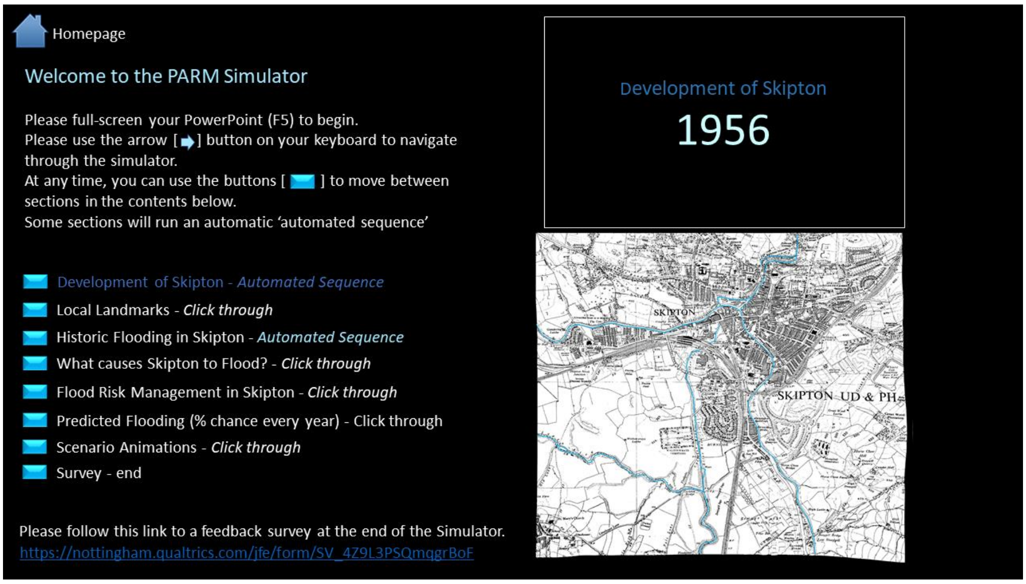

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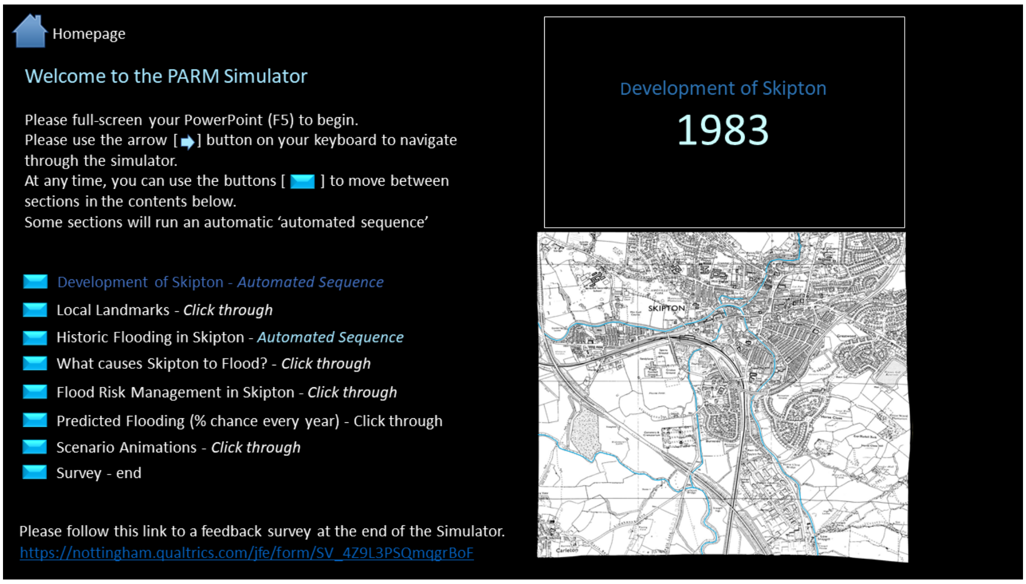

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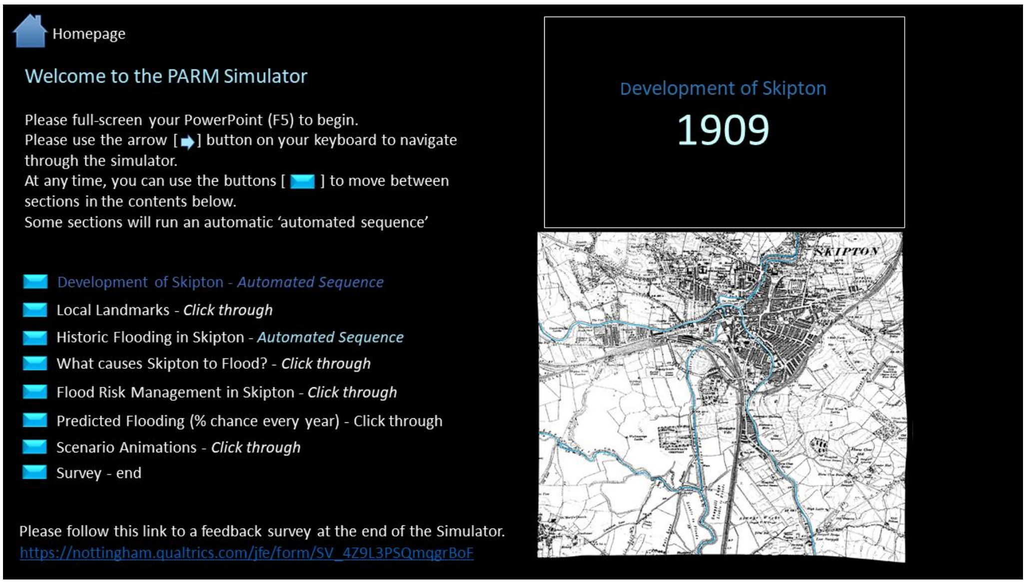

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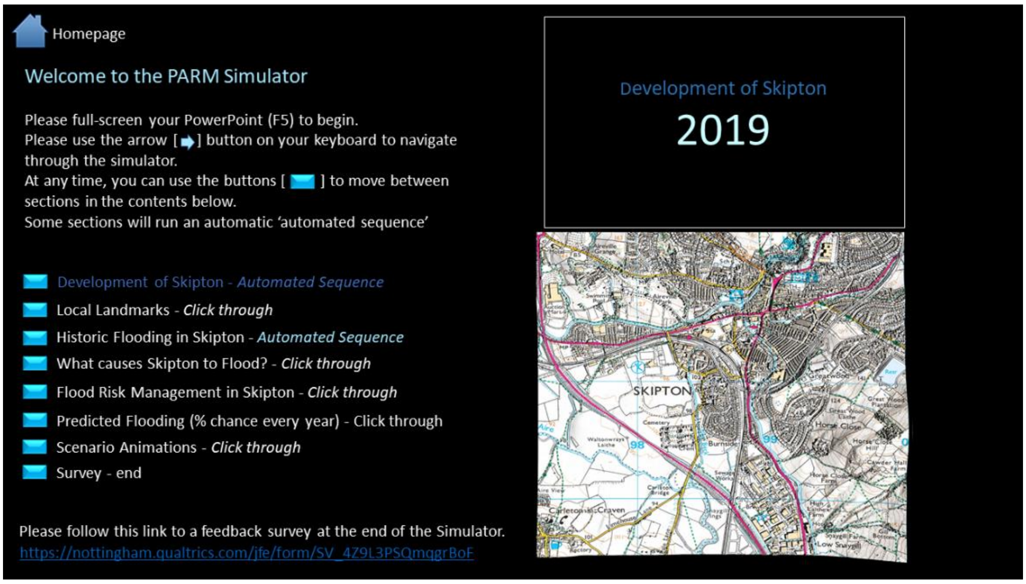

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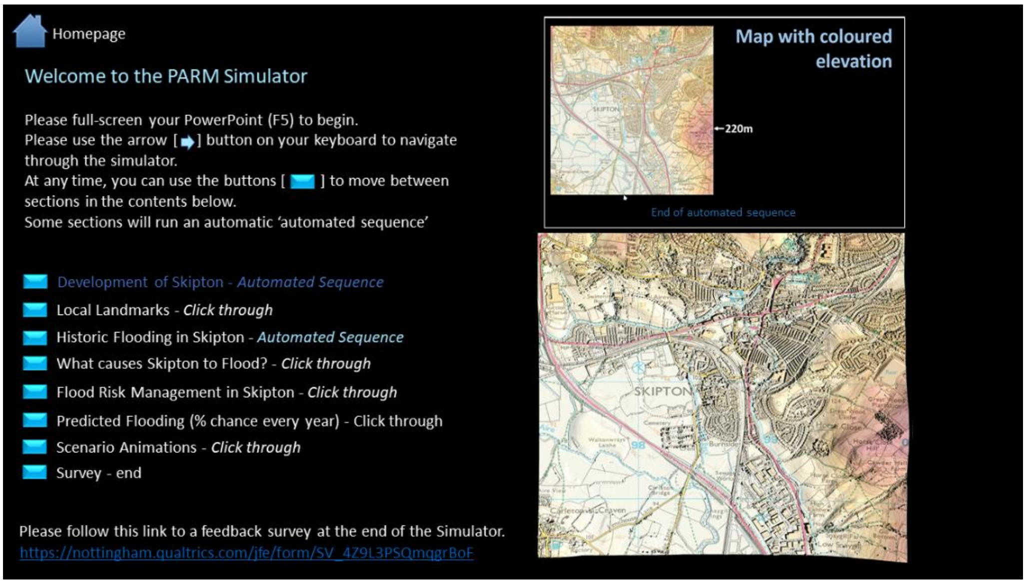

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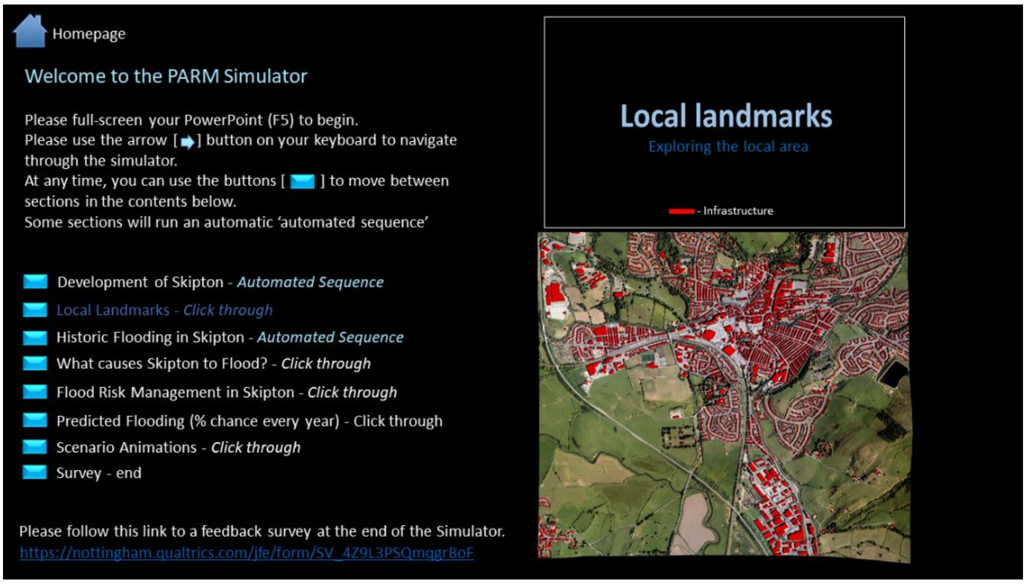

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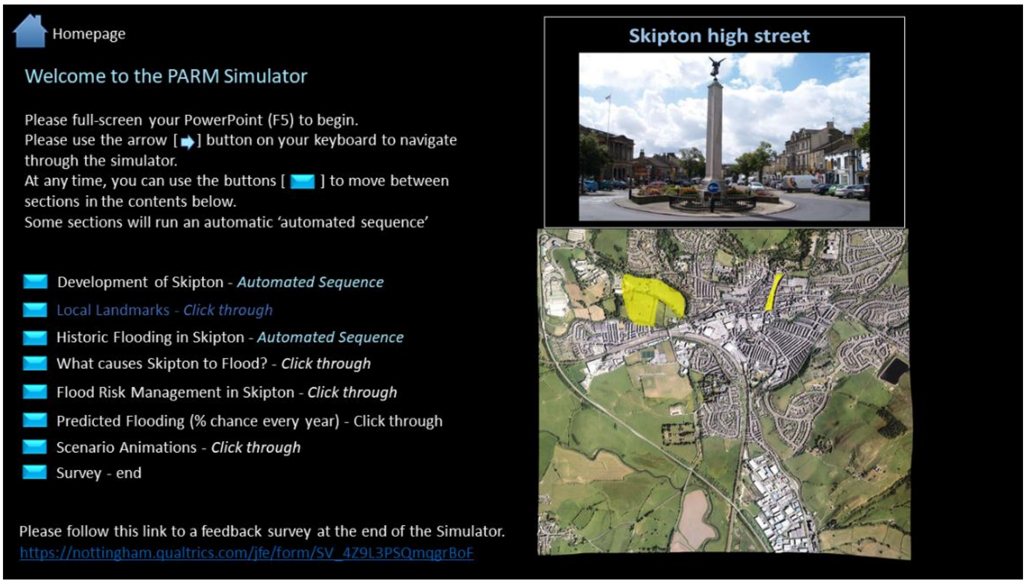

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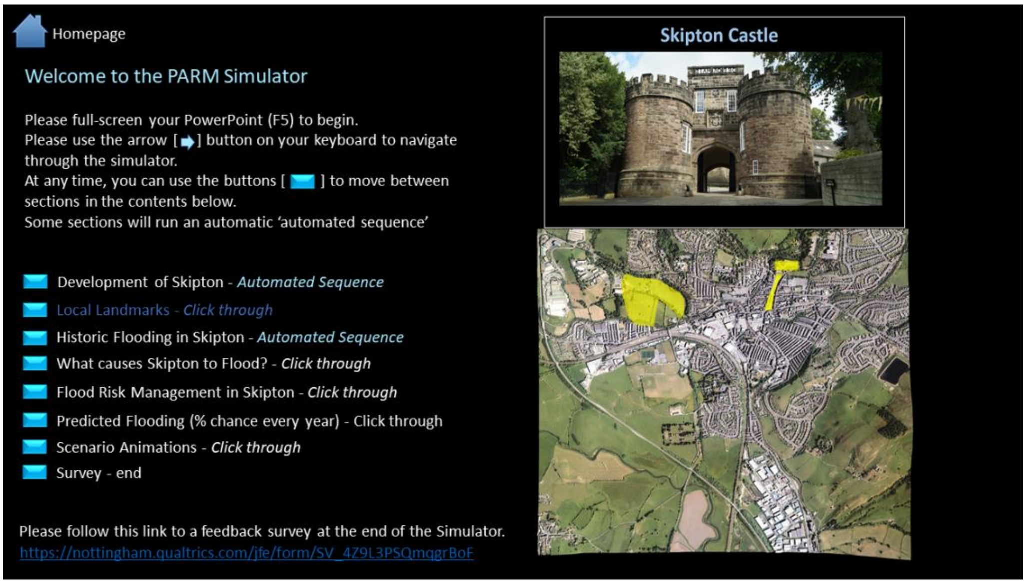

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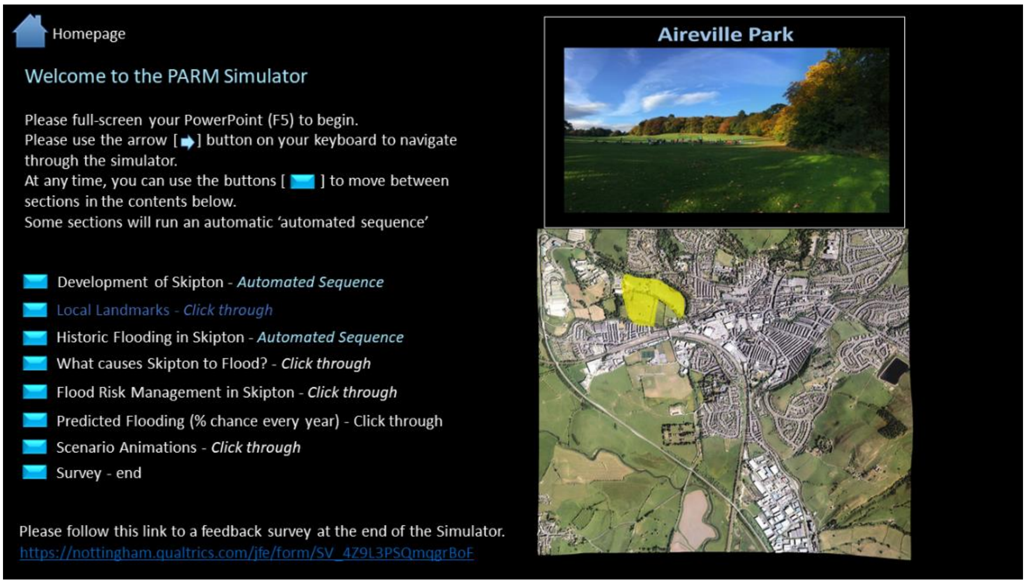

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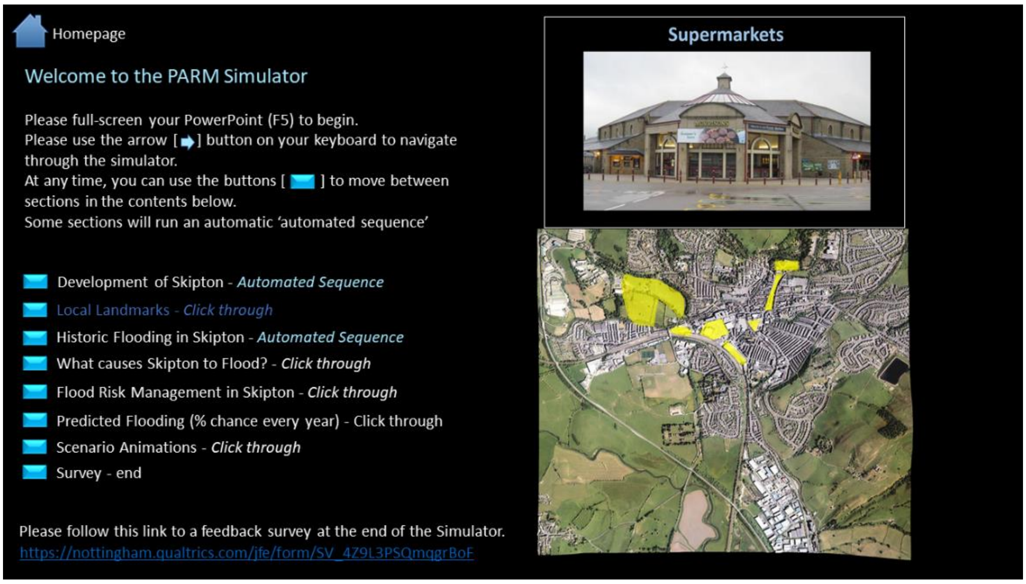

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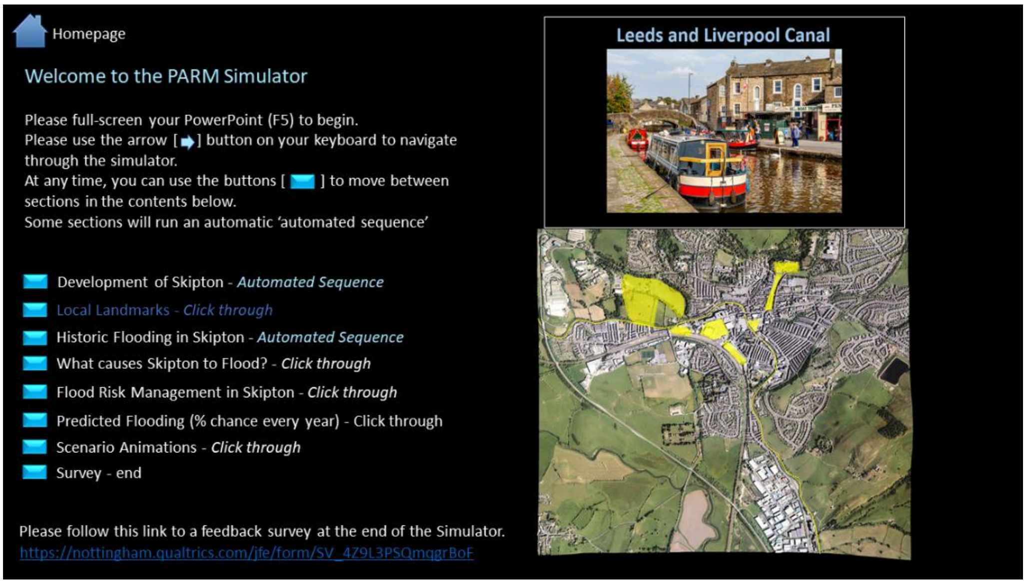

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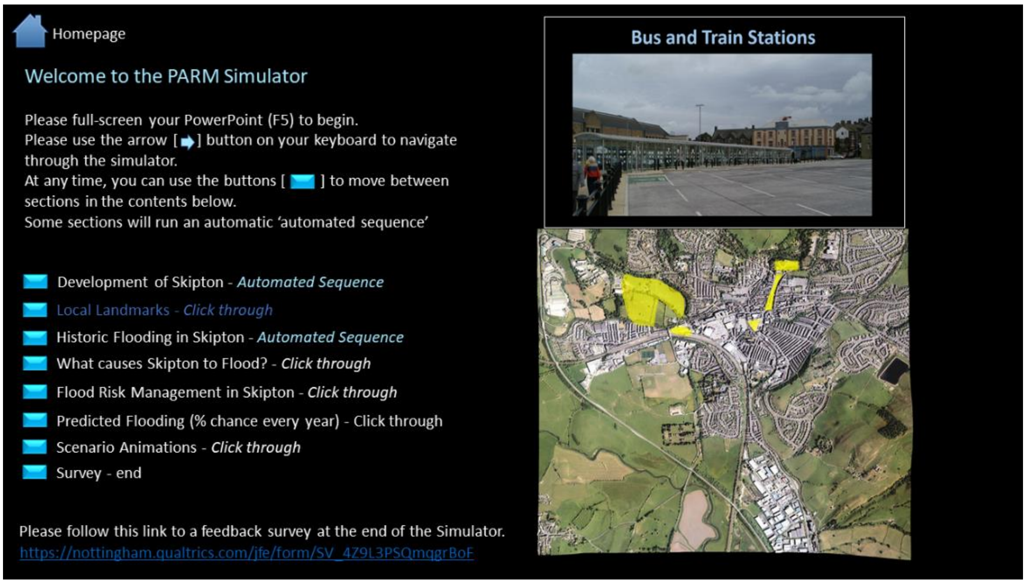

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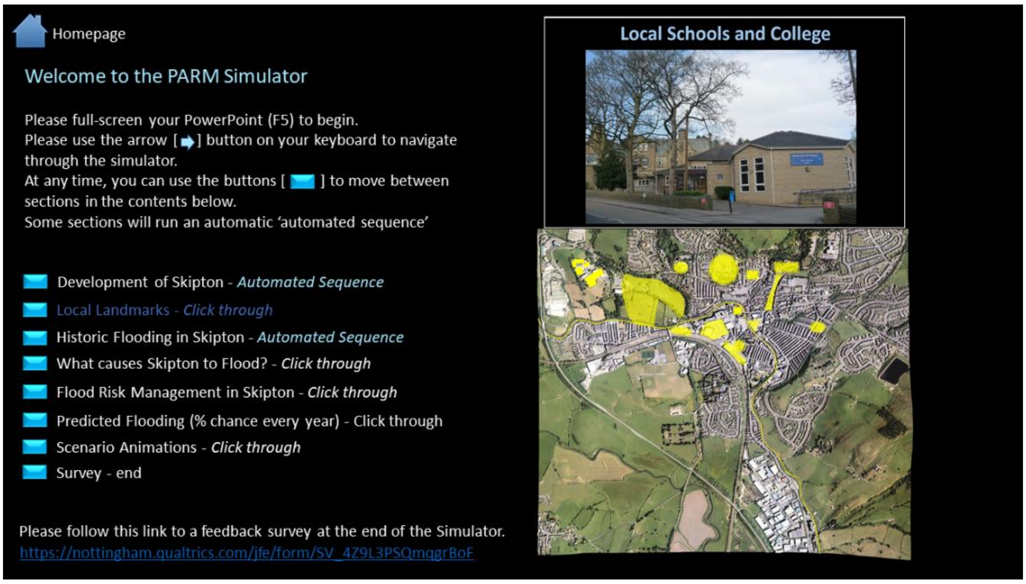

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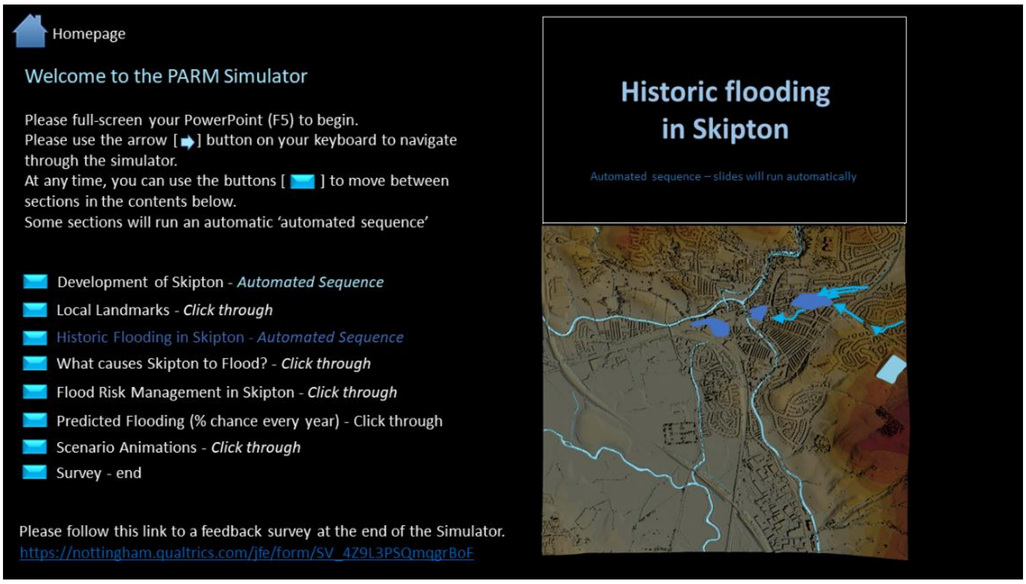

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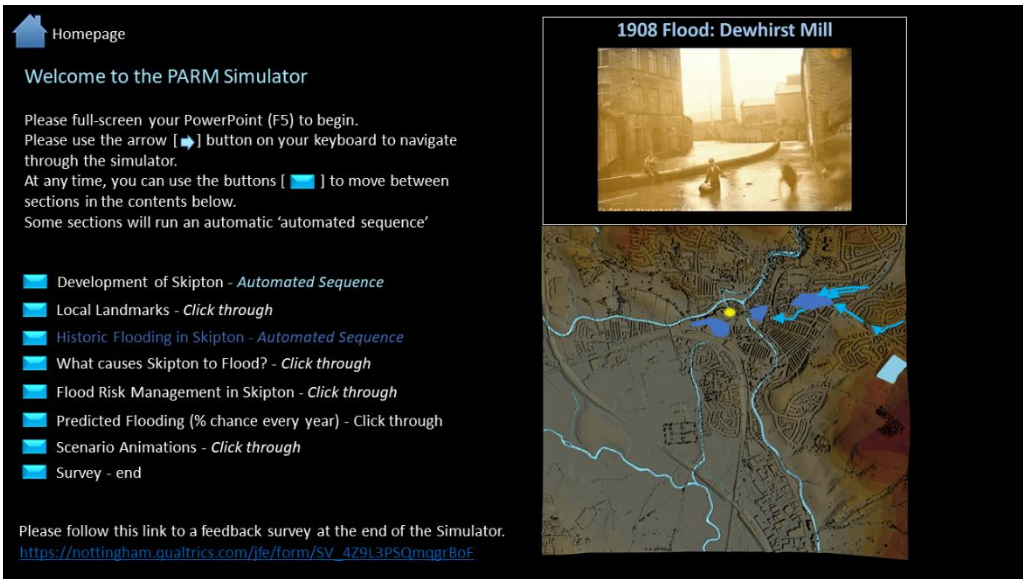

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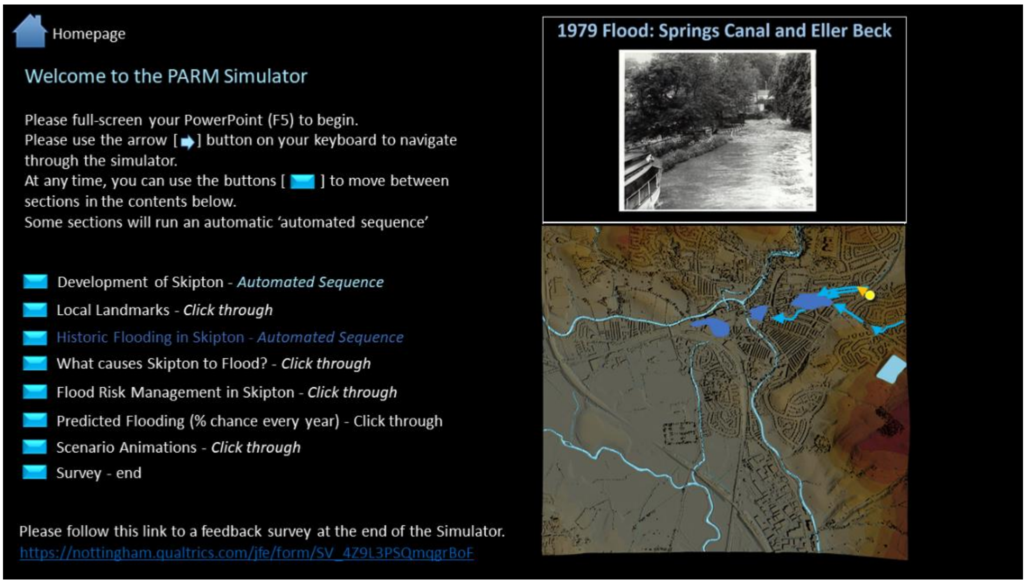

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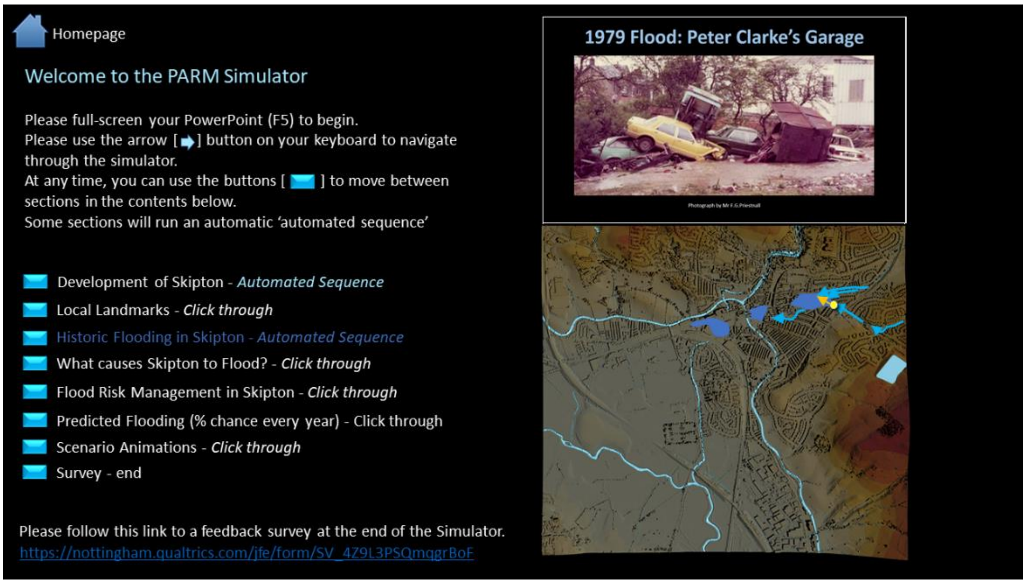

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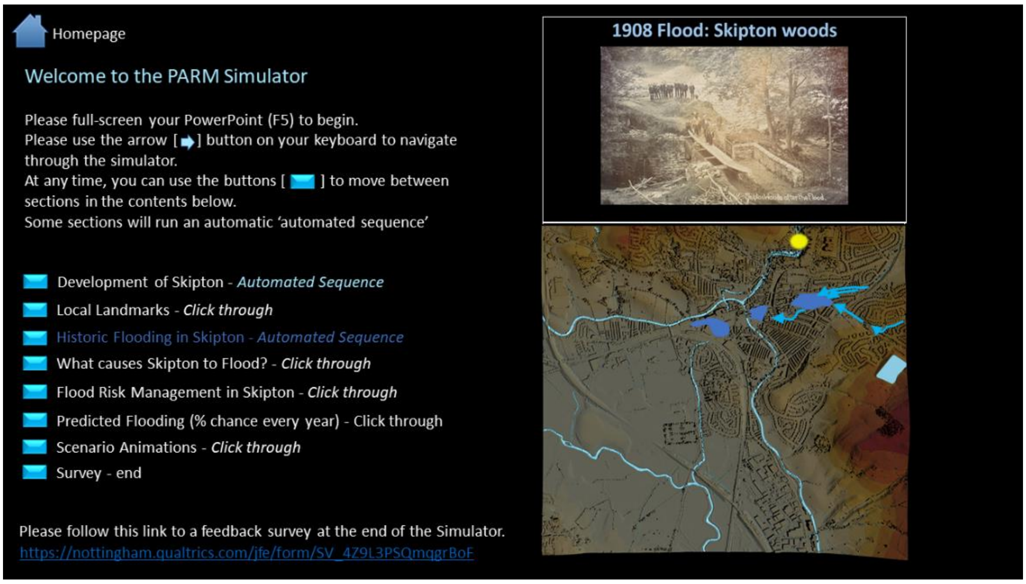

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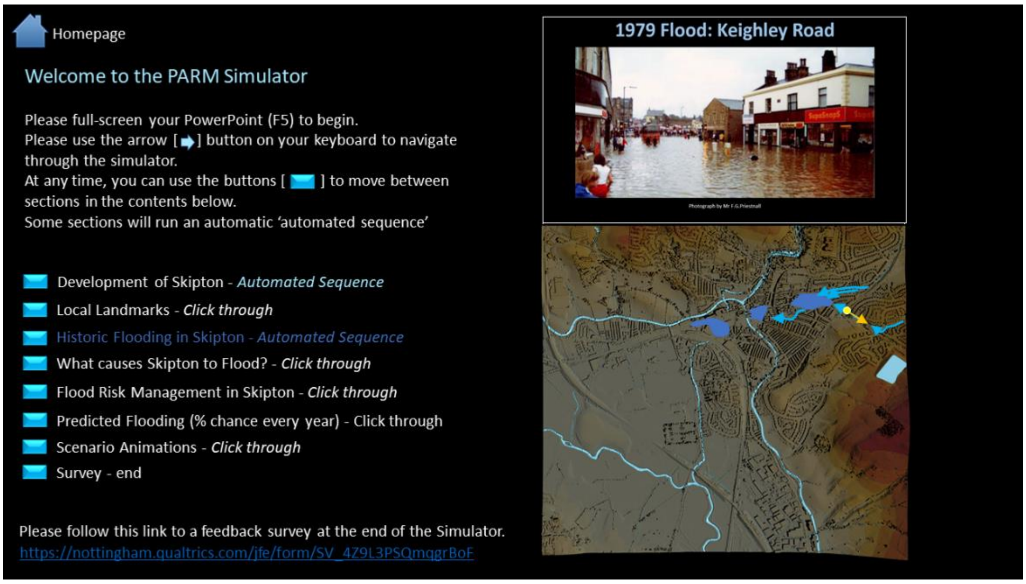

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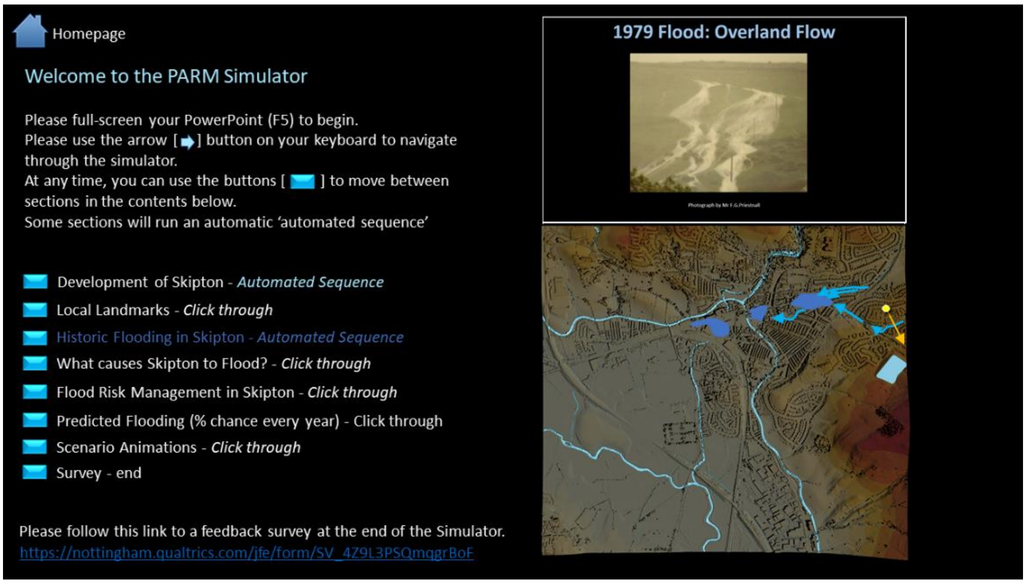

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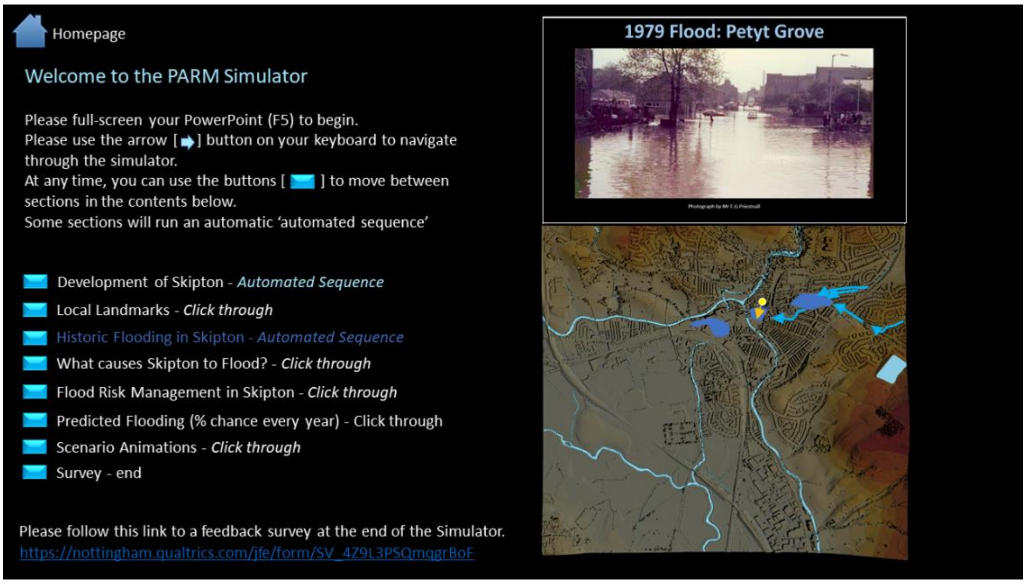

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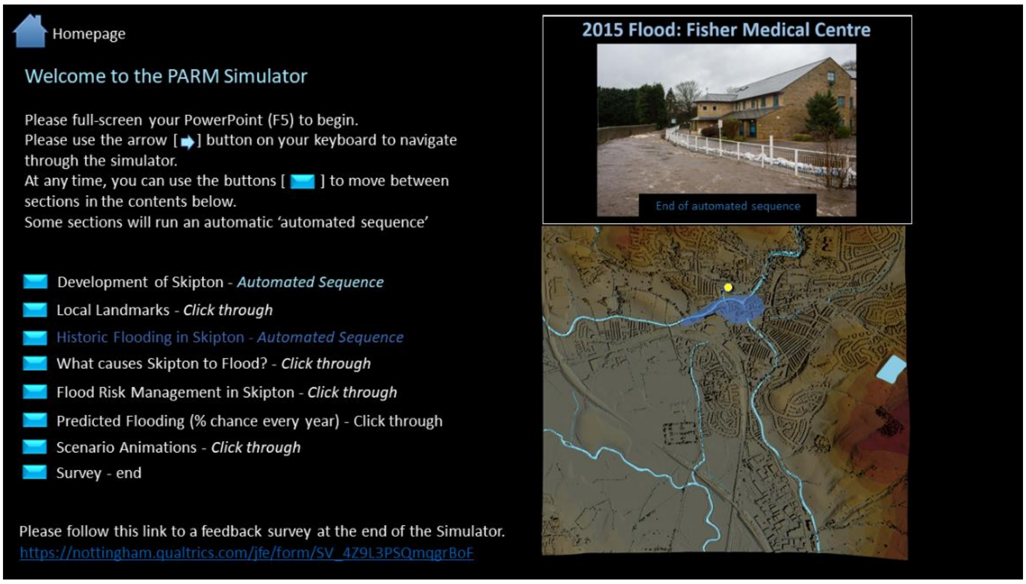

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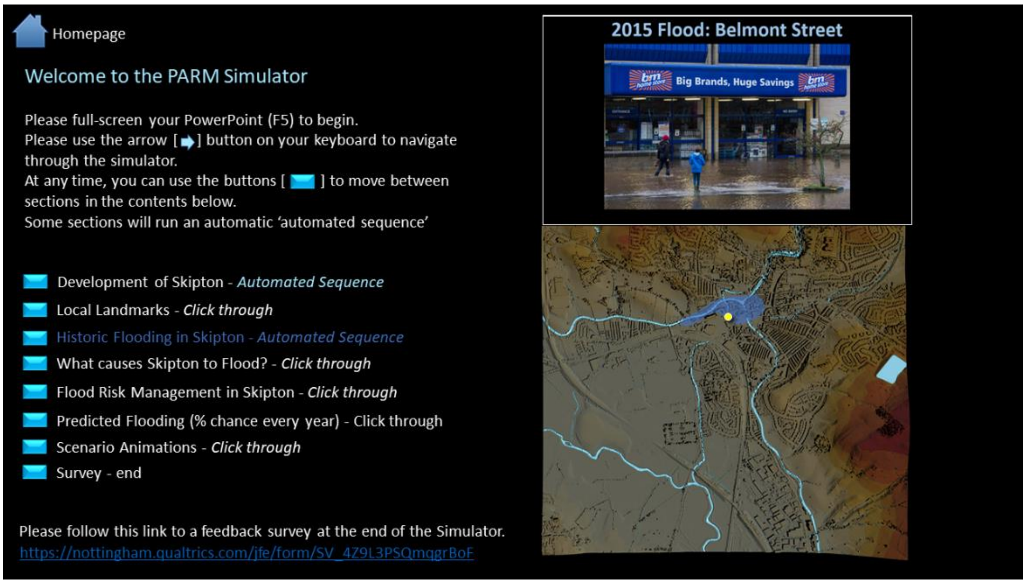

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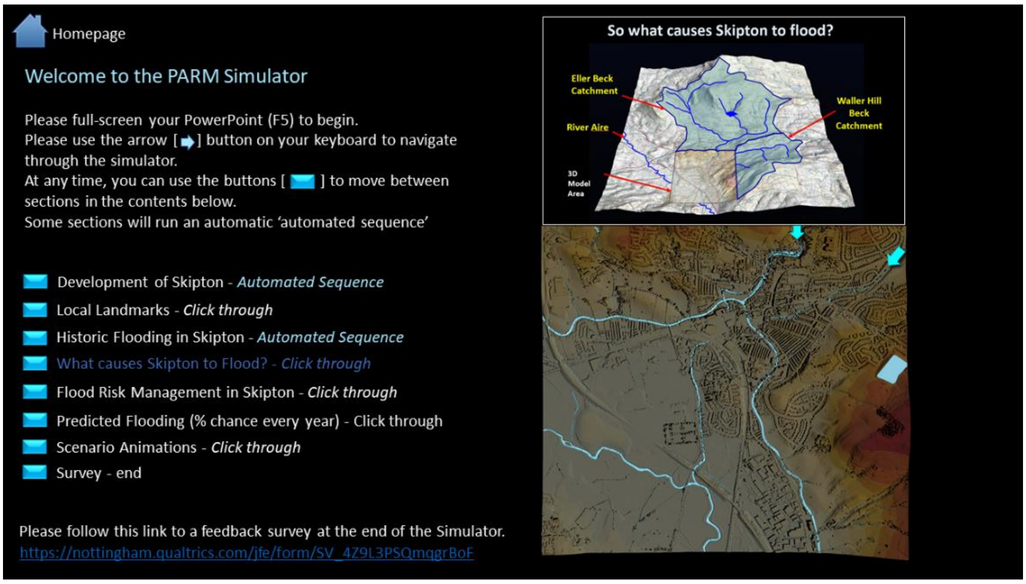

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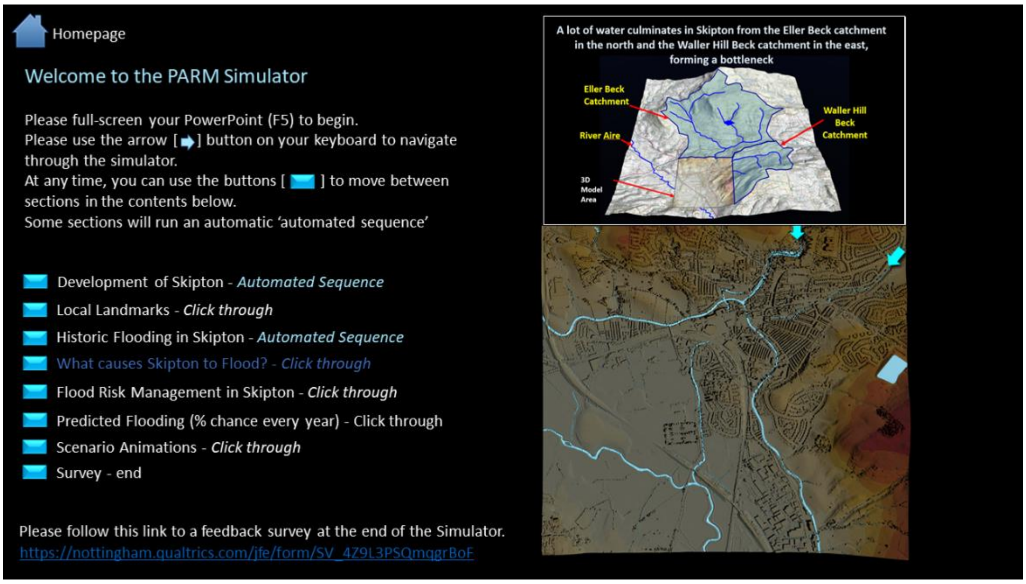

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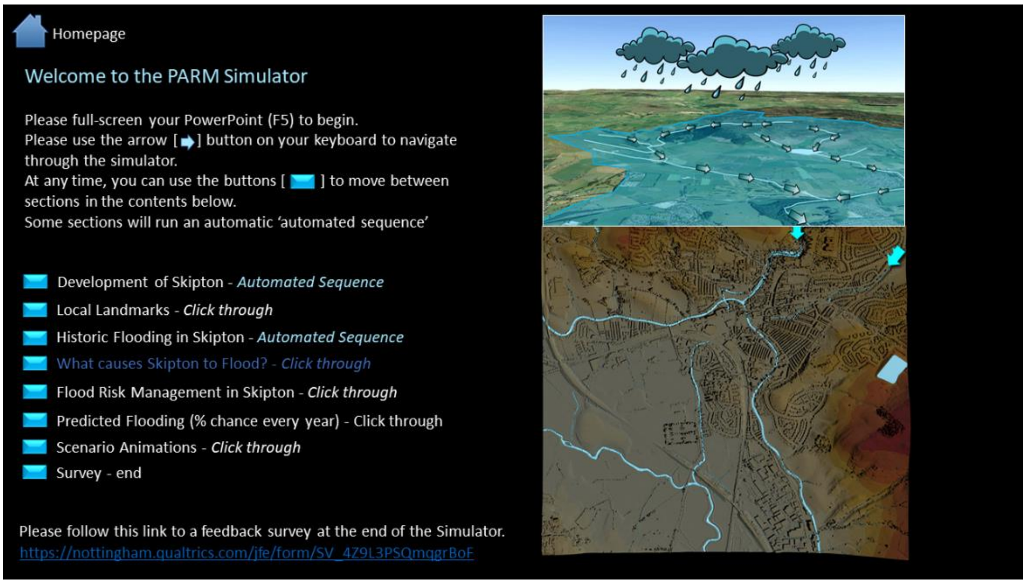

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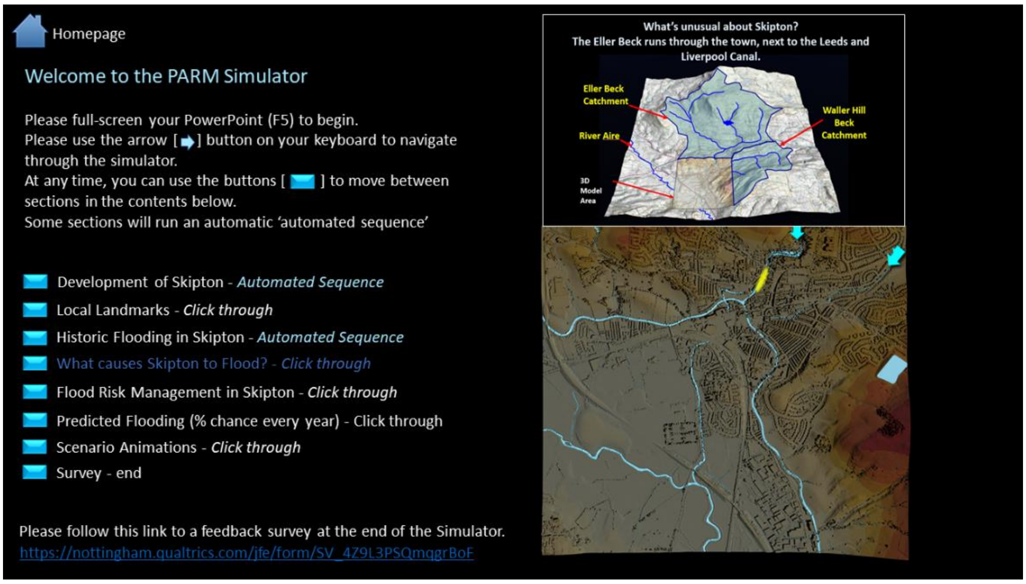

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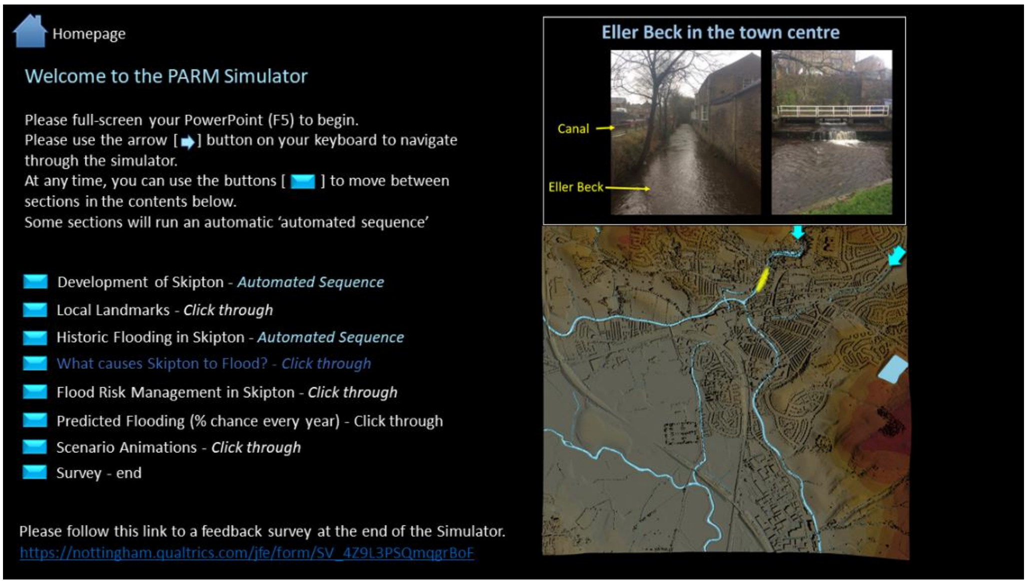

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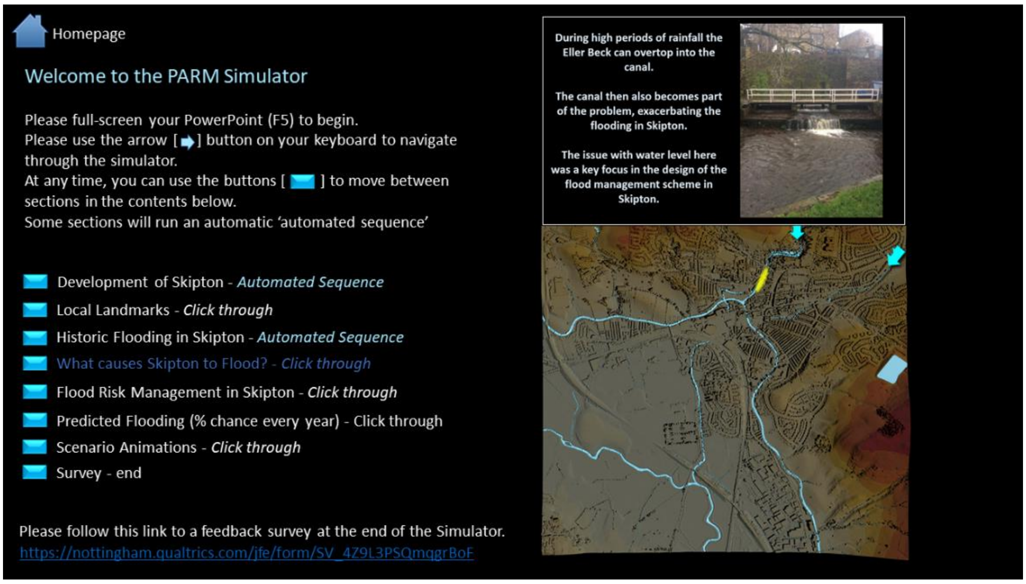

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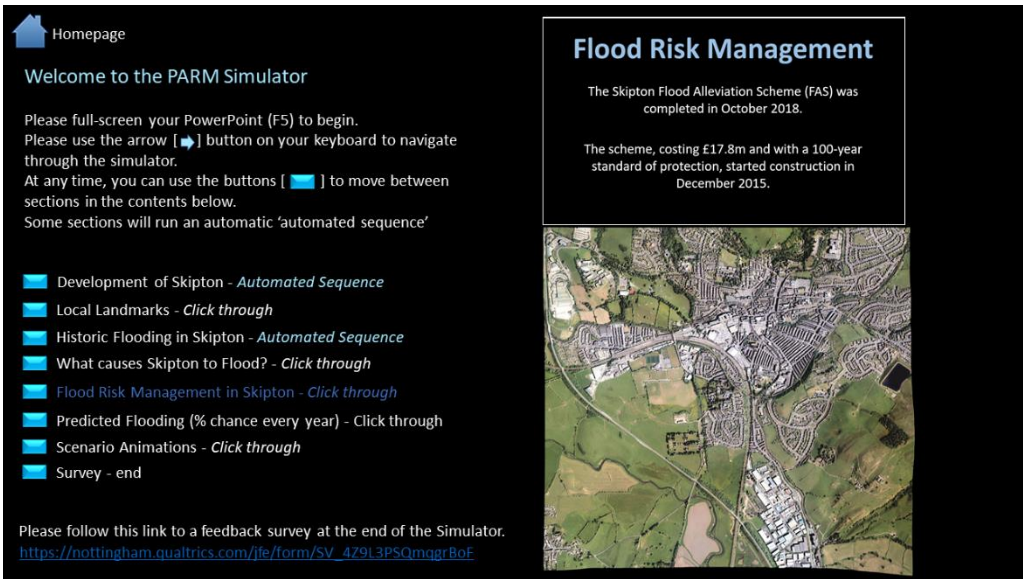

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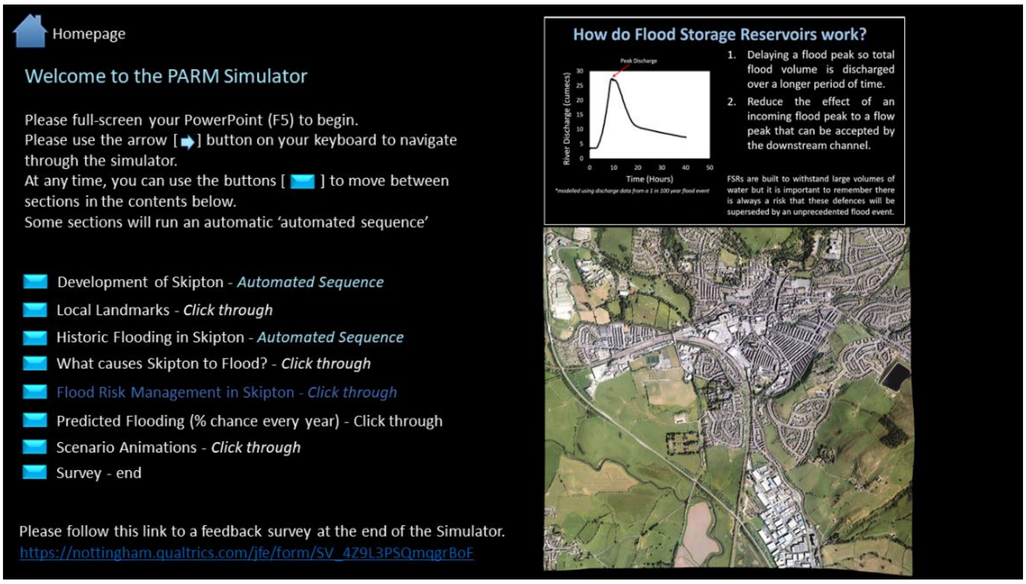

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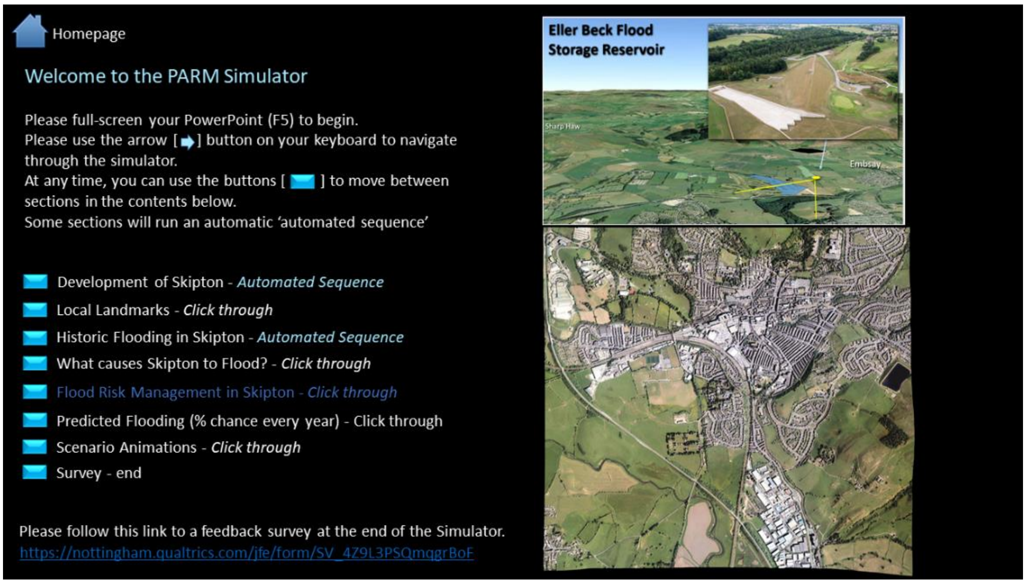

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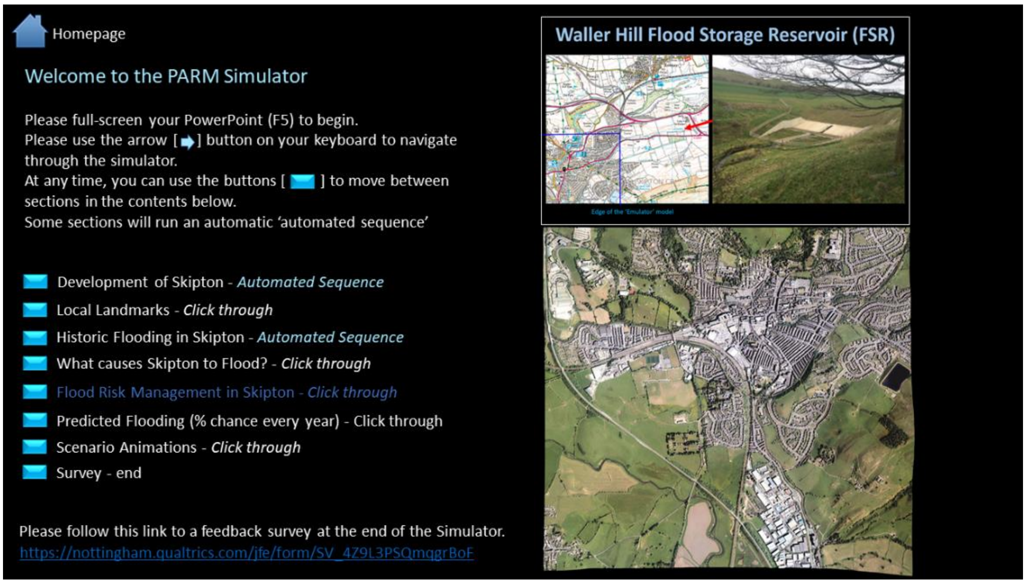

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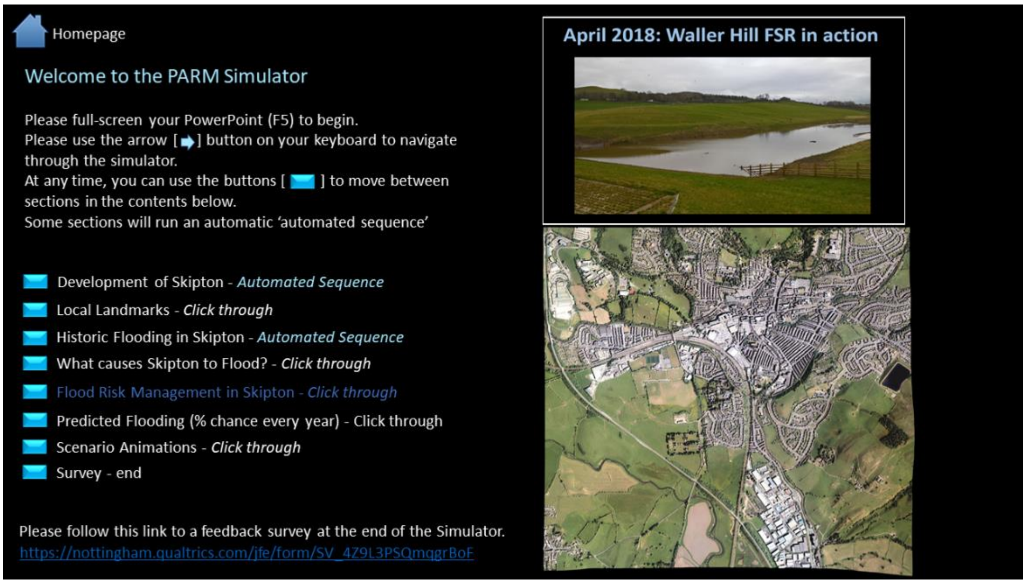

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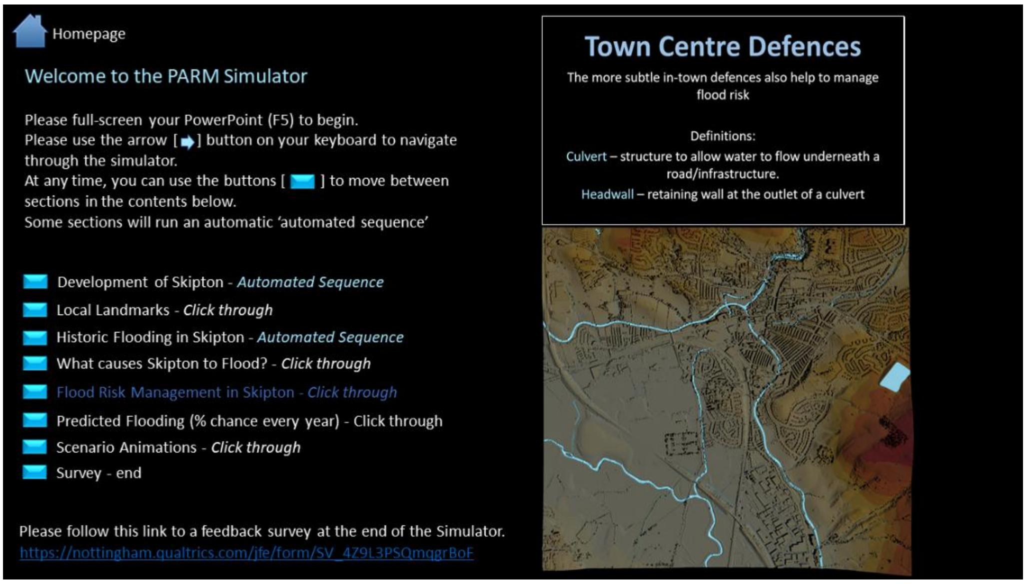

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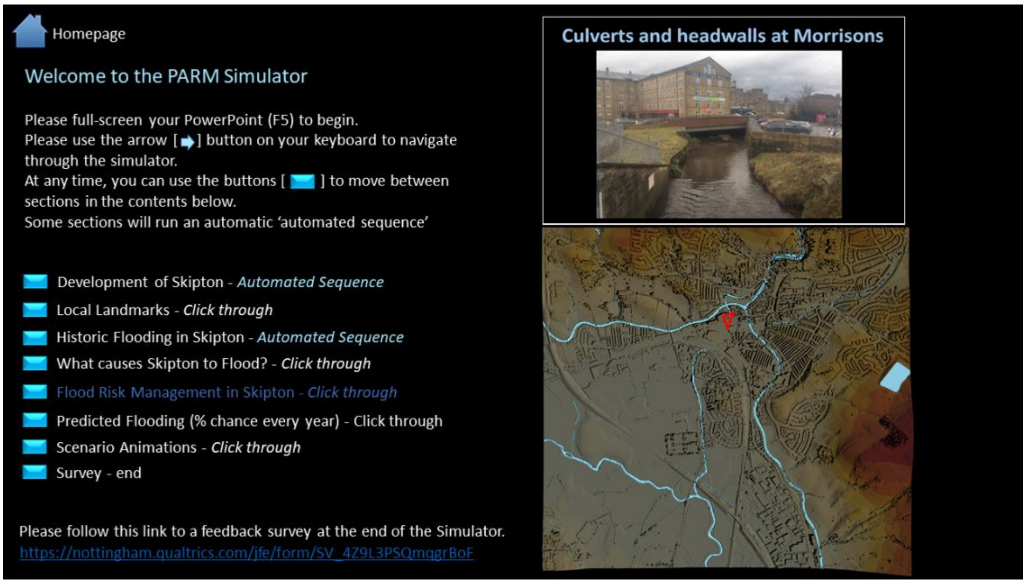

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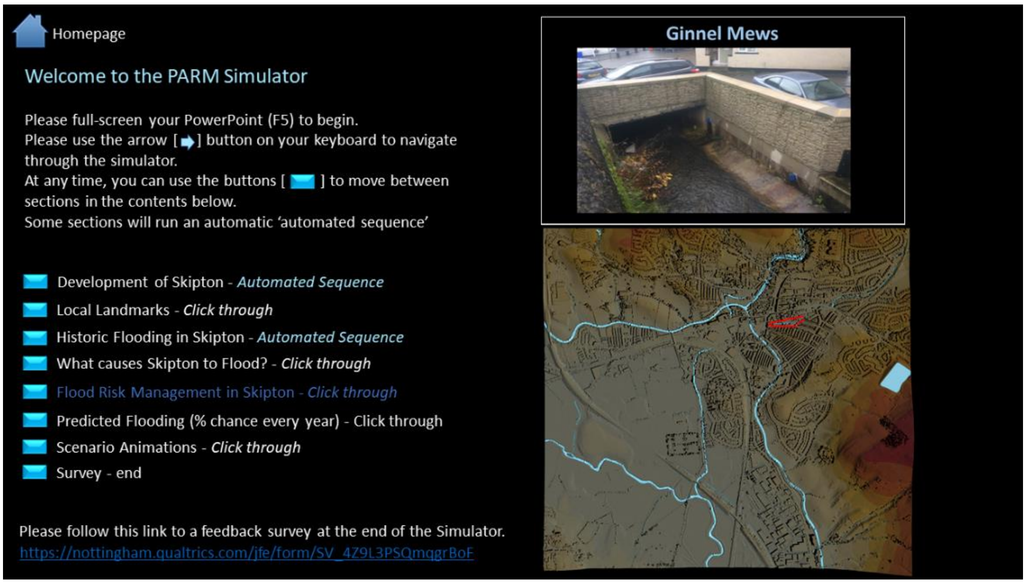

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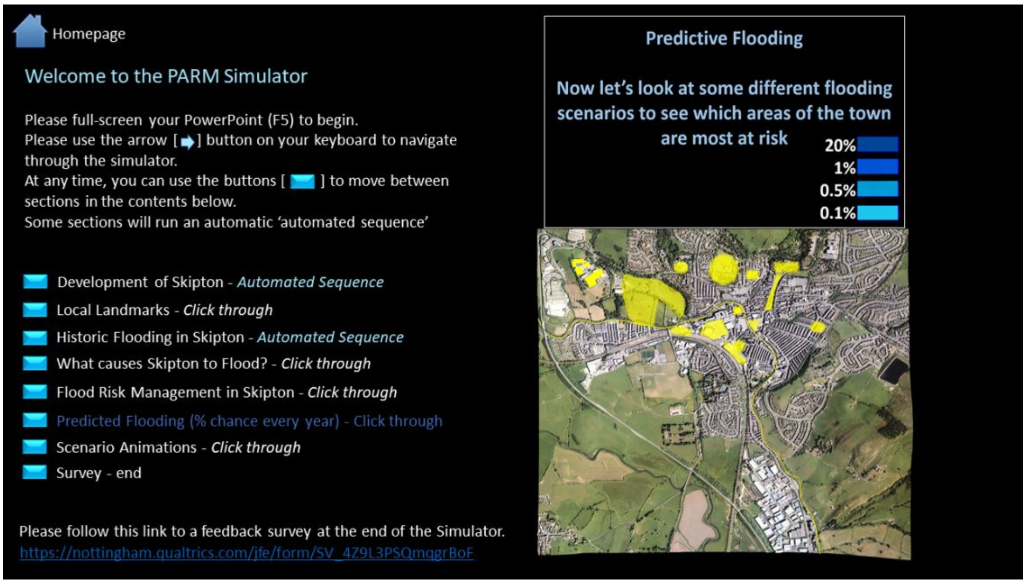

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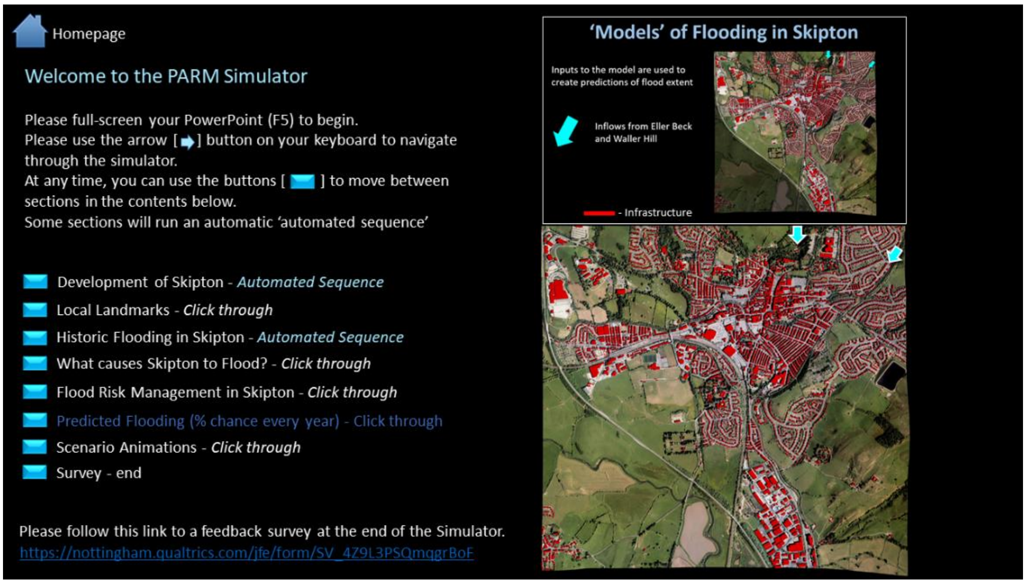

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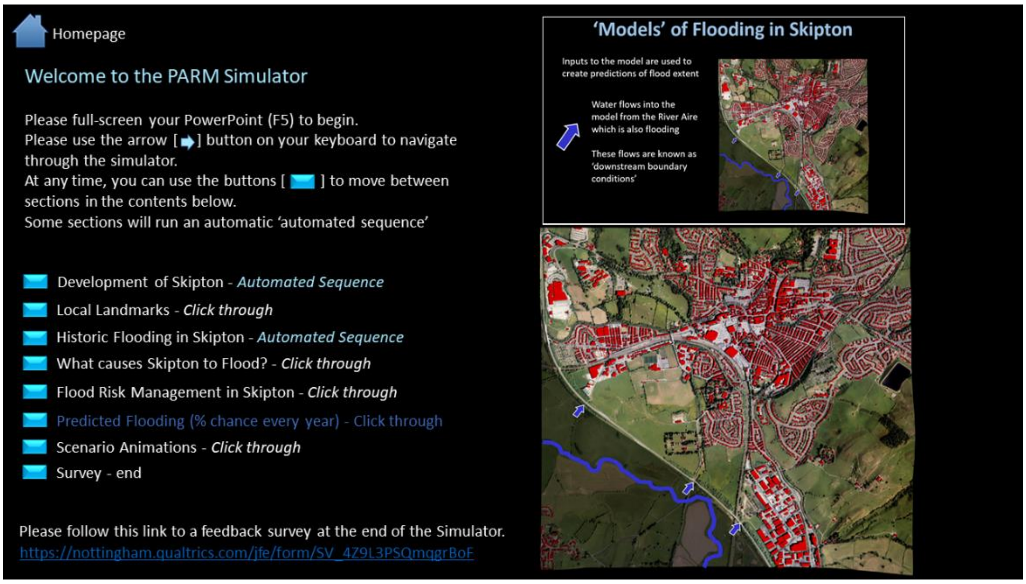

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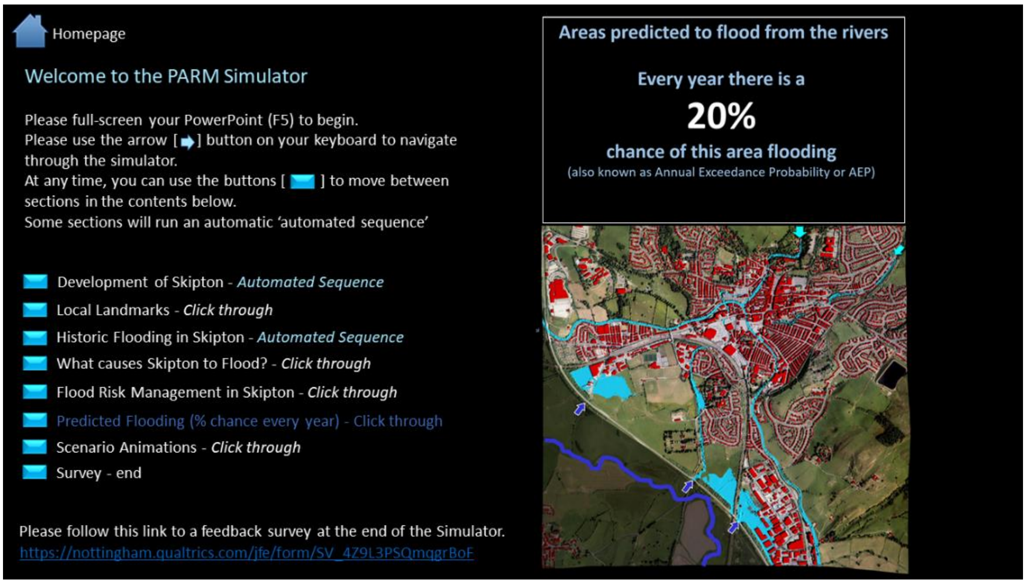

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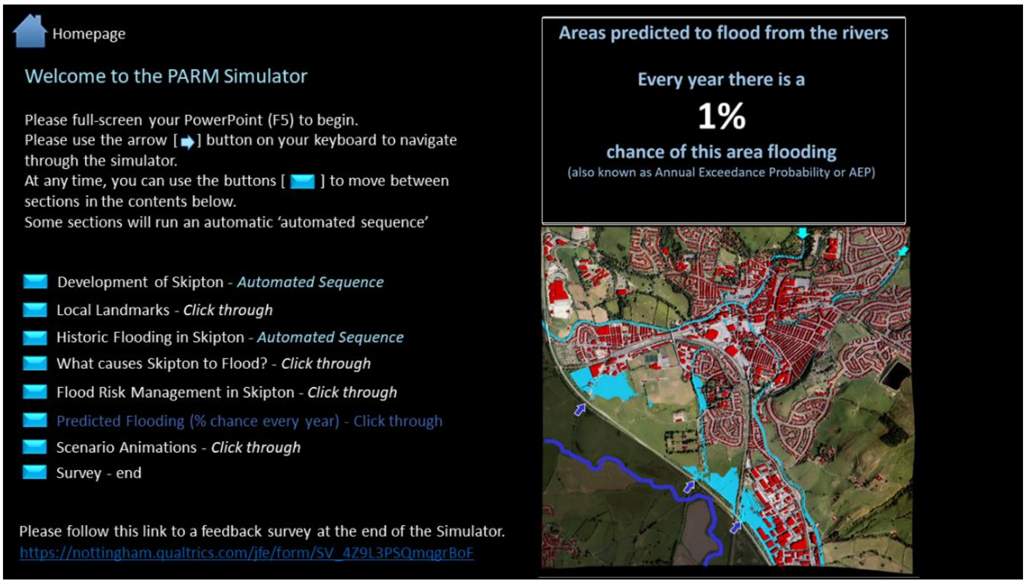

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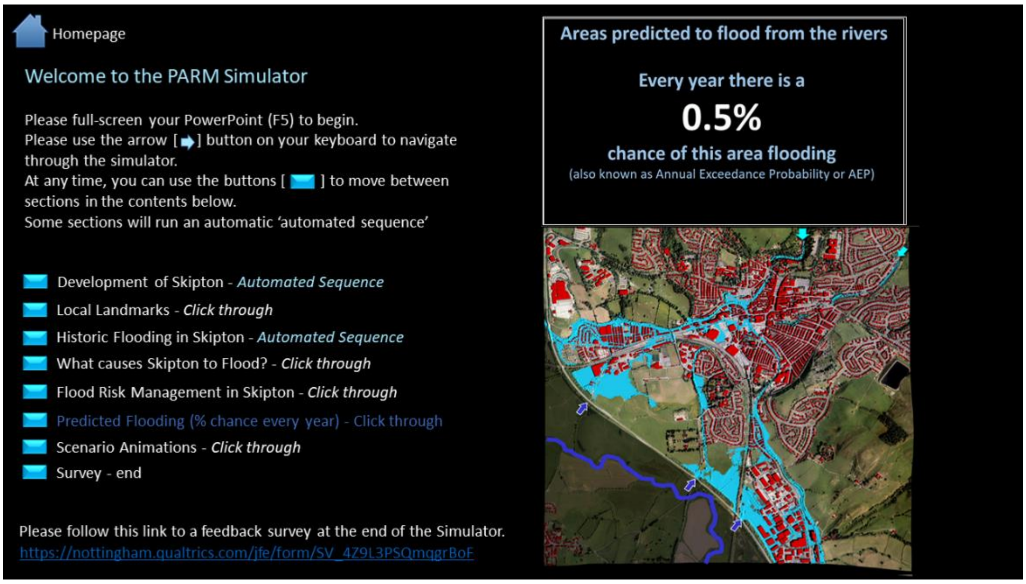

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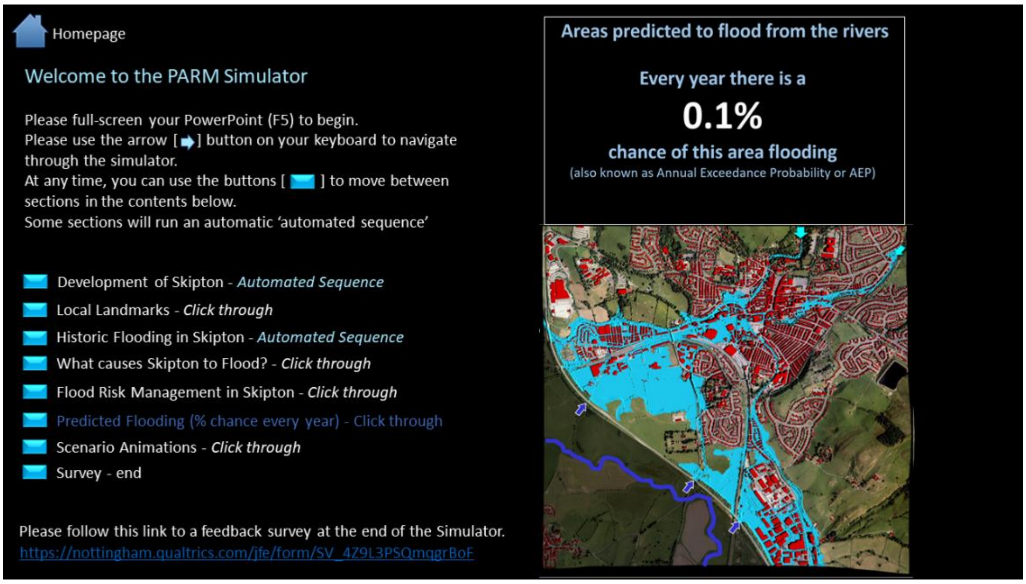

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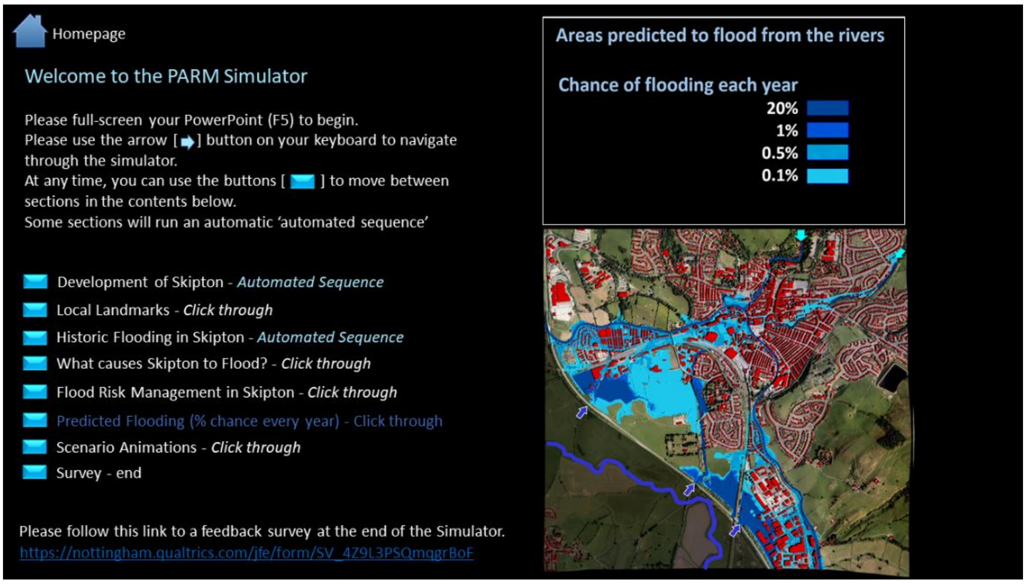

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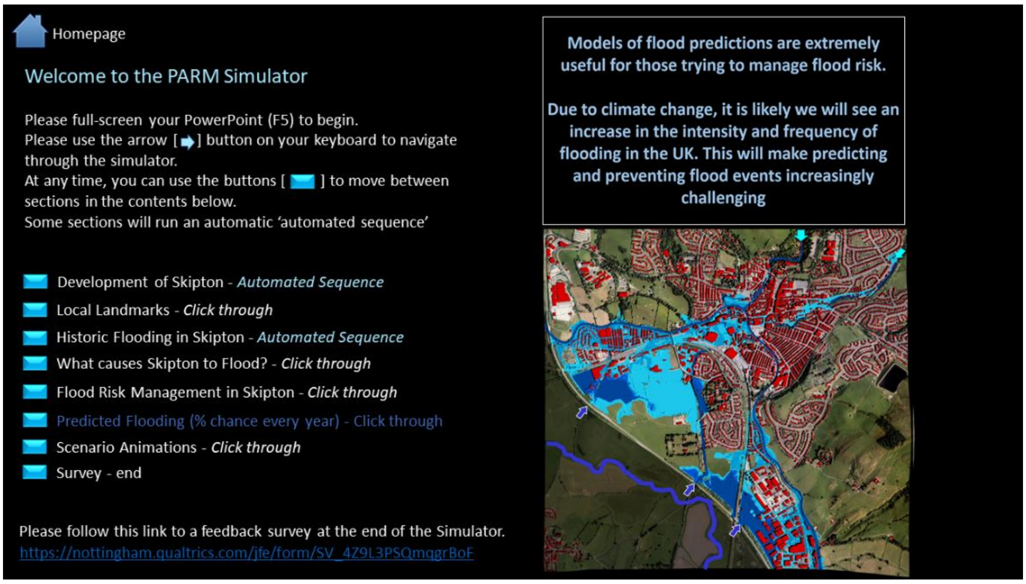

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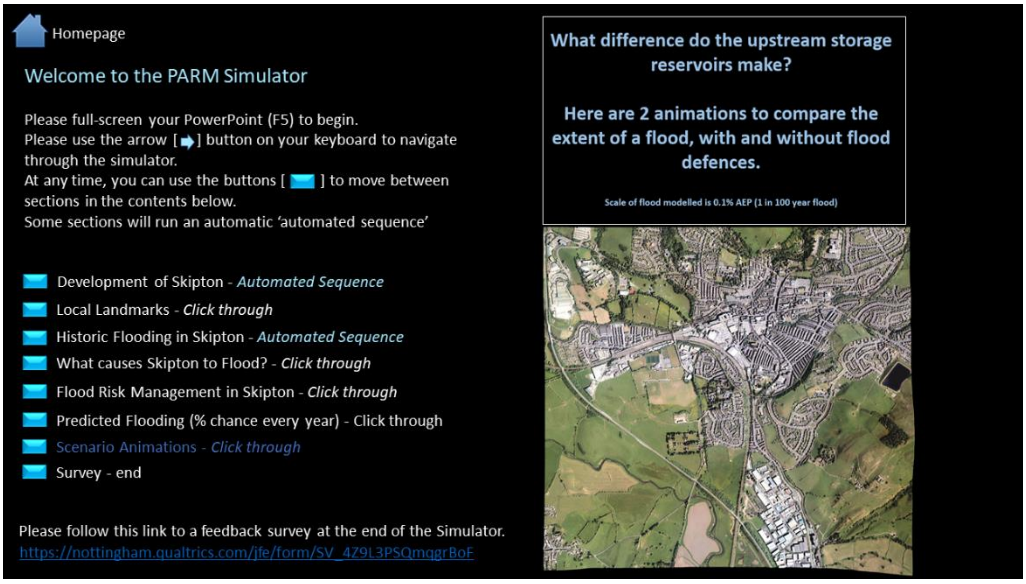

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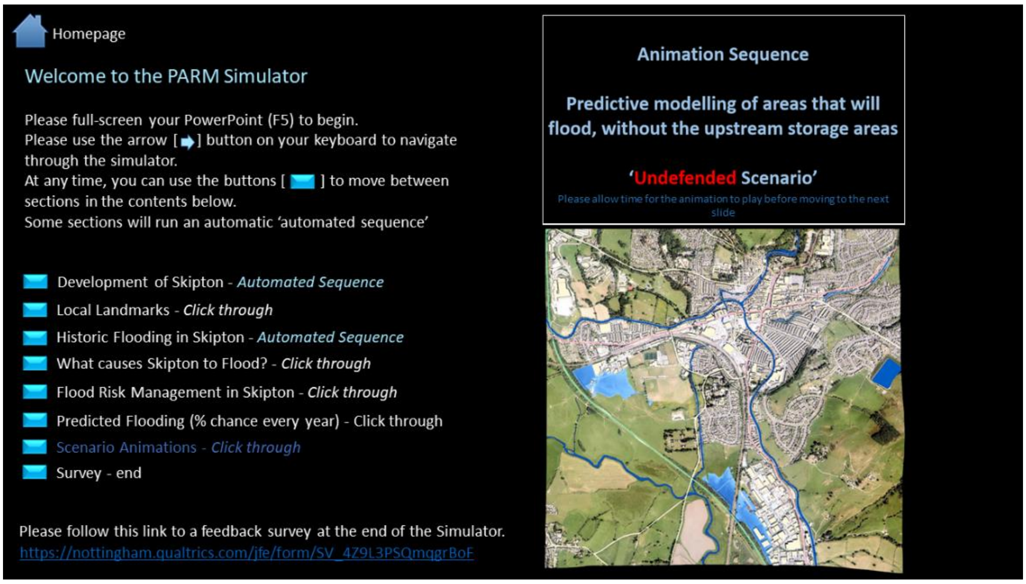
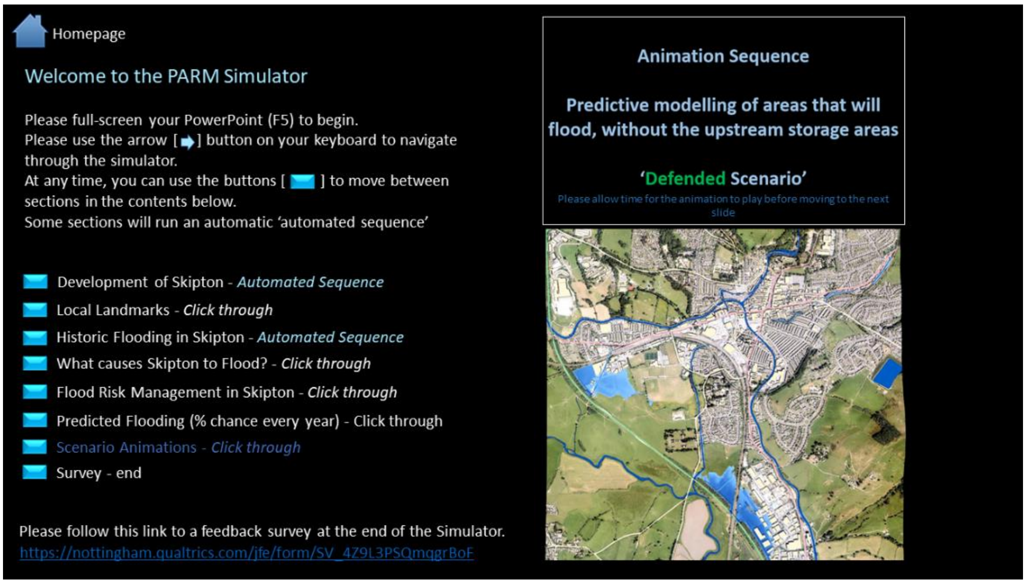
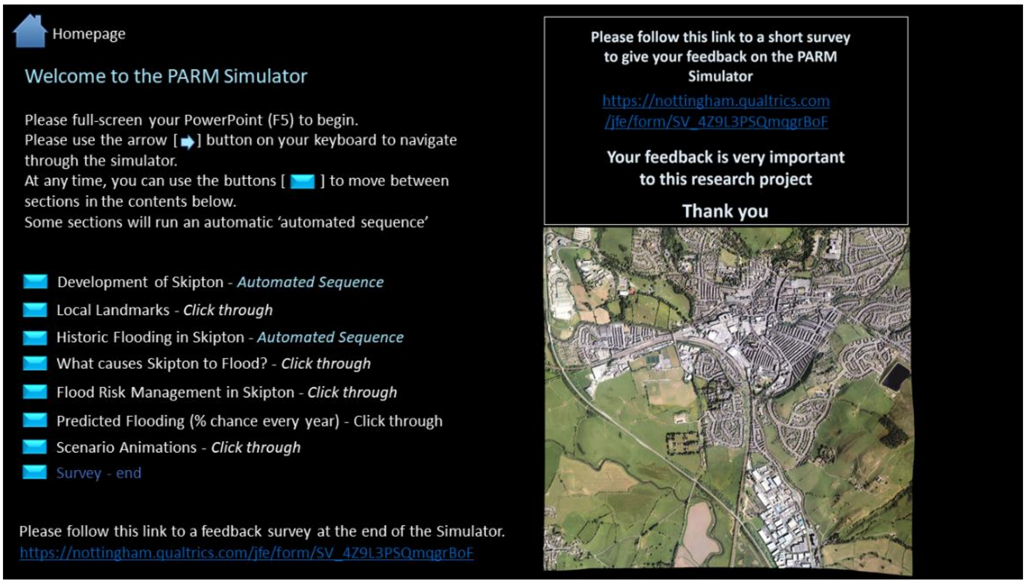


Slide 50



Slide 51

Slide 52



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Appendix 2 Questionnaire distributed online through Qualtrics Survey

SIMULATOR FEEDBACK SURVEY - PARTICIPANT INFORMATION

Now that you have navigated yourself through the simulator, it would be appreciated if you could please take this feedback survey. This questionnaire is made up of 4 sections: General Information, User-Experience, Learning-Experience and Public Engagement. It will take between 5 -10 minutes of your time. Each section has a series of short questions that involve ticking boxes and some questions require slightly longer answers.

This questionnaire is a part of a Masters of Research Project at the School of Geography, University of Nottingham. I expect to present findings from this research in a thesis, and in academic journals. All data collected in this questionnaire in anonymous and so no participants will be able to be identified in the research outputs.

There are no foreseeable risks involved in taking part in this questionnaire. Taking part in this study is entirely voluntary and you may withdraw from the research project at any stage without having to give any reason and withdrawing will not penalise or disadvantage you in any way.

This research has been approved by the School of Geography Research Ethics Committee. If you have any further questions about participating in this research, please contact me or my supervisors:

Researcher: Emily Richardson (lgyelr@nottingham.ac.uk)

Supervisors: Gary Priestnall (gary.priestnall@nottingham.ac.uk) or Matthew Johnson (m.johnson@nottingham.ac.uk)

PRIVACY NOTICE FOR RESEARCH PARTICIPANTS

For information about the University's obligations with respect to your data, who you can get in touch with and your rights as a data subject, please visit: https://www.nottingham.ac.uk/utilities/privacy.aspx.

Why we collect your personal data

We collect personal data under the terms of the University's Royal Charter in our capacity as a teaching and research body to advance education and learning. Specific purposes for data collection on this occasion are so that future contact can be made to carry out further research based on the answers given in the questionnaire.

Legal basis for processing your personal data under GDPR

The legal basis for processing your personal data on this occasion is Article 6(1e) processing is necessary for the performance of a task carried out in the public interest.

How long we keep your data and how will it be stored

The University may store your data for up to 25 years and for a period of no less than 7 years after the research project finishes. The researchers who gathered or processed the data may also store the data indefinitely and reuse it in future research.

Measures to safeguard your stored data include that all data will be stored infolders on the UoN OneDrive. Microsoft OneDrive is an ISO 27001 information security management compliant service that allows secure and controlled sharing of data amongst the research team by encrypting data both in transit and at rest and is approved against the University's Handling Restricted Data Policy.

Who we share your data with

Extracts of data provided may be disclosed in published works that are posted online for use by the scientific community. Your data may also be stored indefinitely on external data repositories (e.g., the UK Data Archive) and be further processed for archiving purposes in the public interest, or for historical, scientific or statistical purposes. It may also move with the researcher who collected your data to another institution in the future.

PARTICIPANT CONSENT FORM: In signing this consent form, I confirm that:

- I have read the participant information and privacy notice.
- I understand the purpose of the research project and my involvement in it.
- I understand that my participation is voluntary, and I may withdraw from the research project at any stage without having to give any reason and withdrawing will not penalise or disadvantage me in any way.
- I have read the privacy notice and I understand how the data will be stored and safeguarded.
- I understand that while information gained during the study may be published, I will not be identified, and my personal results will remain confidential.
- I agree that extracts from the questionnaire may be anonymously quoted in any report or publication arising from the research.
- I understand that the personal data collected from this questionnaire will be accessible to the researcher and the research team only.

- I understand that I may contact the researcher if I require further information about the research, and that I may contact the Research Ethics Coordinator of the School of Education, University of Nottingham, if I wish to make a complaint relating to m/y involvement in the research.
- I am over 18 years old.
- I understand and agree to take part.

Section 1 – General Information

1. Please select your age group
- 18 – 24
- 25 – 39
- 40 – 60
- 60 +

2. Which of these describe you?
- Full-time employed
- Part-time employed
- Not employed for pay
- Caregiver (e.g., children, elderly)
- Homemaker
- Full-time student
- Part-time student
- Other (please specify)

3. Are you familiar with Skipton, UK?
- Yes
- No

4. If Yes

What is your experience of Skipton?
- I live there
- I have lived there
- I live in the nearby area
- I have visited Skipton before
- I have never visited Skipton before

5. Have you personally experienced a flood event in Skipton?
- Yes
- No

Section 2 – User Experience

6. To what extent do you agree with the statements below in relation to user experience. Please tick on box per row.

Statement	Strongly Agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
The Simulator was easy to navigate					
The Simulator's order of contents was logical					
The maps used were clear					
The maps used were useful in helping my understanding of flood risk					
The explanations on each slide were easy to understand					
I understood all the language used in the Simulator					
The images of previous flooding events were emotive and made an impact on me					
The 'local landmarks' helped me to orientate myself in the landscape					
The overall purpose of the simulator was clear					

7. Please rate the Simulator contents according to which sub-section you found the most engaging by dragging the option bars into your preferred order where 1 = most engaging, and 7 = least engaging. (Place your most preferred option at the top of the list.

Section	Rating
Development of Skipton	
Local Landmarks	
What Causes Skipton to Flood	
Historic Flooding in Skipton	
Flood Risk Management in Skipton	
Predicted Flooding (% chance)	
Scenario Animations	

Section 3 – Learning Experience

8. Mark out of 10 how easy it was to understand the following information presented on the simulator. (where 1 is very difficult and 10 is very easy)

Catchment Information	Score
Where the water flows (direction of rivers and streams, where the water flows when it rains)	/10
Where flooding is likely to occur	/10
How frequently places are likely to be flooded	/10
Land use and infrastructure	/10
Layout of the town and local landmarks	/10

9. Please rate the following items on a scale of 1-3, where 1 is 'very helpful' and 3 is 'not very helpful'. Please base your ratings on how helpful this information was to aid understanding of flood risk in Skipton.

Information	Rating
Seeing the modelled animation of both the undefended and defended flood scenarios.	
Seeing how frequently different sized flood events are likely to occur (e.g. 1% AEP, 5% AEP etc.)	
Catchment factors: the catchment shape, river tributaries and direction of rainfall, the canal/Eller beck overspill.	

10. What do you think are the three most significant risks or problems caused by flooding, generally? Please select 3 answers from the options below.

- Damage to homes and other infrastructure
- People's safety
- Land contamination
- Homelessness
- Post-event debris
- Damage to the landscape
- Evacuation
- Access to emergency services
- Access to transport
- Water hazards (strong current, cold water)
- Sanitation and disease
- Economic impact
- Stress on sewer system

11. What was the most interesting or surprising thing you learnt by using the PARM Simulator?

   ………………………………..

12. What information do you think was missing (if any) from the simulator that is needed to understand flood risk in general?

   …………………………………

13. Do you believe that your interaction with the Skipton PARM Simulator improved your understanding of flood risk and flood risk management?

- Yes
- No

14. If no, Why?

   …………………………

Section 4 – Public Engagement

15. Did you/will you sign up for the gov.uk flood alert scheme signposted at the end of the simulator?
- Yes
- No

16. If No, Why?
- I have already signed up to a flood alert scheme
- I don't live in an area at risk to flooding
- I did not see the link on the simulator
- Other

17. To what extent do you agree or disagree with the statements below in relation to user experience. Please tick one box per row.

	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
As a homeowner I have a responsibility to help manage my own flood risk					
Public engagement with local flood risk needs to be improved					
Residents are consulted about new flood management schemes to a good standard					
Generally, the public are well					

informed about their local flood risk					
I am concerned about natural hazards, such as flooding, increasing due to climate change					
Flood managemen t schemes are 100% effective at removing the risk of flooding					

18. Do you think there is value in engagement tools such as the PARM Simulator, as a resource for more effective communication of environmental risk?
- Yes
- No

19. Have you ever seen anything like the PARM simulator before?
- Yes
- No

20. If Yes, what have you seen that is similar?

……………………………………………..

21. Can you think of any other forms of engagement that you think could be used to help understand flood risk?

…………………………………………….

22. Do you have any other comments about your experience with the PARM Simulator?

……………………………………………