CRANFIELD UNIVERSITY

MATTIJN VAN HOEK

WEB-BASED SPATIAL DECISION SUPPORT TOOLS FOR SUPPORTING COMMUNITY RESILIENCE TO EXTREME WEATHER EVENTS

SCHOOL OF APPLIED SCIENCES
Geographical Information Management

MSc
Academic Year: 2010 - 2011

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ABSTRACT

This thesis describes a Web-based geographical information system (GIS) which serves to integrate and collate the model outputs and research findings of the Community Resilience to Extreme Weather project. Various geohazard datasets, including pluvial flooding, subsidence, heat waves, wind storm and drought were analysed and interpreted, enabling their visualisation for local-level impacts on three key stakeholder groups, namely householders, small and medium enterprises and local community policy/decision makers. As geohazards are interlinked is it important to present the effect of the composite and combined risk they pose to communities. This was achieved by superimposing the different geohazards over each other, presenting a combined risk according to given user-specified weightings. This allows stakeholders to analyse and interpret the spatial relationships of the various geohazards. Particular attention was given to the design of the graphical user-interface of a prototype application, serving as the direct link with the stakeholders. The application presented can execute extended geoprocessing services with multiple variables in a web-based GIS environment. Adobe Flex technology was used to draw benefit from the full client computing power available, as well as to allow the deployment of a content-rich interface. Web-based tools were included to provide stakeholders with powerful information to support the local decision making processes at the community scale in the London study area. Stakeholder feedback on the tools developed were analysed and presented, together with a discussion as to the role of such web-based tools for community decision making in London and elsewhere.

Keywords: web-based services, geohazards, extreme weather impacts, community response, climate change

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY OF TERMS

API	Application Programming Interface
CREW	Community Resilience to Extreme Weather
Defra	Department for Environment, Food and Rural Affairs
Double-caching technology	Data tiles are created beforehand and sent to the web client on demand, whereby the tiles received on the client side are stored in a client cache for re-use by future request
EPSRC	Engineering and Physical Sciences Research Council
GIS	Geographical Information System
HTML	Hypertext Mark-up Language
INSPIRE	Infrastructure for Spatial Information in the European Community
LAN	Local Area Network
Mash-up	Cartographic and geographic data
MXML	Macromedia eXtensible Markup Language
NPD	Natural Perils Directory
OGC	OpenGIS Consortium
PSMD	Potential Soil Moisture Deficit
RCM	Regional Climate Model
RIA	Rich Internet Application
SELRZ	South East London Resilience Zone
SME	Small-Medium Enterprises
SVG	Scalable Vector Graphics
UKCP09	United Kingdom Climate Projections 2009
WFS	Web Feature Service
Widget	An application, or a component of an interface, that enables a user to perform a function or access a service

1 INTRODUCTION

This thesis describes research whose key thrust is to highlight and demonstrate the role and opportunities presented for delivering natural hazard information to a range of stakeholders using web-based services in supporting decision making. An especial focus is drawn on exploring the consequences and impacts of future extreme weather events occurring at the local, community scale. Climate has never been a static phenomenon; it is dynamic and constantly changing over time. It is important to analyse the scale of climate change as this phenomena is now seen as the greatest global threat in the 21st century (Costello *et al.* 2009). The UK Climate Projections (UKCP09) funded by Defra were 'purposefully designed to meet the needs of a wide range of people who will want to assess potential impacts of the projected future climate and explore adaptation options to address those impacts' (UKCP09 2011). Based on empirical climatic recordings up to 1990, this initiative developed a range of predications of potential future climate change. UKCP09 undertook this for three time periods, namely: 2020, 2050 and 2080. Within each of these time periods, different probability levels are used, seeking to clarify the likelihood of the predicted events. These events are modelled to be interpreted in a meaningful manner. For instance, the temperature of 2050 is 'very unlikely to be less than' 19℃ or the temperature of 2080 is 'very unlikely to be greater than' 26℃. Decision-makers can then make rational and pragmatic decisions, affecting the communities they serve, upon these predictions.

There is a trend observed in the UK that there has been an increase of temperature of 1℃ in Central England since the 1970s (Jenkins *et al.* 2009). The UKCP09 predictions allow future trends to be derived probabilistically, in contrast to earlier global climate modelling outputs, and thus permit moving beyond such single figure predictions. However, in general it can be noted that there has been very little change in annual precipitation, but that the precipitation in winter is increasing and the precipitation in summer is corresponding decreasing. There is likely also to be a corresponding rise of temperature across the UK, but more in summer than in winter and more in parts of southern England than parts of northern Britain (*Op Cit*. 2009).

The datasets published by the UKCP09 weather generator are used as a key input for a research project funded by Engineering and Physical Sciences Research Council (EPSRC). This research project, entitled '*Community Resilience to Extreme Weather*' (CREW), co-ordinated by Cranfield University, seeks amongst other objectives; to derive sets of tools to facilitate local communities improve their resilience to future extreme weather events. The CREW research considers the local impacts of a range of different geohazards on householders, small-medium enterprises (SMEs) and on local, community-scale policy/decision makers. Geohazards are events and processes that present severe threats to humans, property and the natural and the built environment (Jaedicke *et al*. 2006). The geohazards investigated within the CREW project include pluvial flooding, soil subsidence, heatwaves, wind storm and drought.

Understanding the implications of the future projections of risk from these hazards is of the utmost importance in learning how communities can mitigate the effects of such geohazards. For example the heatwave of August 2003 resulted in 2,045 more deaths than usual in the period from 4 to 13 August, during which temperatures were above 30℃ in the UK (BBC News 2003). Fouillet *et al.* (2006) describe the same heatwave in France, where the death rate for the period from 1 to 20 August resulted in 15,000 more deaths than usual. This study concluded that heatwaves present a threat for the whole European population and in particular the vulnerability for elderly persons living alone. McMichael *et al.* (2008) further noted that, in particular, urban areas are more vulnerable to the effects of climate change. The urban heat island is a well-recognised phenomenon.

Identifying areas of greater vulnerability to extreme weather events places important information in the hands of decision-makers operating at the local community scale. The information that achieves this is often geographical in nature. However, decision makers may not possess formal GIS skills or have access to geographical software tools, less be able to interact with these key datasets with ease. There is a thus a need to develop tools to facilitate dissemination of this key information to this group of stakeholders. Delivering such tools via web-portals allows ubiquitous access, and helps also to raise awareness of the impact of extreme weather events. Ultimately this aims to provide the stakeholder with tools for improving the capacity for resilience of local communities (Porritt *et al*. 2009).

Making such key information accessible enables public sector institutions to create better services for local communities. This also creates opportunities whereby different stakeholders can be more involved in the decision making process (Defra 2008). The Mayor of London note in the draft Strategy of ‘Climate Change Mitigation and Energy’ that they invite stakeholders and the public to comment on this Strategy (Mayor of London 2010). For this, it is necessary that in the first place stakeholders and the public have access to crucial information to allow them to share such vital comments and to engage in the decision-making process. Decisions and policy needs to be made by those seeking to address the current and future vulnerability towards extreme weather events (Adaptation Sub-Committee 2011).

2 AIM AND OBJECTIVES

The research aim of thesis is to ‘investigate the utility of web-based spatial services, drawing on geographical information system (GIS), using geoprocessing tools, for demonstrating the impacts of extreme weather events at the community scale’. A case study is taken in the South East London Resilience Zone (SELRZ). Such impacts will be assessed under a range of scenarios, and will be used to evaluate and offer a range of associated coping measures to the wider CREW research project. The following objectives were set to achieve this:

1. To identify best-practices for web-based GIS applications designed to manage, manipulate and disseminate geoprocessing operations on multi-temporal extreme weather impact datasets;

2. To develop a web-mapping prototype and web-service designed to present and interrogate risk assessment model outputs for each of the selected geohazards;

3. To receive and reflect upon feedback of the designed prototype from various stakeholders who are involved within the CREW project.

3 LITERATURE AND RESOURCE REVIEW

This chapter describes an analysis and review of the geohazard datasets used in this research, and also presents a review of the fundamental aspects of web-based Geographical Information Systems (WebGIS). The chapter finally considers best practises for adopting WebGIS applications on the Internet. This research shares the immediate geographical focus of the CREW project, namely the five southern London Boroughs comprising the ‘South East London Resilience Zone’, or SELRZ, being Croydon, Bromley, Lewisham, Greenwich, and Bexley, see Figure 1.

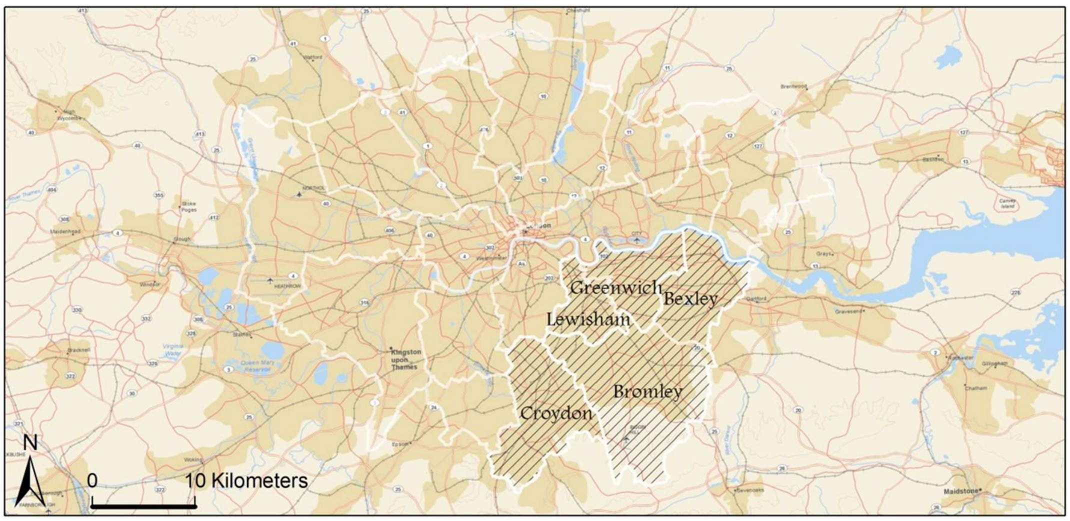

Figure 1 Study area comprising the ‘South East London Resilience Zone’

3.1 Review of resource data

This research was undertaken in the context of the wider CREW project, whose researchers had produced the geohazard datasets adopted in this study. This section describes each of the datasets used in turn.

3.1.1 Wind Mapping Data

The University of Birmingham have undertaken wind velocity modelling, producing datasets derived using the Hadley Centre’s HadRM3P Regional

Climate Model (RCM), in place of the UKCP09 weather generator used in other geohazard models (Baker *et al*. 2010).

The data delivered describes the threshold exceedence frequencies of the wind gust speed (V_G) and maximum hourly mean wind speed (V_H). The three threshold exceedence frequencies are based on the average number of days whereby there is a risk for damage to buildings (V_G>35 ms^{-1}); large vehicles (V_G>18 ms^{-1}) and pedestrians (V_H>15 ms^{-1}). Next to the baseline of each threshold exceedence frequency are delivered three projections for 2020 and similarly three projections for 2050.

The main changes presented shows that there is relatively little change from the baseline climatology, but for ~75% (central estimate 2050) and >95% (90% probability 2050) of the grid cells shows an increase in frequency however they remain low (Baker *et al*. 2010).

3.1.2 Heatwave Data

Research investigating the future trends of heat waves for London has been undertaken by Newcastle University, with data being prepared using the Tyndall land use model combined with remotely-sensed intra-urban temperatures and a building level land use classification of thermal characteristics (Porritt *et al*. 2009). Output data is constructed by a using the mean summer maximum and minimum temperature (T_{max} and T_{min}) for June-August. Together with the T_{max} and T_{min} values, the number of events is also calculated. An 'event' is considered as occurring when the temperature rises above 32℃. This resulting hazard raster dataset is then integrated with a population vulnerability raster dataset whereby the population of each electoral ward is normalised between 0 and 1 to characterise relative vulnerability. The result is a raster dataset that combines both the hazard and the relative population vulnerability that shows the relative vulnerability to the population at given location experiencing a heatwave (Porritt *et al*. 2009).

3.1.3 Clay-related soil subsidence data

Subsidence modelling datasets have been produced by Cranfield University (Blenkinsop et al, 2010) and build upon Cranfield's existing 'Natural Perils Directory' (NPD) (Jones *et al.* 1995). The effect of more extreme weather on the soil is the increase in probability of severe, prolonged drought. Subsidence is caused by the seasonal removal of moisture from the soil with the resulting stress in the soil leading to cracks and finally damage to building foundations or other infrastructure. If the removal of moisture is spatially inconsistent, this will lead to a fluctuating pattern of spatial soil subsidence. This increases the risk of damage to infrastructure in turn.

The possibility of clay soil-related subsidence occurring incorporates two major aspects. Firstly, a soil with clay substrate mineralogy, having the ability to shrink and swell under differing conditions is required. The London region contains many of such soil areas. Secondly, climatic 'drying' of the soil, as measured by the Potential Soil Moisture Deficit (PSMD) must occur, whereby high soil moisture deficit results in the shrinking of soil (and vice versa) based on the clay mineralogy – the realisation of a potential risk. The PSMD is a key factor that can be used to predict potential vulnerability of areas for clay soil-related subsidence since the formations of clay mineralogy will not change significantly by 2020 or 2050.

Based on the PSMD calculations, average clay-soil related subsidence are observed from 51mm for 2020 to 122mm for 2050. The increase in subsidence is not constant over the study area, since both local patterns of soil types containing shrinking clays, and the patterns of spatial climatic-induced PSMD are found to fluctuate across the study area. Variance in the spatial patterns of these factors affects calculation of the results of overall subsidence over the study area.

3.1.4 Pluvial Flooding data

The pluvial flooding data for London is calculated by University of Exeter (Chen *et al*., 2009), identifying regions where there is an increase of vulnerability. Calculations are undertaken based on the effect of different rainfall events occurring at differing locations. These calculations include local elevation, existing drainage, soil absorption rate and future rainfall series. The result is not an ordinary flooding map whereby the rainfall is consistent over the study area and the vulnerability of one area is seen to increase when rainfall is increasing (*Op Cit.* 2009).

Flood modelling results in datasets that identify the locations of multiple flooding events from many permutations of rainfall data, classified by both severity and frequency. The differences in flood depth correspond to the severity, whereas the number of events of a specific flood depth corresponds to the frequency. The dataset shows for each location the vulnerability to both the number of flooded events and the distribution of severity of these flooded events.

Findings show an increase of vulnerability in low-lying areas, areas that are surrounded by higher grounds and areas that do not have sufficient drainage system capacity. It does not necessarily follow that the vulnerability increases when the total discharge of the catchment increases. Indeed, findings identify that areas high in the catchment area far from the river can have a higher vulnerability compared to areas low in the catchment-area close to the river where the discharge is bigger (*Op Cit.* 2009).

3.2 Fundaments of Web-based Geographic Information Systems

This section starts with describing the transition from GIS to Web-based GIS and continues with presenting the best-practices of existing Web-based GIS applications and finish with a comparison of rich Internet applications (RIAs).

3.2.1 The Transition from GIS to Web-based GIS

In the early 1970s the new technology of Geographical information Systems emerged and a powerful tool became available for researchers undertaking geographic analysis. In parallel, the Internet emerged as a global networking system. Today, both GIS and Internet are widely accepted; GIS as representing 'powerful and integrated tools for storing, manipulating, visualizing and analyzing spatial data' (Dragicevic 2004) and Internet in the guise of the World Wide Web where data is made open and accessible to all users. These two new technologies developed initially in parallel, it was only in 1993 when the first web map viewer was developed by Xerox Corporation. From then it evolved from web-cartography, to Internet GIS, to geospatial web, to GeoWeb to the current form of *Web-based GIS* (Dragicevic *et al* 2011). Peng and Tsou (2003) describe the development path of GIS as the process from *mainframe GIS*, where all the programs were in the same mainframe computer and access to data and analysis functions was possible by connecting to a mainframe server through 'dumb' terminals over LANs, to *desktop GIS*, where all the data, user interface and GIS functions are on one computer, to *distributed GIS*, where the user only relies on Internet and wireless networks to access GIS analysis tools and data, which are stored on a remote (or 'cloud') server.

The first viewers were built to show static maps; where it was possible to interact with the map by using pan-identify-zoom features and geo-visualization tools (Kraak and Brown 2001). Kraak and Brown noted how producers of Web-based GIS focussed on:

1. Tool development;
2. Geospatial data access; and
3. Effectiveness.

Yang *et al* (2005) noted how WebGIS was emerging as a 'means of communication, conveying information and knowledge to the public'; also noting how WebGIS should include spatial analysis capability instead of solely web mapping and data delivery. The demand for public access to geospatial data or digital spatial information has intensified since, and the use and development of WebGIS is increasing (Shyy *et al* 2007). In 2003 Peng and Tsou observed that an actual Internet GIS system would be limited by the speed of the bandwidth and that this would therefore potentially preclude interactive mapping and spatial analysis. This is being addressed with emergent high-speed network technologies. Peng and Tsou note they expect that 'Internet 2' will permit this problem to be addressed, and that applications for Internet GIS will be developed and operated with reasonable performance. Yang et al (2005) noted that alongside the rise of high-speed Internet infrastructure, WebGIS applications also are able to become very complex, involving large volumes of data and/or massive user interactions. This is decreasing the performance and effectiveness of the applications. Two challenges are identified that affect this performance:

1. It is seen as necessary to establish standards for publishing data so it is possible to share and interoperate heterogeneous data among different systems, different communities, and different users, as proposed by the Open Geospatial Consortium (OGC) (Buehler and Mckee 1998);
2. System performance needs to be improved so the time of transferring data is reduced to the minimum.

From 2007 the INSPIRE directive aims to establish a European Union spatial data infrastructure to assist in policy-making across boundaries and from local to supra-national level. The full implementation of this infrastructure is required by 2019 (INSPIRE 2007). INSPIRE is leading to the emergence and adoption of formalised standards for web-based services facilitating interoperability between computer systems. Standards are now available for a range of data and application services.

In seeking to address the issues outlined above, Yang et al (2005) describe a number of techniques for improving the performance of WebGIS for both raster data and vector data, being based on progressive transmission where image compression techniques are used to gradually extract and transmit raster data. The raster image is sent in pieces (tiles) from the server to the client side where the raster image is gradually reconstructed. There also arises a hierarchical or pyramid data structure if this is undertaken at differing levels of detail. This is termed a ‘caching’ technique such that data tiles are created beforehand and send to the client on demand. It is also termed a double cache technology if the tiles received on the client side can be stored in a client cache so the tiles can be re-used by future request (Wang and Hu 2009). For vector data the performance of data transmission is achieved through indexing. Indexing of the vector data can be undertaken spatially or thematically, where spatial indexing considers the size of each object. Conversely, thematic indexing considers feature attributes such as Postcode, address, telephone number etc. Since the performance of a distributed system is greatly affected by the volume of transmitted data it is of the utmost importance to reduce the transmission volume of data. This can be achieved through various compression techniques whereby lossless compression preserves all raster values, and lossy compression does not retain the exact values of each pixel (ESRI 2011).

With the increasing rise of Internet bandwidth speed and the growing power of sensor and platform technologies, the geospatial community is entering now a period of *distributed GIS*. Today, there is much data that has been collected and is made available on the Internet. However, much of this data has never been analysed exhaustively (Yue *et al.* 2011), for example remote sensed imagery. Geospatial users may therefore experience a data-rich environment, where new technologies are changing an actual analysis-poor environment (Di 2004). The analysis of data is usually undertaken by making use of geoprocessing workflows. These geoprocessing workflows consist of input datasets, geoprocessing tools and new datasets (output). This approach allows geospatial users to ‘chain’ together sequences of tools, whereby different tools combined can automate work and solve complex problems (ESRI Developer Network 2007). When these tools are used on the Internet is it important that the input and output requirements are well defined so they can be independently executable. In a desktop GIS system the output datasets of a geoprocessing workflow are physically archived data products, whereas the output datasets of a geoprocessing workflow within a distributed GIS system are *virtual data products* (Yue *et al* 2011). In the latter case, data products therefore do not necessarily exist in a permanent archive, being more transitory in nature.

As access to geospatial data becomes more widely accessible due the acceptance of OGC (Open Geospatial Consortium) interoperability standards, and as imagery and base-mapping become more easily and readily available, this in turn will foster development of distributed geoprocessing services. Such services will allow online users to access, assemble, model and analyse both data and geoprocessing resources based on their own needs (Tao 2001). The OGC has provided rules for geospatial processing services. These rules not only standardise input and outputs (requests and responses), but also define how a client can request the execution of a process and how the output from the process is handled (OGC 2011). A critical note of the feasibility of geoprocessing services is made by Friis-Chrisstensen *et al*. (2007) who argues that it will requires too much transport and geoprocessing of large amounts of data when large datasets are datasets are published as a Web Feature Service (or 'WFS', an OGC standard).

For calculations to be undertaken on such large amounts of data, not only must the appropriate OGC standards be subscribed to, but also web browser capabilities must be able to handle the tasks. Often, one implication of this is that the processing power of the geospatial user's system is not fully utilised. Accordingly, this results in enormous computational pressure bearing on the server-side environment at the same time that the processing power of the client-side remains barely used. Secondly, an HTML-based page, representing the predominant mark-up language for web pages, is seen as unsophisticated for both expressiveness and interactivity/interoperability required for actual WebGIS applications, due the static technology, as opposed to more-advanced dynamic 'rich-media' technologies. Thirdly traditional Web-based GIS applications are not developed cross-platform and are depending on the operation system platform, resulting in poor compatibility. (Shi *et al* 2011; Shen *et al* 2010; Wei *et al* 2010; Wang and Hu 2009).

One technology class seeking to address both the insufficient use of the browser capabilities and the simplicity of HTML are rich Internet applications (RIA) using technologies such as Silverlight, Flash and Flex. These technologies originated from Macromedia, Inc., but have since been integrated within the offerings of Adobe Systems, Inc. RIAs are able to 'combine the media-rich power of the traditional desktop with the deployment and content-rich nature of web applications' (Allaire 2002). Furthermore are RIAs able to store data on the client side (1), improve the basics graphics model of HTML (2) and has one environment that contain the application interface, the content and the communication between those two (3) (*Op Cit.* 2002). All together is this reducing the application load time, the bandwidth requirements and the server load. Several new products are appearing in the field of RIAs. For Web-based GIS applications has this brought a broad range of new developing opportunities (Wei *et al* 2010; Wang and Hu 2009).

3.2.2 Web-based GIS best practices

In seeking to develop prototype geohazard tools, it is important to identify first best practices adopted in other parallel web services. This section therefore presents a series of web-based mapping portals considered by the author as providing examples of best-practice in subjects as crime, statistics and health.

Local crime and policing website for England and Wales

(*http://www.police.uk/*). This is a website designed and builds by Rock Kitchen Harris. It is a website that provides a tool to portray crime in cities. By entering your Postcode, the tool shows, via a website page, the region of the Postcode, where the monthly crime rate is displayed in tabular and graphic form. Crimes are displayed by the use of a cluster technique, so multiple crimes that occur within a specific distance with each other will be clustered together and when the user zooms in to the cluster are the crimes displayed in the street of occurrence. To understand quickly the spatial representation of different types of crime, the website adopts a division of seven different crimes. These different crimes 'classes' can be individually selected where each of the colours is picked, in a way that clearly distinguishes each from each other. By clicking on the crime spot more information about the crime is shown in a popup window.

Mapping America: Every City, Every Block

(*http://projects.nytimes.com/census/2010/explorer*). This website from the New York Times, created by Bloch M, Carter S, McLean, A., uses the Census Bureau's American Community Survey based on samples from 2005 to 2009 and presents these census data across the USA. The power of this web mapping application derives from the use of Google Maps as a basemap, being both reliable and quick. The colours of this basemap are edited and changed into grey scale to optimise the visualisation effect of the colourful mash-up overlays. The colours used are clearly distinctive and relaxing for the eyes. The classification is based on five different classes and presented by dots. The dots represent a number of people with the dot size increasing as the scale becomes larger. By hovering over the map it also shows in black lines the boundaries of the census tracts when at small scales and counties when at large scale. Together with the black lined boundary shows it a popup with detailed information about the area.

Illinois Public Health Community Map

(*http://healthcarereportcard.illinois.gov/maps*). This is a US website from the State of Illinois created by IPRO eService's. It provides consumers with information about the quality of health care provided in Illinois and highlights socioeconomic and racial/ethnic disparities that may exist. This powerful web application is able to combine spatial information and interact this with complete information such as demographics. This information is presented by pie-charts and bar-charts. By doing this the website is able to present a combination of text, charts and maps. These charts and maps are selectable whereby the corresponding parts of the charts and maps are highlighted. Next to these selectable events is presented additional supporting information accessed through pop-up windows activated by hovering the mouse over the different communities on the map. Corresponding data are directly changed in the charts.

Drawing out best practice

Many more websites were visited and further to this the corresponding published papers were analysed when available (Boulos *et al.* 2010, Wood *et al.* 2007, Shyy *et al.* 2007, Boulos *et al.* 2005a, Boulos 2005b). Appendix A provides with more insight in the whole body of web-based mapping portals that were analysed. Table 1 presents the results of the analysis of the research to determine the best practices. Through the adoption of side-by-side comparison of the different features of a web mapping application is it possible to easily contrast the different sites. It can be observed that two commonalities between the sites are first the use of different basemaps, and second the ability to benefit from additional supporting information such as charts and info windows. The use of temporal data is only used in two applications whereas the ability to create *virtual data products* is not used within the applications analysed. In three of the ten web-based GIS applications is made use of geoprocessing services, what provides more functionality to the application.

A summation of the best practices observed in these web GIS sites can be identified thus:

- The use of carefully selected, sympathetic colour schemes for both mash-ups and basemaps / background imagery;
- Allowance for more detailed information at a larger scale and vice versa;
- Provision of supporting information about the areas of concern, through the use of both popup windows and charts;
- Provision of the ability to chart key data on the map, in a spatial context;
- The provision of access to temporal data by using time–slider events.

These observations are therefore adopted as candidate design features of the system as taken forward, being included in the design philosophy of the prototype developed as part of this research.

Table 1 Side-by-side comparison of Web-based GIS applications

	Ease of pan and zoom	Quality of basemaps	Changeable basemaps	Sympathetic colour schemes	Double caching technique	Additional supporting information	Temporal data (time-slider events)	Ability to create virtual data products	Geoprocessing Services
Local crime and policing website for England and Wales	+	±	-	+	+	+	-	-	+
Mapping America: Every City, Every Block	+	+	-	+	+	+	-	-	-
Illinois Public Health Community Map	±	-	-	+	-	+	-	-	-
UK Climate and Community Action Map	+	±	+	-	+	±	-	-	-
TNO Dinoloket	-	-	-	-	±	±	-	-	+
EPSRC Towards Successful Suburban Town Centers Project	+	±	+	±	+	±	-	-	-
Landis National Soil Resources Institute	-	±	-	+	±	+	-	-	-
Live train map for the London Underground	+	±	+	±	+	+	+	-	-
San Francisco Crime spotting	+	-	-	+	+	+	+	-	+

Note: '+': application fully supports the feature, '±': application support the feature but the quality is debatable, '-': application doesn't support the feature.

3.2.3 Comparison of RIAs

A rich Internet application (RIA) WebGIS could be based on several underlying, existing RIA products. Two popular RIA environments are Flex from Adobe Systems, Inc. and Silverlight from Microsoft Corporation.

3.2.3.1 Adobe Flex technology

Flex technology can be used to resolve the issues noted in traditional Web-based GIS applications. It is able to make full use of the client computing power and can access multi-sources, displaying both raster and vector data. In this case, vector data can be separated in content and form, enabling geographic information to be visualised dynamically. Cross-platform compatibility is ensured by the ubiquity of the Adobe Flash Player plug-in, being supported cross-platform and cross-system. In combination with the ESRI geoprocessing services is Flex highly suitable to undertake geoprocessing on the web (Xu 2010; Wei *et al* 2010; Wang and Hu 2009; ESRI 2010).

3.2.3.2 Microsoft Silverlight

RIAs based on Silverlight technology are made accessible through the installation of cross-browser and cross-platform plugins. Silverlight also permits the combination of video, interactive content and other applications within one environment. It integrates with a variety of Microsoft's wider software technologies. It allows the use of Scalable Vector Graphics (SVG) technology, thereby supporting vector data management. Silverlight provides overall a powerful and dynamic connection with the user (Shi *et al* 2011; Yang *et al* 2010; Ping *et al* 2009).

3.2.3.3 ArcGIS Viewer/API for Flex

ESRI have recently released a series of developer tools, 'ArcGIS Viewers', developed in RIA environments, which allow customisation and production of live web-mapping environments. Versions exist for both of the key RIA environments noted above. It was decided for this research to adopt the ESRI FlexViewer platforms (ArcGIS Viewer for Flex) due to its capabilities, as well as the ubiquity of the flash browser plug-in.

Using Adobe Flex technology it is possible to integrate the ArcGIS Viewer/API for Flex. This enables the developer to build a dynamic RIA, drawing data directly from ArcGIS Server. Within this RIA it is possible to use the resources of ArcGIS Server as well as wider components and features of Adobe Flex. This makes it possible to enable and combine fully the strengths of both software technologies. One of these combined strengths is the ability to link feature services and geoprocessing models from ArcGIS Server, as well as the ability to create charts and graphs within Adobe Flex (Adobe 2011, ESRI 2010).

4 METHODOLOGY

In the previous chapter the literature and resource is reviewed. Various best-practices of web-based mapping applications were discussed. The chapter concludes with descriptions of the differences between RIAs. This chapter describes the proposed methodology to draw from this and to use the geoprocessing capabilities of a geographical information system to provide dynamic, on-demand models that run within such a RIA.

The research was divided in four elements that are interlinked, but can be discussed separately. The four different components are:

1. Data preparation and building of a geoprocessing model;
2. Publishing and running geoprocessing service in the server;
3. Inclusion of a geoprocessing service within a RIA;
4. Feedback on the prototype application.

4.1 Data preparation and building of a geoprocessing model

The literature and resource review conclude that the resources delivered are all based on severity of hazards, but the form and content vary for each of the delivered datasets. To compare and combine the datasets is it necessary that there is a uniform scale whereby the model output datasets are normalised.

Key to the development of the geoprocessing model is the ability to allow interactive weightings and multi-criteria selections applied for each of the geohazards. To make selections and in order to allow interactive weightings, it was decided to develop a new geoprocessing model to enables these criteria.

For both the data preparation tasks and for the building of a geoprocessing model, ESRI's ArcGIS Desktop used. This software package provides both powerful tools to transform datasets and the ability to develop new geoprocessing models. Furthermore is ArcGIS Desktop very powerful in combination with ArcGIS Server.

4.2 Publishing and running geoprocessing service in the server

Both Open Source and commercially software packages can be used to publish spatial data and services. For this research it was decided to use ArcGIS Server to publish both the spatial data and, more important, the geoprocessing service. Geoprocessing models developed within ArcGIS Desktop can be published to the ArcGIS Server. In contrast, such geoprocessing models cannot (yet) be published using Open Source software as MapServer. This is a strong argument in favour of using the commercial proprietary software approach offered by ESRI. By choosing ArcGIS Server as platform to publish spatial data and tool layers as geoprocessing services, the service published also retains the legend settings from ArcGIS Desktop. This facilitates greatly the process of developing prototype applications.

4.3 Inclusion of a geoprocessing service within a RIA

To build an interactive mapping application, it was decided to adopt the Adobe Flex technology since it is able to make full use of client computing power, it can work on and present both vector and raster data and it is supported cross-platform and cross-system. In combination with the ArcGIS Viewer and API for Flex is it possible to build a Web based mapping application where both the data can be visualised and where it is possible to run geoprocessing services.

4.4 Feedback on the prototype application

To receive feedback on the prototype application developed, the tool was presented to the wider CREW project Advisory Board and a key stakeholder questionnaire was conducted by both the Advisory Board and other stakeholders and partners of the CREW project as well as Cranfield staff.

Figure 2 summaries the methodology in a block scheme discussed above.

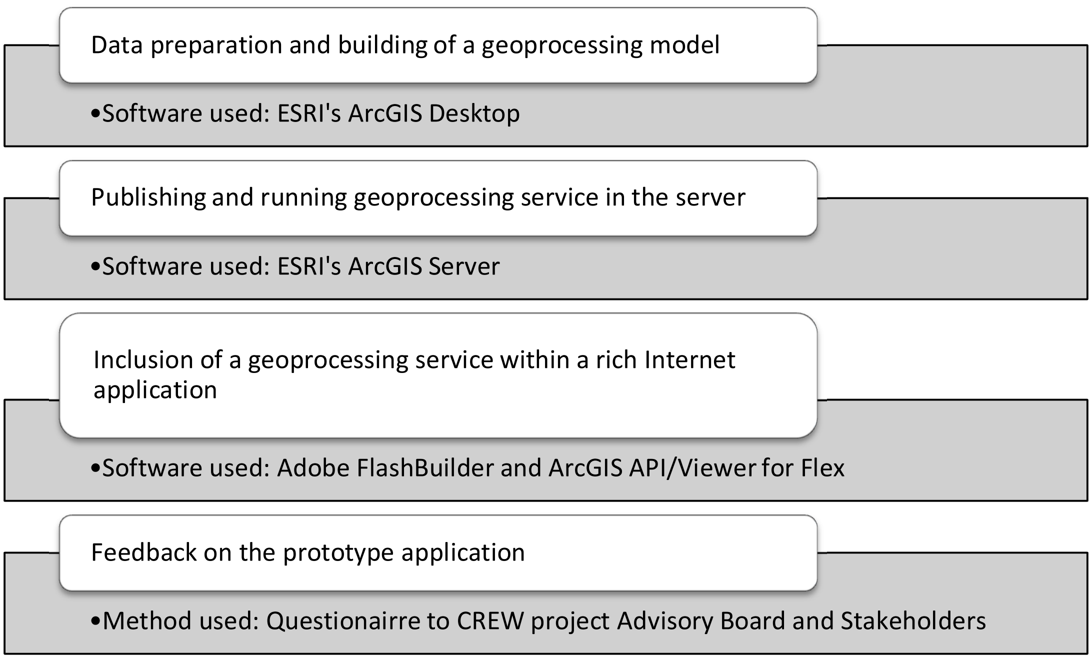

Figure 2 Block scheme of the proposed methodology

5 RESULTS

This section describes the results according to the methodology adopted, as described in the previous chapter. The results describe how geoprocessing models are built in ArcGIS Desktop and how this approach addresses data format problems with the differences between ArcGIS Desktop and ArcGIS Server. Also described is how it was found to be possible to include the published geoprocessing model in a RIA through the adoption of the ArcGIS

Flex API. The chapter concludes with an analysis of the results of the questionnaire, received from a wide range of important stakeholders.

5.1 Data preparation and building of a geoprocessing model

A geoprocessing model on the web is built by using a range of different software packages which contribute all together to an interactive application made then accessible on the Internet.

The objective of the geoprocessing model is to derive and present a vulnerability map where the user can change the value of importance of each of the geohazards considered. This is achieved by running the ArcGIS 'Weighted Overlay' tool, where it is possible to overlay several raster datasets using a common measurement scale and weighting. Each raster layer thus requires a scalable 'importance' or influence that can be set by the user in an interactive, easy-to-use, RIA. An additional objective for this geoprocessing model on the web is that the user can thus easily adjust the input selection based on the user priorities. The input selection can change for different years and within each year there are multiple scenarios. For the wind-related geohazards it also should be possible to select different categories for each scenario.

Based on the analysis of the data delivered, it was decided to prepare 42 different raster datasets for use as inputs. The numbers for each hazard representing the range of scenarios and temporal periods for each. The division of the raster datasets is as follows:

- 21 raster datasets for the hazard of wind;
- 7 raster datasets for the hazard of pluvial and fluvial flooding;
- 7 raster datasets for the hazard of soil subsidence;
- 7 raster datasets for the hazard of heatwaves.

Uniform scales of hazard severity exist across each raster datasets, but all data is calculated dependent on the nature of the hazard itself. For this the combination of the different hazards is not a straightforward process. In general it can be noted that all the outputs are converted to raster datasets with a uniform preference scale from 1 to 10 by using both the 'Feature to Raster' tool and the 'Reclassify' tool from respectively the 'Conversion' and 'Spatial Analyst' tool package within ESRI ArcGIS. To convert a feature layer to a raster dataset is it necessary that the selected field's data is in integer form. The delivered dataset with non-integer fields are therefore converted to logical corresponding integers. For example the range of the modelled subsidence is from extremely low to extremely high risk and this is converted to a 1 to 10 scale where 1 corresponds to extremely low and 10 to an extremely high risk.

For the modelled pluvial flooding the risk map adapted so that the 9 fields that relate to each of the 9 different hazards are combined into one field, where the most severe hazard is number 9 and the least severe hazard is number 1. The risk map is thus built based on the number of events that are passing the threshold for the different hazards. The events are derived from different permutations of rainfall data at the catchment scale (Simms and Hallett, 2011).

Since less severe hazards occur more often than the more severe hazards, so more weight is given to the more severe hazards. The Python expression used in the 'Calculate Value' tool multiplies the likely severity with the respective hazard class before adding the results together.

5.2 Publishing and running geoprocessing services in the server

A key aspect to the methodology employed is in executing geoprocessing models called directly from ArcGIS Server. A key difference in doing this in ArcGIS Server, rather than directly in ArcGIS Desktop, is that there are limitations of data types for the input and outputs of geoprocessing models in ArcGIS Server. The reason for this is that the input is submitted on the client side and the output is sent back to the client side, for this it is necessary that both the input and output are supported by the browser capabilities of the client. All the tools in the model are executed in ArcGIS Server and with this there are no any limitations or restrictions. Figure 3 illustrates a subset of the process in a block scheme, visualising the geoprocessing process in a way that the input and output are in the browser and the execution of the different tools as well as model iterations are undertaken in ArcGIS Server.

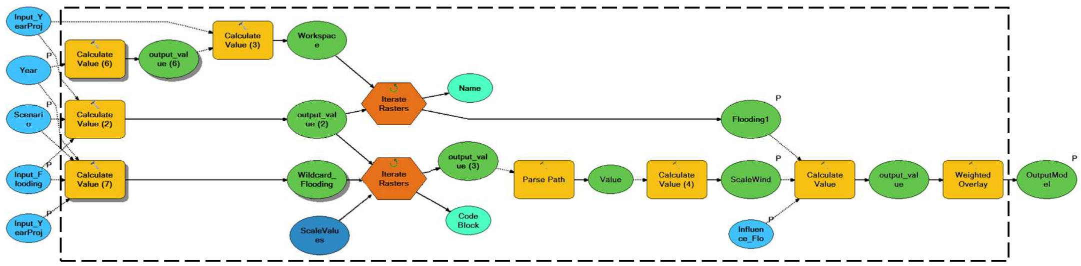

Figure 3 Simplified version of original geoprocessing model.

Note: *Light yellow ovals represent inputs, yellow rectangles are tools, green ovals are the output of the tools (which can be used as input again) and the orange hexagons are folder iterators. The tools inside the dotted box run from ArcGIS Server, where the input and output are only seen on the client-side*

To derive a geoprocessing model that executes well on the Internet by using ArcGIS Server is it important that it works in ArcGIS Desktop also. However, if a model runs in ArcGIS Desktop 10 it was found that this does not necessarily mean that it will also run on ArcGIS Server. One of the limitations of the ESRI tools established by this research is that by running a geoprocessing model on the web, raster datasets and tables become excluded from any calculation as possible inputs. Furthermore, it was found that it was not normally possible to produce raster datasets as outputs – a surprising discovery. Since the 'Weighted Overlay' tool has a weighted overlay table as input and a raster dataset as output is it important to circumvent this issue to tackle this issue. This is achieved by building the weighted overlay table by combining string values together. The different strings correspond to a concatenation of the catalogue path of the location of each raster file, the raster's weight of importance and the different scale values for each raster. Only the raster's weight of importance is then changeable by the user, achieved by setting this as a parameter in ArcGIS ModelBuilder. This was a key discovery in this project in presenting combined overlay data to the application user. This approach is extensible to other modelling contexts also.

The Weighted Overlay tool uses four vulnerability raster files to analyse combined, multiple vulnerability based on the weights of importance for each raster. Since 42 different raster datasets are prepared, is it important that the user can make a selection based on the users' preferences without seeing and scrolling through all of the prepared raster files. This is achieved by making the year of projection, the likelihood of calculated scenarios and the risk category variable all easily interactive by using a so-called 'accordion-navigation' tool. By using the 'accordion-navigation' approach, whereby options offered to the user can be opened and collapsed again as required, it was found to be possible to present the users with one choice at a given moment so as not to be overwhelming through having too many choices and selections. Figure 3 illustrates the geoprocessing process of making a selection based on the input, leading to the 'Weighted Overlay' tool for one of the four layers. The process identifies two iterating processes, where the first iterating process is collecting the catalogue path of the raster datasets and the second iterating process is selecting the scale values for the selected raster. The entire geoprocessing model is presented and explained in full in Appendix B.

The output of the model is a raster data layer. A raster data layer can normally not be drawn within ArcGIS Server. This problem is addressed by using a *result map service*. This service is created by publishing an ArcMap document with the geoprocessing model as a tool layer within ArcGIS Server, instead of publishing the Toolbox. This innovation, developed by the author, is central to the way the tool manages and presents multiple value criteria to the user. The output of tasks is accordingly drawn by the result map service on the server side and not drawn up on the client side. This makes it possible to display raster data types, which in effect is unsupported by the browser of the client. The tool was tested successfully in ESRI's ArcGIS Services Directory to determine if the geoprocessing model can run the model correctly, delivering the outputs required. The parameter descriptions of the model can be used as parameters in Adobe Flash Builder in combination with the ArcGIS API (Application programming interface) for Flex development environment.

5.3 Inclusion of a geoprocessing service within a RIA

The ArcGIS API for Flex represents a set of libraries which can be loaded from within Adobe Flash Builder to provide possibility framework for developing RIAs (RIAs) layered above ArcGIS Server. Flex enables the developer to create an interactive Web-based mapping application, which can be prototyped for quick evaluation. It is possible to develop custom applications and ‘applets’ by integrating ArcGIS Server maps and Web services within Adobe Flash Builder (an integrated development environment or IDE) using Flex with the ArcGIS API for Flex.

Flex applications are developed using MXML and ActionScript languages, where MXML is used to lay out the page and where ActionScript comprises an object-oriented procedural programming languages that enables actions to different objects (ArcGIS API for Flex, 2011). These actions are invoked by a positive return from, so-called, listener events.

The application built in Adobe Flash Builder use different libraries to understand the actions prescribed to the different objects. To call a library in MXML code the following code is used, Figure 4.

```
<?xml version="1.0" encoding="utf-8"?>
xmlns:s="library://ns.adobe.com/flex/spark"
xmlns:mx="library://ns.adobe.com/flex/mx"
xmlns:esri="http://www.esri.com/2008/ags"
```

Figure 4 Call of library in MXML

To set up a geoprocessing event, the MXML code needs to be directed to the correct geoprocessing model. The address needed for this is the URL found in the ArcGIS Services Directory. By assigning an ID to the geoprocessing event it was found by the author to be possible to invoke the event in the ActionScript when needed, Figure 5. The Sections below present only key software code fragments, the full source code being presented in Appendix C.

```
<esri:Geoprocessor id="gp"
jobComplete="onJobComplete(event)"
        url="http://mattijn-
pc/ArcGIS/rest/services/startmap7/GPServer/Model"
useAMF="true"/>
```

Figure 5 Setting up of geoprocessor event

The actions connected to the objects are invoked by using ActionScript code. Some actions derive from the different invoked libraries. The following ActionScript code (Figure 6) shows how various actions can be imported via the various enabled libraries.

```
import com.esri.ags.events.GeoprocessorEvent;
import com.esri.ags.layers.GPResultImageLayer;
import com.esri.ags.tasks.Geoprocessor;
```

Figure 6 Call libraries of ArcGIS API for Flex to setup connection with ArcGIS Server

A function provides a way to group actions with a single name (Learning ActionScript 3.0, 2011). The following ActionScript code describes the group of actions that is conducted after clicking a button. This button needs to submit the relevant data (in this case the input parameters for the geoprocessing model) and needs to activate a new function that manages the output of the geoprocessing model. By declaring a variable and assigning values to this variable in instantiating an object, it was found to be possible to submit the input parameters to the geoprocessing model in ArcGIS Server. It is then possible to register the function to 'listen' for the event by using the event source object. In this model the 'status_update' is used to activate the corresponding function (statUpdate) as the geoprocessing event is finished, Figure 7.

```
private function Button_clickHandler(event:MouseEvent):void
{
var params:Object;
params =
{
"Influence_Wind": txtWind.text,
"Influence_Flooding": txtFlooding.text,
"Influence_Subsidence": txtSubsidence.text,
"Influence_Heatwaves": txtHeatwaves.text,
"Input_WindCategory": txtInWndCgy.text,
"Scenario": txtInScen.text,
```

```
"Year": txtInYear.text
};
gp.submitJob(params);
gp.addEventListener(GeoprocessorEvent.STATUS_UPDATE,
statUpdate);
}
}
```

Figure 7 Simplified code to submit parameters to the geoprocessing service

Note: Function that describes the parameters wich will be submitted. A listener is added to receive continuous status updates.

Once the event listener receives notification that the job is complete it will trigger a new function that collects the data from ArcGIS Server and adds it as layer to the ArcGIS Flex Viewer, so presenting the results to the end-user. In the following ActionScript code, the function getData() is triggered if the job is complete and then, within the function use is made of an 'if-statement' to check if the event listener also has the status update of 'job complete', Figure 8. If this condition is met it instantiates a new object. This object is the output of the geoprocessing model as identified, having a unique job id and the output parameter as known in ArcGIS Services Directory. This object is subsequently added to the map as new layer.

```
private function getData():void
{
if(txtMessage.text == "Map is successfully created") {
myImageLayer                                           =
gp.getResultImageLayer(theJobId,"OutputModel9")
myImageLayer.name="Output Geoprocessing";
map.addLayer(myImageLayer,-1);
}
else {
Alert.show("Map error, try again");
}
}
```

Figure 8 Simplified code to add results to the map

Note: Function that describes how to add the result to the mapping application when it receives the status update of the ArcGIS Server geoprocessing service that the 'Map is successfully created'.

All together this process results in a comprehensive rich Internet web-based GIS application that is accessible by the client, embodying the novel approaches of this research in connecting ArcGIS Server and the model builder tool's geoprocessing server to support a user enquiry. In chapter 3.2.2 are the web-based GIS best practices discussed and based on the derived priorities is the prototype application developed. Table 2 represents an overview of the strengths and weaknesses of the prototype developed. Most of the best-practices are included, except time-slider events as well as additional demographic information.

Table 2 Priorities of prototype WebGIS application

	Ease of pan and zoom	Quality of basemaps	Changeable basemaps	Sympathetic colour schemes	Double caching technique	Additional supporting information	Temporal data (time-slider events)	Ability to create virtual data products	Geoprocessing Services
Prototype CREW Vulnerability Mapper	+	±	+	+	+	±	-	+	+

Note: '+': application fully supports the feature, '±': application support the feature but the quality is debatable, '-': application doesn't support the feature.

Figure 9 visualise a screenshot of the application build, where the user-specified weightings can be changed in the *widget* on the right as well as the year of production, likelihood of scenarios and the risk category for the wind speed. Furthermore is shown a widget (bottom left) that can provide additional supporting information by creating an elevation profile chart on a user-specified line. Another widget enables the integration of Google Streetview to aid navigation around the study area. A full walkthrough of a typical session is accessible in Appendix D.

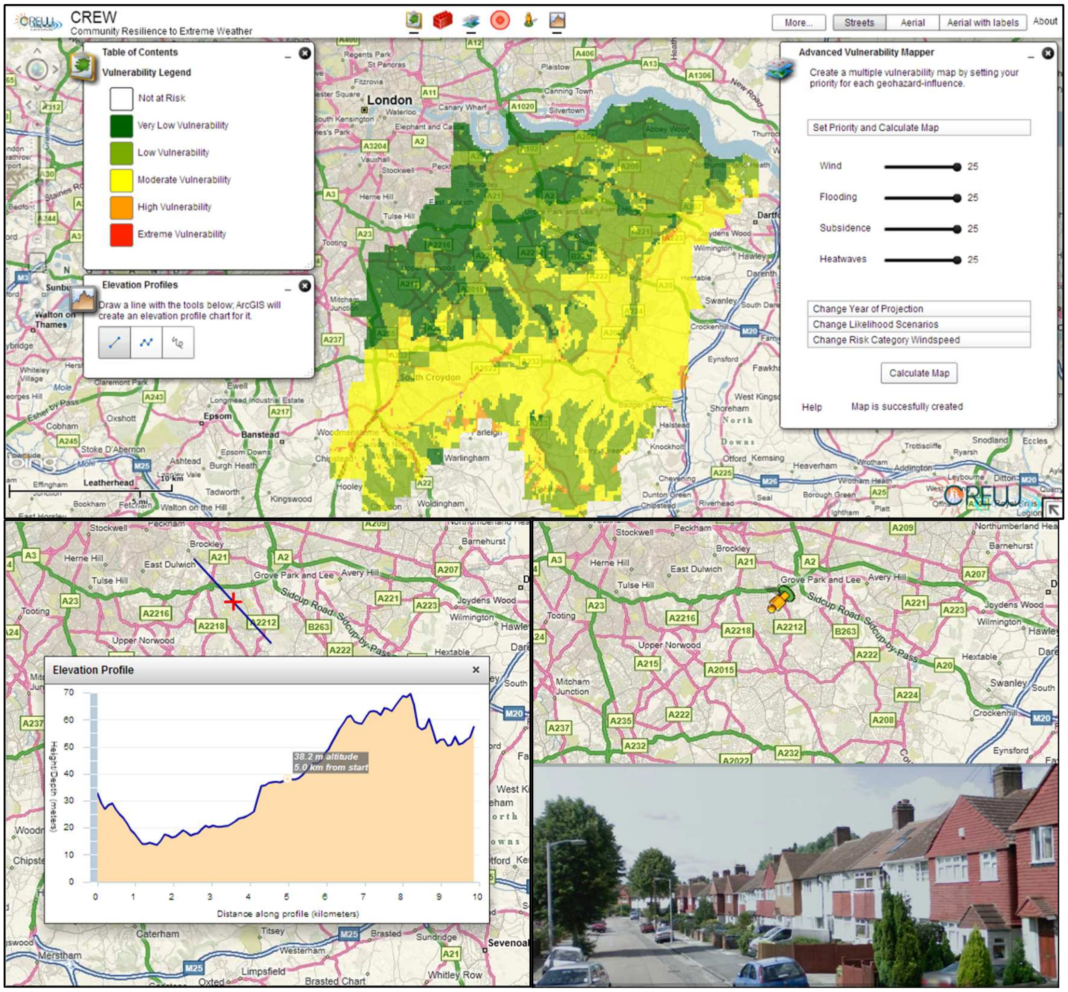

Figure 9 Prototype CREW Vulnerability Mapper

Note: the screenshot of the application on the top presents a virtual data product that is created based on the user-specified weightings and selections. The screenshot bottom left presents a widget that provide additional supporting information by creating an elevation profile chart whereas the screenshot bottom right present the integration of Google StreetView to aid navigation around the study area.

To prototype the application, a number of production servers were used to publish the tool, Figure 10. This tool was then used to elicit stakeholder responses.

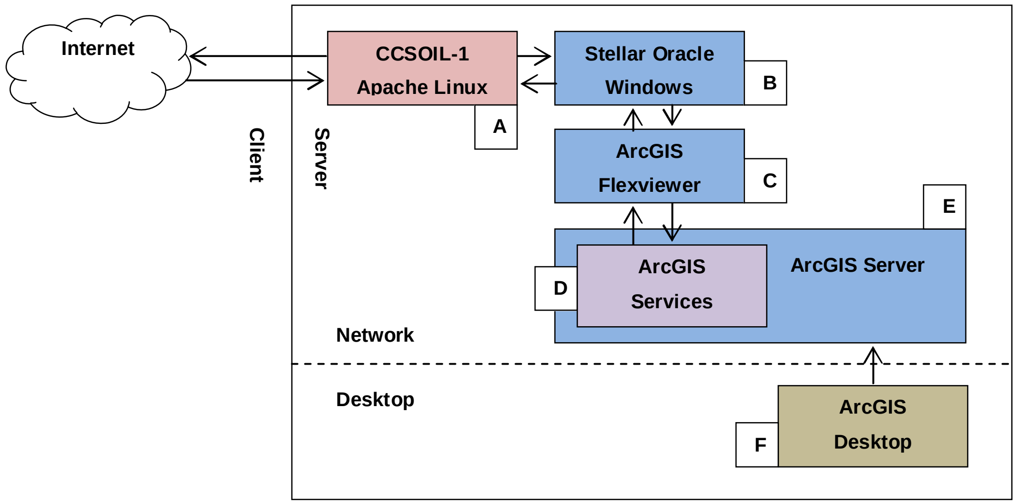

Figure 10 Describes the followed approach to set-up the ArcGIS Flexviewer inside the test servers in Cranfield University.

A test server '*ccsoil-1'* was used, provided by the CREW project team in Cranfield University. This server runs on the open source 'Apache' webserver in a Linux environment. ArcGIS Server runs on a different parallel server named '*stellar'*, having an *Oracle* installation for the webserver in a Microsoft Windows environment. To access the ArcGIS Services Directory on the *ccsoil-1* server a reverse proxy was used. A reverse proxy is a type of proxy server that can forward requests from the client on the public accessible server, such as *ccsoil-1* to another internal server behind a firewall, such as the *stellar* server. In this way the application can be presented for review by stakeholders and other users yet remain secure within the Cranfield IT environment.

5.4 Feedback on the prototype application

In order to ascertain the responses of likely end users for the tool developed, the author was fortunate to be able to meet with the wider CREW Project Advisory Board, presenting the tool in person at a board meeting, and providing a questionnaire for subsequent completion (returned to the author either by mail or completed online). The questionnaire is presented in Appendix E.

The findings of the questionnaire (presented in Appendix F) indicate that the application loads quickly and the interface is seen as user-friendly. The respondees see it as ‘good to excellent’ that this type of application is presented as a web tool, whereby a majority agree that a combined vulnerability scale with six classes is preferred; where green correspond to a low risk of vulnerability and red to an extreme risk of vulnerability.

For the user interface of the applications developed are the horizontal sliders (to allow changes to the influence of the different geohazards) rated as ‘fine to excellent’, where the accordion navigation (to specialise selections) rated as ‘good to excellent’.

Respondees are willing to wait 3 minutes to calculate a vulnerability map, but according to the respondees the calculation of the vulnerability map in the application developed is 10 – 30 seconds.

A series of applets, or ‘widgets’, developed to add depth and context to the results, were also assessed according to the respondees as ‘fine to excellent’, whereby was mentioned that these ‘widgets’ do indeed add depth and context to the results. The remarks given to the Google Streetview Application make clear that respondees prefer a resizable window and more information as to where Google Streetview is available within the map application.

Remarks were also given to the ‘science’ behind the data used in the application. This is quite expected as decisions could potentially be based upon these outputs. This request is fed back to the wider CREW project team as information is currently lacking as to the origin of the datasets as well as the assessment of the risk associated with the interpretation of the models.

6 DISCUSSION

The outputs of the predicted calculated weather patterns from UKCP09, and the consequent geohazard modelling outputs for a series of pertinent climate-related impacts for South East London are drawn from the CREW project for use in this research. This CREW project focuses on the impacts of extreme weather events and how local communities can become more resilient to the effects of these various impacts. The study area of South East London Resilience Zone ranges from a dense urban environment where the impacts of the extreme weather effects can have big influences in a metropolis like London, to a more rural environment towards the North Downs. The research presented here is also conducted in the context of the Spatial Development Strategy for Greater London, published by the Mayor of London. This key policy document sets out an integrated economic, environmental, transport and social framework for the development of London over the next 20–25 years where both geographical and locational aspects of other strategies of the Mayor of London are drawn together. In this strategy a response is discussed as to planning for the impacts of climate change, where the principle focus is seen to be to reduce carbon dioxide emission and energy and waste spillage (Mayor of London, 2011). One of the main outputs of the CREW project is the developing of prototypes whereby the outputs can act as a spatial decision support system to aid rational decision making. This research project therefore can be seen as directly addressing certain of the concerns of this policy document.

The Mayor of Londons office have been responsible for producing a series of mapping tools for addressing climate impacts, for example the London Heat Map Tool and the London Brownfield Land interactive map. These do visualise spatial datasets, but are predominantly static and provide unsophisticated interactivity as required for a contemporary WebGIS application seeking to interact and communicate important issues with the widest stakeholder community. The prototype tool developed within this research could form the basis for a new generation of toolkit for Boroughs, developers, policymakers and stakeholders, providing a better understanding of the complicated processes of spatial analysis through the adoption of more-advanced dynamic ‘rich-media’ technology. This research demonstrates that it is possible to visualise the many variables which are interlinked, placing the controls to achieve this analysis into hands of the web user. Furthermore the research shows that the respondees to the questionnaire react positively to the prototype web application. However, this also reveals a need for more information on the origin of the datasets, as a means to enhance confidence in the results, and also how to assess and interpret composite, combined risk maps. Feedback also identifies how respondees propose the idea to integrate the application with other sources of data such as geo-demographics. Web-based services from the Office of National Statistics, revealing clustered census data, lend themselves well for example to future integration with this type of prototype mapping approach.

This study has been able to demonstrate that according to demonstrable best-practices in web-based GIS it is important to adopt a design philosophy that combines both the sympathetic colour schemes and the functionality of geoprocessing services. It must be noted that in the developed application the spatial-temporal data analysis of different scenarios was not implemented as ArcGIS Viewer for Flex was used as viewer application what give both freedom and constraints. As ArcGIS Viewer for Flex is connected to ArcGIS Desktop is it possible to visualise how data changes over time, when the data contain an attribute which stores the date. However, scenarios do not necessarily comprise a date; as a result temporal change of different scenarios was not included.

7 CONCLUSIONS

This research allows the statement of a number of key conclusions, pertaining to the aims and objectives set out.

The design philosophy for the developed prototype was based on the identified best-practices for web-based GIS applications. This design philosophy includes the carefully selected, sympathetic colour schemes, the ability to provide additional supporting information and process, manage, and analyse spatial-temporal data whereby geoprocessing services are very powerful by delivering more functionality to the application.

The use of geoprocessing services in combination with web services was adopted to present and interrogate risk assessment model outputs for each of the selected geohazards. This makes it possible to run an automated geoprocessing model on the web. In combination with rich Internet applications is it possible to deliver a ready to use a tool in a user-friendly interface. The power of this system is not only the ability of accessibility to multiple layers, but also the ability to create new *virtual data products*. This enables the client to undertake analysis based on their own preferences, where the resulting map is a unique product. This represents a key outcome for the research.

The web-based mapping application provides users with a powerful yet simple-to-use and ultimately extensible analysis package. The research evaluated differing technical approaches to the requirements, settling on Adobe Flex technology in combination with the ArcGIS as a powerful development medium for such decision support tools.

Following the reflection on the feedback of the user questionnaire, it can be concluded that extensive stakeholder engagement is needed to explore the possibilities for combining datasets having differing spatial-temporal accuracies, as well as allowing for reliability tests to be conducted for the results in demonstrating the impacts of extreme weather events at the community scale. Furthermore, needing consideration is the elucidation of the origin of the datasets adopted and used in the research. Such supporting information should be placed for the user to consult within the prototype applications successors.

Thanks to the approach adopted, such impacts can be assessed under a range of scenarios, and may be used to evaluate and incorporate a range of associated coping measures within the wider CREW project. Web tools such as the prototype application presented can therefore be seen to provide a sound basis for supporting community-based decision making in cities such as London as to the impacts of future extreme weather.

Acknowledgements

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APPENDICES

Appendix A Web-based GIS best practices

UK Climate and Community Action Map

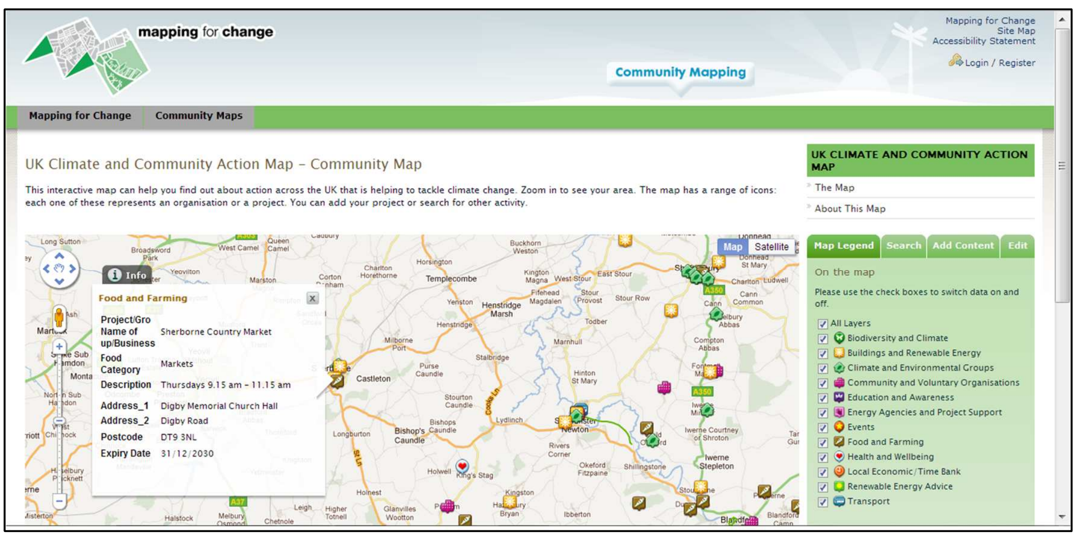
http://www.communitymaps.org.uk/

This map is being developed by the Low Carbon Communities Network and Mapping for Change for the Communities and Climate Action Alliance.

This interactive map can help you find out about action across the UK that is helping to tackle climate change.

	Ease of pan and zoom	Quality of basemaps	Changeable basemaps	Sympathetic colour schemes	Double caching technique	Additional supporting information	Temporal data (time-slider events)	Ability to create virtual data products	Geoprocessing Services
UK Climate and Community Action Map	+	±	+	-	+	±	-	-	-

Note: '+': application fully supports the feature, '±': application support the feature but the quality is debatable, '-': application doesn't support the feature.



San Francisco Crime Spotting

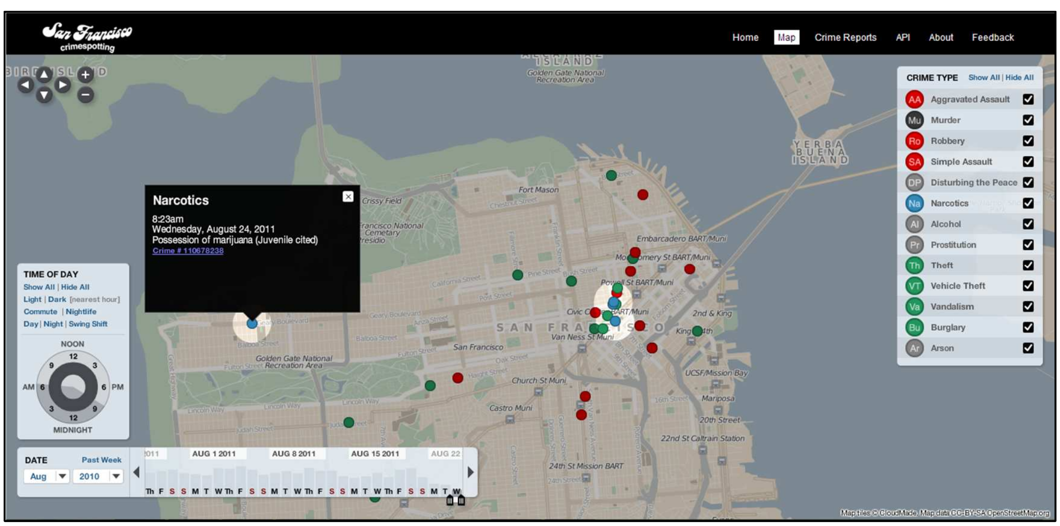
http://sanfrancisco.crimespotting.org/

San Francisco Crimespotting was designed and built by Stamen Design.

San Francisco Crimespotting is an interactive map of crimes in San Francisco, California, and a better way of understanding crime in cities.

	Ease of pan and zoom	Quality of basemaps	Changeable basemaps	Sympathetic colour schemes	Double caching technique	Additional supporting information	Temporal data (time-slider events)	Ability to create virtual data products	Geoprocessing Services
San Francisco Crime spotting	+	-	-	+	+	+	+	-	+

Note: '+': application fully supports the feature, '±': application support the feature but the quality is debatable, '-': application doesn't support the feature.



TNO DINOLoket

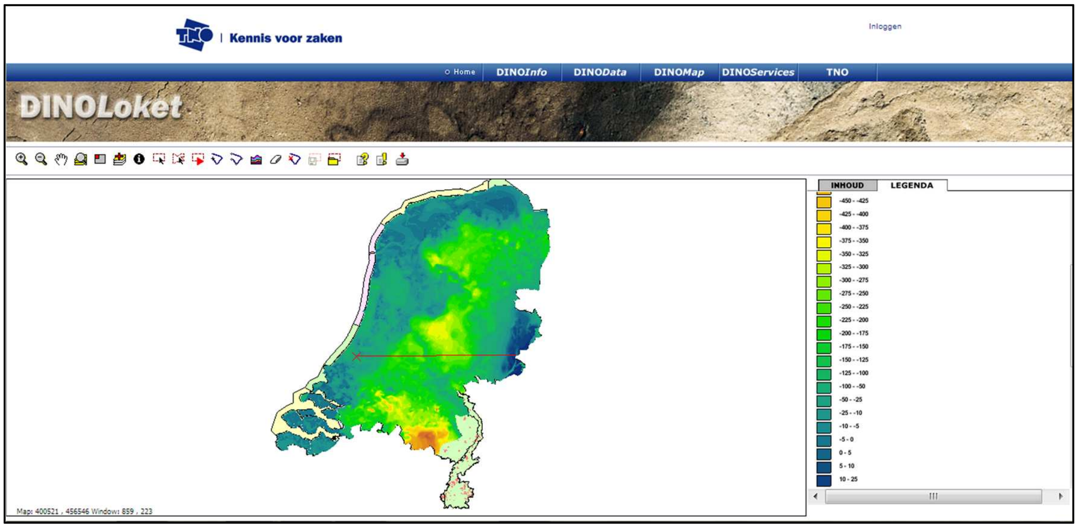
http://www.dinoloket.nl/

The application is developed by TNO. TNO is a Dutch Organization for Applied Scientific Research

The DINO system is the central repository for geoscientific data on the deep and shallow subsurface of the Netherlands.

	Ease of pan and zoom	Quality of basemaps	Changeable basemaps	Sympathetic colour schemes	Double caching technique	Additional supporting information	Temporal data (time-slider events)	Ability to create virtual data products	Geoprocessing Services
TNO Dinoloket	-	-	-	-	±	±	-	-	+

Note: '+': application fully supports the feature, '±': application support the feature but the quality is debatable, '-': application doesn't support the feature.



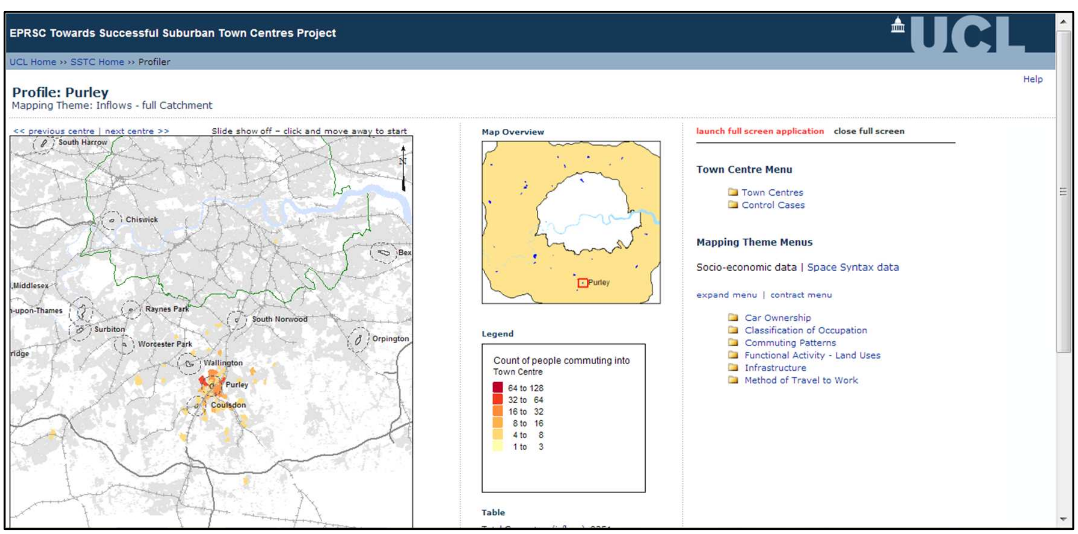
EPSRC Towards Successful Suburban Town Centres Project

http://www.sstc.ucl.ac.uk/profiler/profiler.php

Towards Successful Suburban Town Centres: a study of the relationship between morphology, sociability, economics and accessibility

	Ease of pan and zoom	Quality of basemaps	Changeable basemaps	Sympathetic colour schemes	Double caching technique	Additional supporting information	Temporal data (time-slider events)	Ability to create virtual data products	Geoprocessing Services
EPSRC Towards Successful Suburban Town Centers Project	+	±	+	±	+	±	-	-	-

Note: '+': application fully supports the feature, '±': application support the feature but the quality is debatable, '-': application doesn't support the feature.



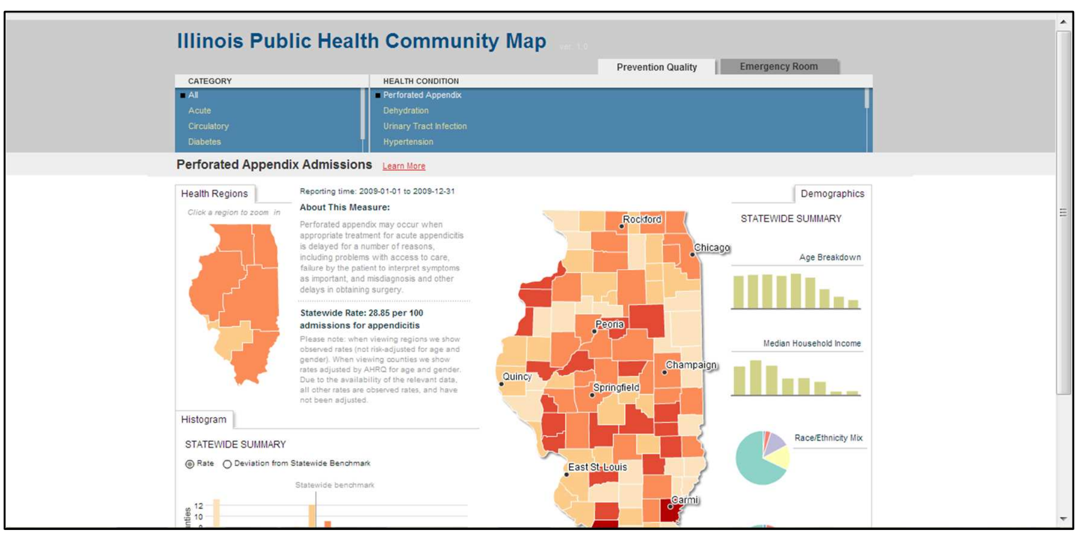
Illinois Public Health Community Map

http://www.healthcarereportcard.illinois.gov/maps

The purpose of this Web site is to make information about the quality of health in communities available to the public, and highlight socioeconomic and racial/ethnic disparities that may exist.

	Ease of pan and zoom	Quality of basemaps	Changeable basemaps	Sympathetic colour schemes	Double caching technique	Additional supporting information	Temporal data (time-slider events)	Ability to create virtual data products	Geoprocessing Services
Illinois Public Health Community Map	±	-	-	+	-	+	-	-	-

Note: '+': application fully supports the feature, '±': application support the feature but the quality is debatable, '-': application doesn't support the feature.



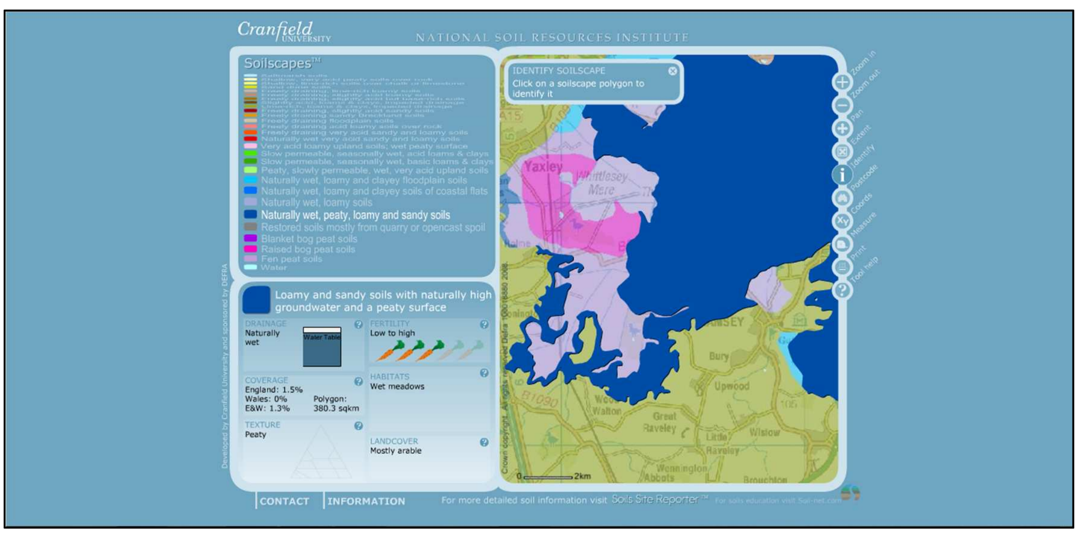
Landis – National Soil Resources Institute

http://www.landis.org.uk/soilscapes/

Cranfield University's National Soil Resources Institute (NSRI) have the responsibility for holding and disseminating soils information in England and Wales.The Soilscapes Viewer is a free, easy-to-use, online soil reporting tool which produces summary soils information for a specific location, based upon the NSRI “Soilscapes” soil thematic dataset.

	Ease of pan and zoom	Quality of basemaps	Changeable basemaps	Sympathetic colour schemes	Double caching technique	Additional supporting information	Temporal data (time-slider events)	Ability to create virtual data products	Geoprocessing Services
Landis National Soil Resources Institute	-	±	-	+	±	+	-	-	-

Note: ‘+’: application fully supports the feature, ‘±’: application support the feature but the quality is debatable, ‘-‘: application doesn’t support the feature.



Live Train map for the London Underground

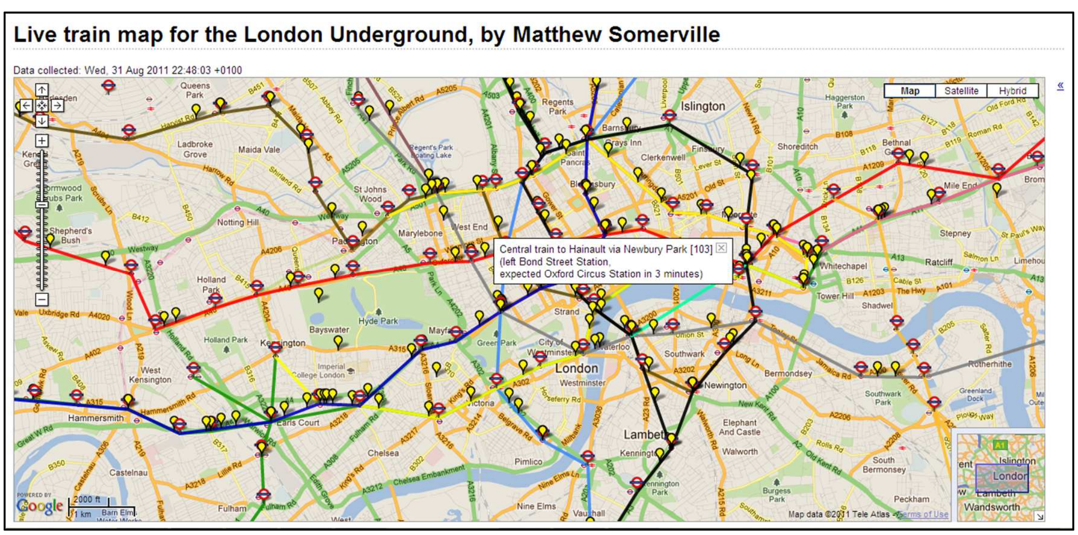
http://traintimes.org.uk/map/tube/

The application is developed at Science Hackday on 19/20th June 2010 by Matthew Somerville (with helpful hinderances from Frances Berriman and James Aylett).

This map shows all trains (yellow pins) on the London Underground network in approximately real time

	Ease of pan and zoom	Quality of basemaps	Changeable basemaps	Sympathetic colour schemes	Double caching technique	Additional supporting information	Temporal data (time-slider events)	Ability to create virtual data products	Geoprocessing Services
Live train map for the London Underground	+	±	+	±	+	+	+	-	-

Note: '+': application fully supports the feature, '±': application support the feature but the quality is debatable, '-': application doesn't support the feature.



Mapping America: Every City, Every Block

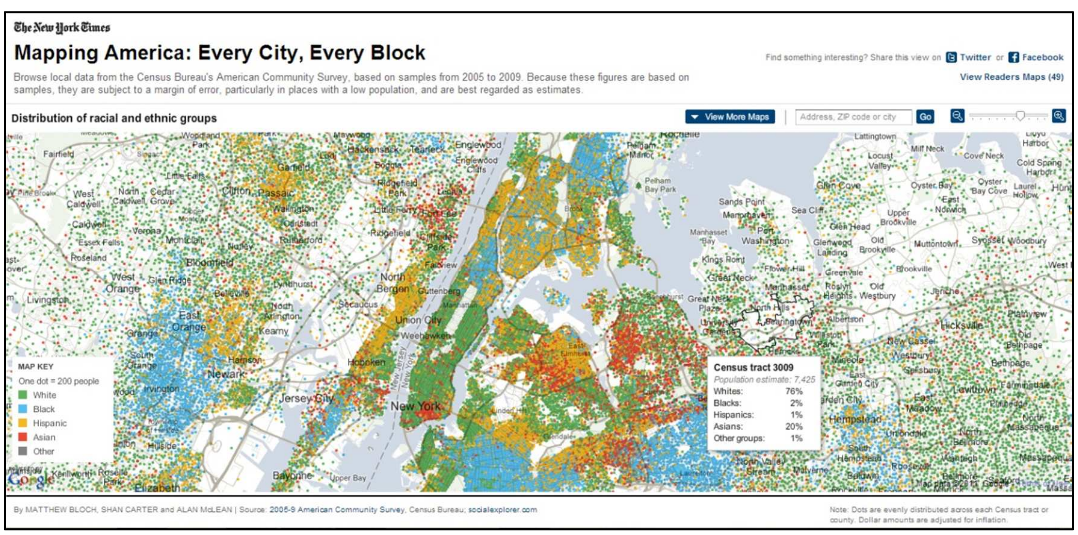
http://projects.nytimes.com/census/2010/explorer

Website developed by Matthew Bloch, Shan Charter and Alan

Browse local data from the Census Bureau's American Community Survey, based on samples from 2005 to 2009. Because these figures are based on samples, they are subject to a margin of error, particularly in places with a low population, and are best regarded as estimates.

	Ease of pan and zoom	Quality of basemaps	Changeable basemaps	Sympathetic colour schemes	Double caching technique	Additional supporting information	Temporal data (time-slider events)	Ability to create virtual data products	Geoprocessing Services
Mapping America: Every City, Every Block	+	+	-	+	+	+	-	-	-

Note: '+': application fully supports the feature, '±': application support the feature but the quality is debatable, '-': application doesn't support the feature.



Local crime and policing website for England and Wales

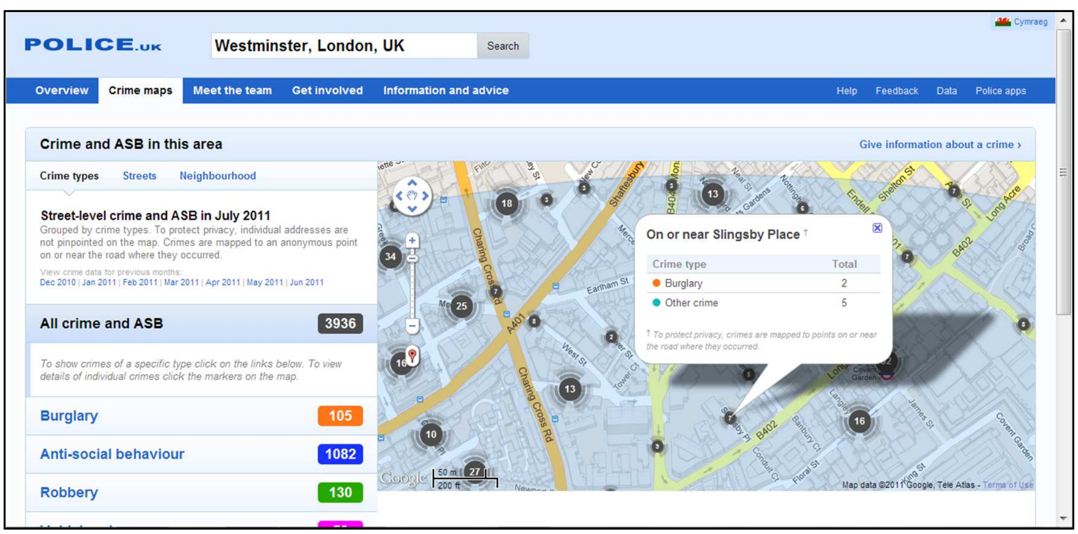
http://www.police.uk/

Web application development by Rock Kitchen Harris.

CrimeMapper is a powerful web application that provides up to date local policing and crime information in England and Wales.

	Ease of pan and zoom	Quality of basemaps	Changeable basemaps	Sympathetic colour schemes	Double caching technique	Additional supporting information	Temporal data (time-slider events)	Ability to create virtual data products	Geoprocessing Services
Local crime and policing website for England and Wales	+	±	-	+	+	+	-	-	+

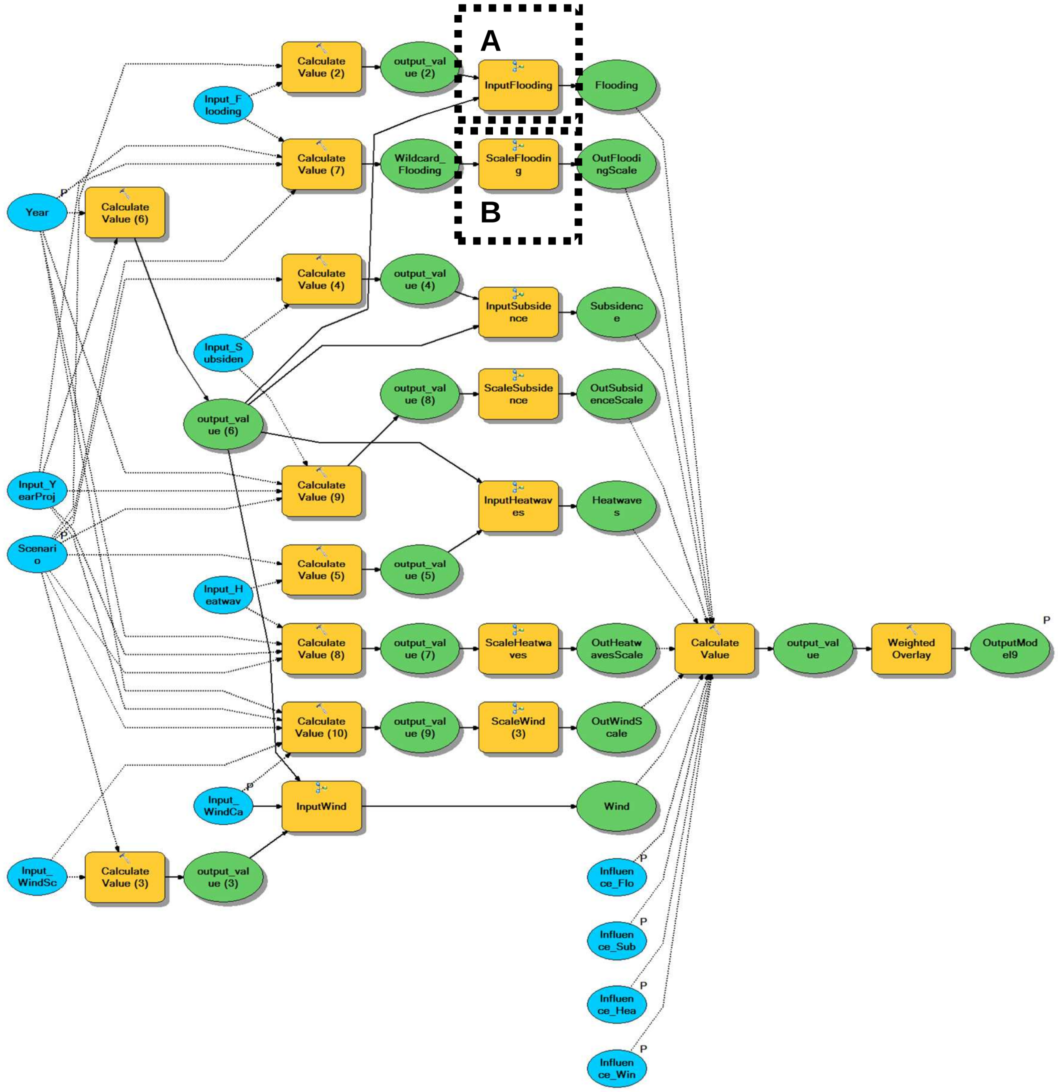
Note: '+': application fully supports the feature, '±': application support the feature but the quality is debatable, '-': application doesn't support the feature.



Appendix B Full Geoprocessing Model

Based on the input selections will it select the correct datasets and with the weight given will it calculate one new data raster (virtual data product).

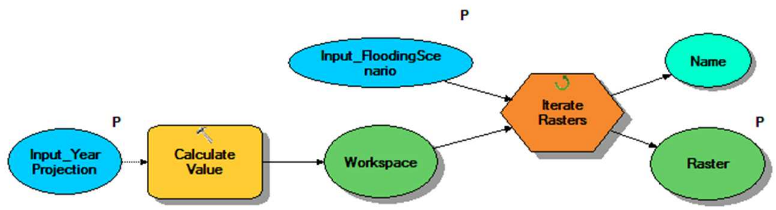
The light blue ovals represent strings, yellow rectangles are different calculation tools and green ovals are the outputs, which can be an input for another tool again. In the top right corner of some strings is placed a P, this means that this object is a parameter. The parameters are linked to the input selection of the 'widget'. The most right output also contains a parameter; this output is programmed as output and will be returned to the map application, if created.



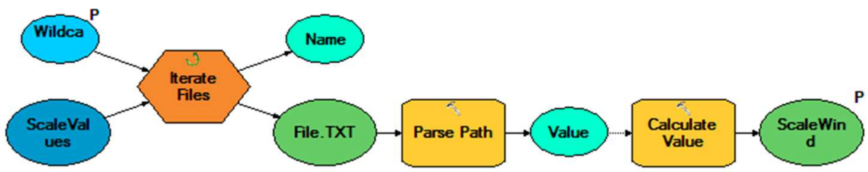
In the above shown geoprocessing model are varies geoprocessing models embedded to enable the use of multiple iterators. For each geohazards are geoprocessing models embedded. The following figures represent these two geoprocessing models that are indicated in the figure with A and B.

Geoprocessing model A is a raster iterator that will select the one of the 42 raster datasets by using the input of the selected year and selected scenario. Geoprocessing model B is also using a iterator but it searches for text files based on the type of geohazards, year of projection and the likelihood of the scenarios. Only the filename of the text file is used, since it represents the weighting scale.

A



B



Appendix C Developers Code Advanced Vulnerability Mapper

The application is developed by using MXML and ActionScript languages. Where MXML is used to lay out the page and where ActionScript comprises an object-oriented procedural programming language that enables actions to different objects.

The code presented underneath is for the 'Advanced Vulnerability Mapper'. It starts with invoking different libraries for the ActionScript code and it ends with the MXML code to lay out the user-interface of the application.

```
<?xml version="1.0" encoding="utf-8"?>
<!--
////////////////////////////////////////////////////////////////////////
     //
     // Copyright (c) 2011 M. VAN HOEK
     //
     // Cheese, tulips, clumps
     //
////////////////////////////////////////////////////////////////////////
-->
<viewer:BaseWidget xmlns:fx="http://ns.adobe.com/mxml/2009"
                   xmlns:s="library://ns.adobe.com/flex/spark"
                   xmlns:mx="library://ns.adobe.com/flex/mx"
                   xmlns:esri="http://www.esri.com/2008/ags"
                   xmlns:viewer="com.esri.viewer.*"         width="360"
height="500"        borderColor="#C71C1C"        backgroundAlpha="1.0"
contentBackgroundAlpha="1.0">
<fx:Declarations>
<esri:Geoprocessor id="gp"
jobComplete="onJobComplete(event)"
url="http://www.extreme-weather-impacts.net/ArcGIS/rest/services/
CREWgeoprocessAdvanced_II_MVH/GPServer/Model"
useAMF="true"/>
<s:RadioButtonGroup id="radiogroup1"/>
<s:RadioButtonGroup id="radiogroup2"/>
</fx:Declarations>
<fx:Script>
<![CDATA[

import com.esri.ags.components.supportClasses.IntegerField;
import com.esri.ags.events.GeoprocessorEvent;
import com.esri.ags.layers.GPResultImageLayer;
import com.esri.ags.tasks.Geoprocessor;
import mx.controls.Alert;
import spark.components.HSlider;
import spark.events.TextOperationEvent;
[Bindable]
private var swfMessage:Boolean = false;
```

```
[Bindable]
private var InYear:String = "2050";
[Bindable]
private var InScen:String = "50";
[Bindable]
private var InWndCgy:String = "pds";
private var myImageLayer:GPResultImageLayer;
private var theJobId:String;
private var params:Object;

/*This function called when the button Calculate Map is clicked.
Firstly it checks if the sum of input is equal to 100 if not: error
message.
By clicking Calculate Map it is submitting the parameters of each
influence of the four hazards (as Strings). There is a listener which
check for updates of the Geoprocessing Event.*/
private function Button_clickHandler(event:MouseEvent):void
{
if (txtSumInput.text > "0")
      {
      if (txtMessage.text == "")
            {
            swfMessage =true;
            params =
            {
            "Influence_Wind": txtWind0.text,
            "Influence_Flooding": txtFlooding0.text,
            "Influence_Subsidence": txtSubsidence0.text,
            "Influence_Heatwaves": txtHeatwaves0.text,
            "Input_WindCategory": txtInWndCgy.text,
            "Scenario": txtInScen.text,
            "Year": txtInYear.text
            };
//Alert.show("Checkpoint1: Sum of input is 100");
            gp.submitJob(params);
            gp.addEventListener(GeoprocessorEvent.STATUS_UPDATE,
statUpdate);
            }
      else
            {
      if (txtMessage.text == "Map is succesfully created")
            {
            swfMessage =true;
            params =
            {
            "Influence_Wind": txtWind0.text,
            "Influence_Flooding": txtFlooding0.text,
            "Influence_Subsidence": txtSubsidence0.text,
            "Influence_Heatwaves": txtHeatwaves0.text,
            "Input_WindCategory": txtInWndCgy.text,
            "Scenario": txtInScen.text,
            "Year": txtInYear.text
            };
//Alert.show("Checkpoint1: Sum of input is 100");
            gp.submitJob(params);
            gp.addEventListener(GeoprocessorEvent.STATUS_UPDATE,
            statUpdate);
            }
      else
            {
```

```
            Alert.show("Just click once, otherwise it will calculate
            two maps.");
            }
            }
            }
      else
            {
            Alert.show("Set influence for geohazard layers");
            }
}
/*The jobStatus is decoded and returned as readible text*/
private function statUpdate(event:GeoprocessorEvent):void
{
txtMessage.text = decodeJobInfoStatus(event.jobInfo.jobStatus);
}
/*After submitJob() is the jobId set as String*/
private  function onJobComplete(event:GeoprocessorEvent):void
{
theJobId = event.jobInfo.jobId.toString();
//Alert.show("Checkpoint2: JobId is" theJobId);
this.callLater(getData);
}
/*If the jobStatus comes back with succes the output is drawn as a
new layer within the viewer with an opacity of 0.7*/
private function getData():void
{
      if(txtMessage.text == "Map is succesfully created")
            {
//Alert.show("Checkpoint3: There is result...somewhere");
            swfMessage = false;
            map.removeLayer(myImageLayer);
            myImageLayer                                              =
            gp.getResultImageLayer(theJobId,"OutputModel9")MyImageLaye
            r.name="Output Geoprocessing";
            myImageLayer.alpha=0.7;
            map.addLayer(myImageLayer,-1);
            }
      else
            {
            Alert.show("You found a little bug, make sure that the sum
            of input is 100, due to rounding it is sometimes 99 or
            101.");
            swfMessage = false;
            }
}
private function geoprocessing_closeHandler(event:Event):void
{
map.removeLayer(myImageLayer);
}
/*Function shows the different values of the jobStatus */
private function decodeJobInfoStatus(value:String):String
{
var retVal:String = "";
switch(value){
case "esriJobCancelling":
{
retVal = "Job Cancelling";
break;
}
case "esriJobDeleted":
```

```
{
retVal = "Job Deleted";
break;
}
case "esriJobDeleting":
{
retVal = "Job Deleting";
break;
}
case "esriJobExecuting":
{
retVal = "Analysis of submitted data...";
break;
}
case "esriJobFailed":
{
retVal = "Try again. Make sure the sum of input is 100";
break;
}
case "esriJobNew":
{
retVal = "Job New";
break;
}
case "esriJobSubmitted":
{
retVal = "Influence data is submitted";
break;
}
case "esriJobSucceeded":
{
retVal = "Map is succesfully created";
break;
}
case "esriJobTimedOut":
{
retVal = "Job Timed Out";
break;
}
case "esriJobWaiting":
{
retVal = "Processing of data";
break;
}
}
return retVal;
}
// CHANGE YEAR OF PROJECTION
private function Button2050(event:MouseEvent):void
{
if (Toggle2050.selected = true)
      {
      Toggle2050.selected = true;
      Toggle2020.selected = false;
      ToggleNow.selected = false;
      InYear = "2050";
      }
else
      {
      Toggle2050.selected = true;
```

```
        Toggle2020.selected = false;
        ToggleNow.selected = false;
        }
}
private function Button2020(event:MouseEvent):void
{
if (Toggle2020.selected = true)
        {
        Toggle2050.selected = false;
        Toggle2020.selected = true;
        ToggleNow.selected = false;
        InYear = "2020";
        }
else
        {
        Toggle2050.selected = false;
        Toggle2020.selected = true;
        ToggleNow.selected = false;
        }
}
private function ButtonNow(event:MouseEvent):void
{
if (ToggleNow.selected = true)
        {
        Toggle2050.selected = false;
        Toggle2020.selected = false;
        ToggleNow.selected = true;
        InYear = "Now";
//The scenario for Actual Data is only available as Estimated Risk
        ERisk.selected = true;
        URisk.selected = false;
        ORisk.selected = false;
        InScen = "50";
        }
else
        {
        Toggle2050.selected = true;
        Toggle2020.selected = false;
        ToggleNow.selected = false;
        }
}
// CHANGE LIKELIHOOD SCENARIOS
private function UnderRisk(event:MouseEvent):void
{
if (ToggleNow.selected == true)
        {
        Alert.show("The Year of Projection is set as 'Now'. For the
        actual situation is only the 'Estimated Risk' scenario
        available. To change the scenario, change the Year of Projection
        first.");
        URisk.selected = false;
        ERisk.selected = true;
        ORisk.selected = false;
        InScen = "50";
        }
else
        {
        if (URisk.selected = true)
                {
                URisk.selected = true;
```

```
            ERisk.selected = false;
            ORisk.selected = false;
            InScen = "10";
            }
      else
            {
            URisk.selected = true;
            ERisk.selected = false;
            ORisk.selected = false;
            }
      }
}
private function EstRisk(event:MouseEvent):void
{
if (ERisk.selected = true)
      {
      URisk.selected = false;
      ERisk.selected = true;
      ORisk.selected = false;
      InScen = "50";
      }
else
      {
      URisk.selected = false;
      ERisk.selected = true;
      ORisk.selected = false;
      }
}
private function OverRisk(event:MouseEvent):void
{
if (ToggleNow.selected == true)
      {
      Alert.show("The Year of Projection is set as 'Now'. For the
      actual situation is only the 'Estimated Risk' scenario
      available. To change the scenario, change the Year of Projection
      first.");
      URisk.selected = false;
      ERisk.selected = true;
      ORisk.selected = false;
      InScen = "50";
      }
else
      {
      if (ORisk.selected = true)
            {
            URisk.selected = false;
            ERisk.selected = false;
            ORisk.selected = true;
            InScen = "90";
            }
      else
            {
            URisk.selected = false;
            ERisk.selected = false;
            ORisk.selected = true;
            }
      }
}
//CHANGE RISK CATEGORY WINDSPEED
private function ButtonPedestrians(event:MouseEvent):void
```

```
{
if (Pedestrians.selected = true)
      {
      Pedestrians.selected = true;
      Vehicles.selected = false;
      Buildings.selected = false;
      InWndCgy = "pds";
      }
else
      {
      Pedestrians.selected = true;
      Vehicles.selected = false;
      Buildings.selected = false;
      }
}
private function ButtonVehicles(event:MouseEvent):void
{
if (Vehicles.selected = true)
      {
      Pedestrians.selected = false;
      Vehicles.selected = true;
      Buildings.selected = false;
      InWndCgy = "vhs";
      }
else
      {
      Pedestrians.selected = false;
      Vehicles.selected = true;
      Buildings.selected = false;
      }
}
private function ButtonBuildings(event:MouseEvent):void
{
if (Buildings.selected = true)
      {
      Pedestrians.selected = false;
      Vehicles.selected = false;
      Buildings.selected = true;
      InWndCgy = "bld";
      }
else
      {
      Pedestrians.selected = false;
      Vehicles.selected = false;
      Buildings.selected = true;
      }
}
]]>
</fx:Script>
<viewer:WidgetTemplate id="InfluenceWidget"
closed="geoprocessing_closeHandler(event)"
width="360" height="500">
<viewer:layout>
<s:VerticalLayout gap="20" horizontalAlign="center"
verticalAlign="middle"/>
</viewer:layout>
<s:Label text="Create a multiple vulnerability map by setting your
priority for each geohazard-influence." height="46" width="283"/>
<mx:Accordion width="287" height="293" borderVisible="false"
backgroundAlpha="0.0" contentBackgroundAlpha="0.0" fontSize="12">
```

```
<s:NavigatorContent label="Set Priority and Calculate Map"
width="100%" height="100%">

<s:HGroup width="260" height="20" verticalAlign="middle" x="15"
y="30">
<s:Label text="Wind" id="lblWind" verticalAlign="middle"/>
<mx:Spacer width="42"/>
<s:HSlider id="SliderWind" minimum="0" maximum="100" stepSize="2"
value="20" liveDragging="true"/>
<mx:Text id="txtWind0" width="30" height="20"
text="{Math.round(SliderWind.value*100/SliderOverall.value)}"
enabled="true" color="#000000"/>
</s:HGroup>

<s:HGroup width="260" height="20" verticalAlign="middle" x="15"
y="70">
<s:Label text="Flooding" id="lblFlooding"/>
<mx:Spacer width="22"/>
<s:HSlider id="SliderFlooding" minimum="0" maximum="100" stepSize="2"
value="40" liveDragging="true"/>
<mx:Text id="txtFlooding0" width="30" height="20"
text="{Math.round(SliderFlooding.value*100/SliderOverall.value)}"
enabled="true" color="#000000"/>
</s:HGroup>

<s:HGroup width="260" height="20" verticalAlign="middle" x="15"
y="110">
<s:Label text="Subsidence" id="lblSubsidence"/>
<mx:Spacer width="4"/>
<s:HSlider id="SliderSubsidence" minimum="0" maximum="100"
stepSize="2" value="30" liveDragging="true"/>
<mx:Text id="txtSubsidence0" width="30" height="20"
text="{Math.round(SliderSubsidence.value*100/SliderOverall.value)}"
enabled="true" color="#000000"/>
</s:HGroup>

<s:HGroup width="260" height="20" fontWeight="normal"
fontStyle="normal" textDecoration="none" lineThrough="false"
verticalAlign="middle" x="15" y="150">
<s:Label text="Heatwaves" id="lblHeatwaves"/>
<mx:Spacer width="9"/>
<s:HSlider id="SliderHeatwaves" minimum="0" maximum="100" stepSize="2"
value="10" liveDragging="true"/>
<mx:Text id="txtHeatwaves0" width="30" height="20"
text="{Math.round(SliderHeatwaves.value*100/SliderOverall.value)}"
enabled="true"/>
</s:HGroup>

<s:HGroup width="260" height="20" fontWeight="normal"
fontStyle="normal" textDecoration="none" lineThrough="false"
verticalAlign="middle" visible="false" x="15" y="181">
<s:Label text="Overall" id="lblAll"/>
<mx:Spacer width="32"/>
<s:HSlider id="SliderOverall" minimum="0" maximum="400" stepSize="2"
value="{Math.round(SliderHeatwaves.value+SliderSubsidence.value+Slider
Flooding.value+SliderWind.value)}" liveDragging="true"/>
<mx:Text id="txtSumInput" width="30" height="20" y="-2"
text="{Math.round(SliderHeatwaves.value+SliderSubsidence.value+SliderF
looding.value+SliderWind.value)}" enabled="true"/>
</s:HGroup>
```

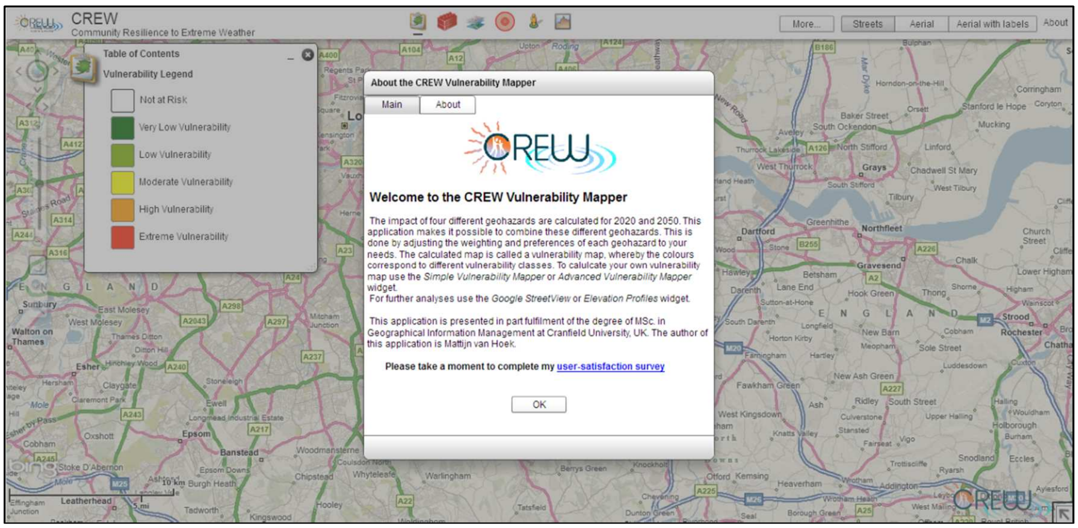
```
</s:NavigatorContent>

<s:NavigatorContent label="Change Year of Projection" width="100%"
height="100%">
<s:Label text="Year of Projection" id="lblWind0"
verticalAlign="middle" x="95" y="91"/>
<s:HGroup x="42" y="103" width="200" height="38"
verticalAlign="middle" gap="20" paddingLeft="3">
<s:ToggleButton label="Now" width="51" height="27" id="ToggleNow"
enabled="true" selected="false" click="ButtonNow(event)"/>
<s:ToggleButton label="2020" width="51" height="27" id="Toggle2020"
enabled="true" selected="false" click="Button2020(event)"/>
<s:ToggleButton label="2050" width="51" height="27" id="Toggle2050"
enabled="true" selected="true" click="Button2050(event)"/>
</s:HGroup>
<s:Label x="17" y="17" text="The vulnerability map can be calculated
for different projections. Click on one of the toggle buttons to
change the projection year." textAlign="left" height="55"
width="256"/>
</s:NavigatorContent>

<s:NavigatorContent label="Change Likelihood Scenarios" width="100%"
height="100%">
<s:Label x="10" y="17" text="The vulnerability map can be calculated
based on different scenarios. Change the scenario by clicking the
required scenario." textAlign="left" height="49" width="256"/>
<s:ToggleButton x="45" y="76" height="27" width="40" id="URisk"
enabled="true" selected="false" click="UnderRisk(event)"/>
<s:Label x="98" y="85" text="Underestimated Risk"/>
<s:ToggleButton x="45" y="124" height="27" width="40" id="ERisk"
enabled="true" selected="true" click="EstRisk(event)"/>
<s:Label x="98" y="133" text="Estimated Risk"/>
<s:ToggleButton x="45" y="170" height="27" width="40" id="ORisk"
enabled="true" selected="false" click="OverRisk(event)"/>
<s:Label x="98" y="179" text="Overestimated Risk"/>
</s:NavigatorContent>

<s:NavigatorContent label="Change Risk Category Windspeed"
width="100%" height="100%" backgroundAlpha="1.0"
contentBackgroundAlpha="1.0">
<s:Label x="15" y="24" text="The options below relate only to
windspeed. For the windspeed is it possible to change the risk to
different risk-events." height="48" width="256"/>
<s:ToggleButton x="45" y="79" height="27" width="40" id="Pedestrians"
enabled="true" selected="true" click="ButtonPedestrians(event)"/>
<s:Label x="98" y="88" text="Risk for Pedestrians"/>
<s:ToggleButton x="45" y="127" height="27" width="40" id="Vehicles"
enabled="true" selected="false" click="ButtonVehicles(event)"/>
<s:Label x="98" y="136" text="Risk for Vehicles"/>
<s:ToggleButton x="45" y="173" height="27" width="40" id="Buildings"
enabled="true" selected="false" click="ButtonBuildings(event)"/>
<s:Label x="98" y="182" text="Risk for Buildings"/>
</s:NavigatorContent>
</mx:Accordion>

<s:HGroup width="220" height="27">
<mx:Text id="txtInYear" text="{InYear}" visible="false" width="24"
height="27"/>
<mx:Text width="25" height="22" id="txtInScen" text="{InScen}"
visible="false"/>
```

```
<s:Button id="Calculate" label="Calculate Map"
click="Button_clickHandler(event)" height="27"/>
<mx:Text width="22" height="22" id="txtInWndCgy" text="{InWndCgy}"
visible="false"/>
</s:HGroup>
<s:HGroup id="boxMessage"
width="100%"
verticalAlign="middle">
<mx:LinkButton label="Help"
width="45"
click="navigateToURL(new URLRequest('http://www.extreme-weather-
impacts.net/flexviewer/advanced.html'), 'quote')"/>
<mx:Image id="loading"
source="assets/images/Red_glow.swf"
visible="{swfMessage}" width="16" height="16"/>
<s:Label id="txtMessage"
width="200"
text=""/>
</s:HGroup>
</viewer:WidgetTemplate>
</viewer:BaseWidget>
```

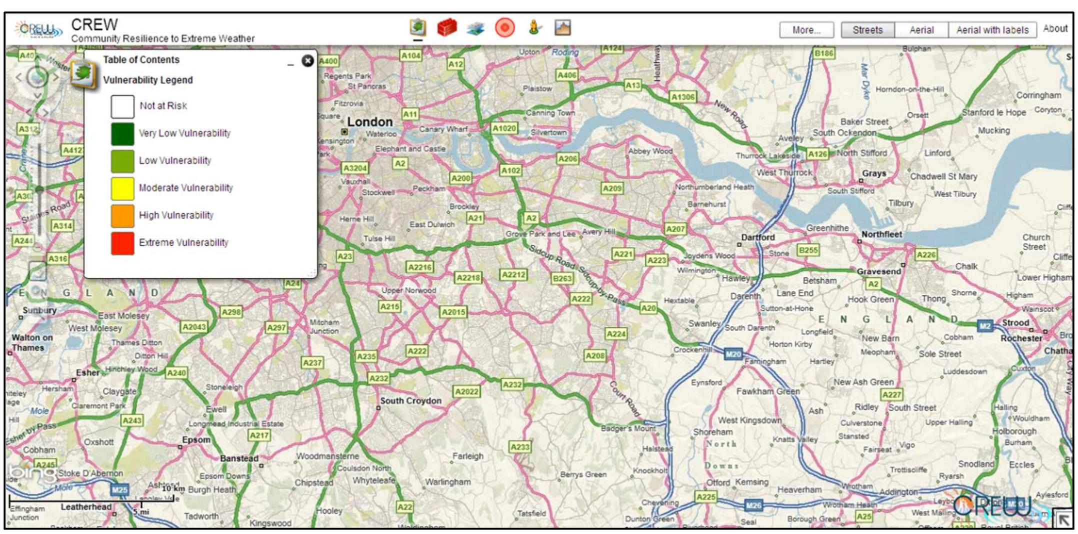
Appendix D Walkthrough CREW Vulnerability Mapper

The following annotated screenshots present the prototype application for a typical session. A separate video is attached with the walkthrough as shown below.

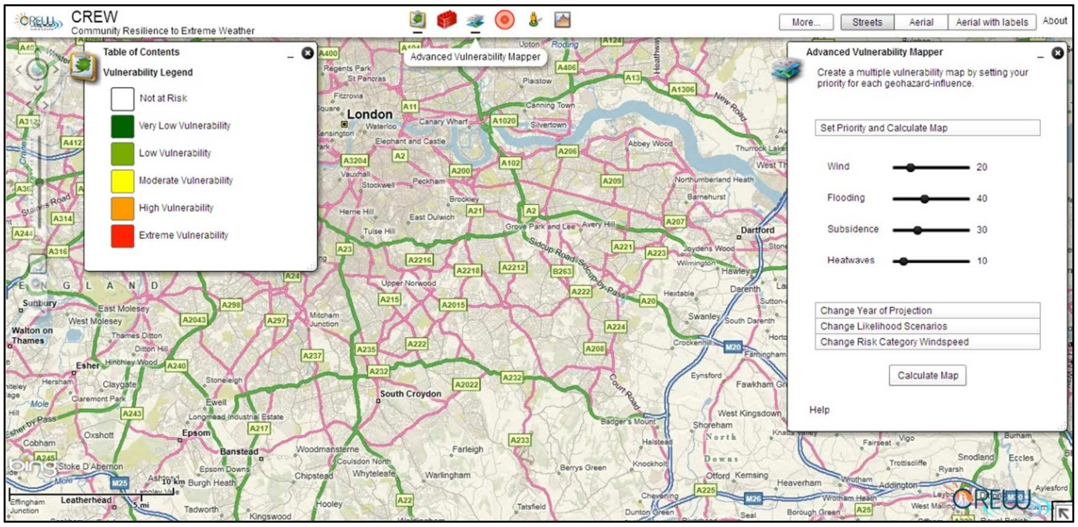
The application starts with an ‘about’ screen with general information about the application as well as showing the possibility to obtain supporting background information.



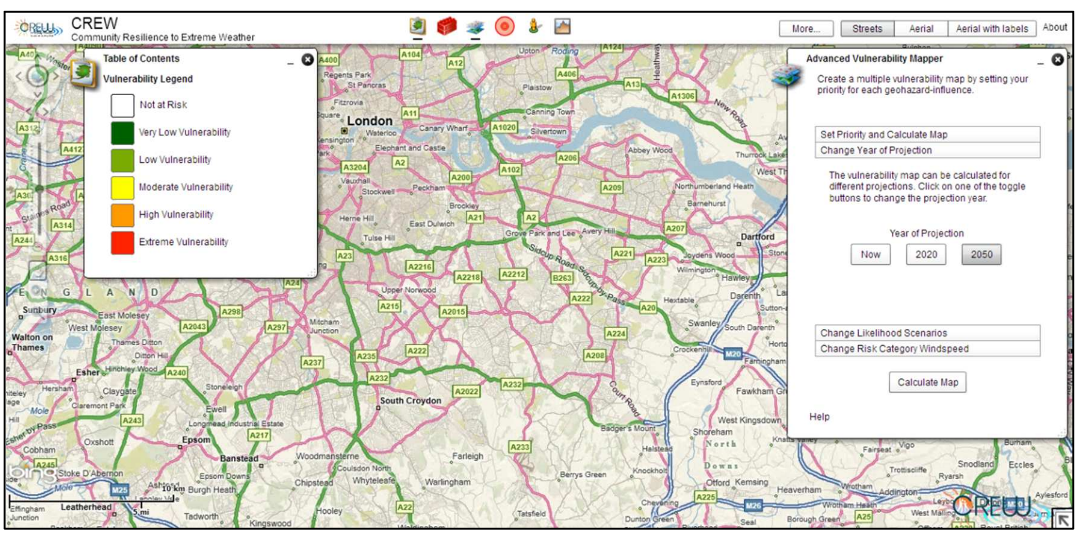
When OK is pressed, the basemap is presented in combination with the table of contents. The vulnerability legend shows six classes, from ‘Not at Risk’ to ‘Extreme Vulnerability’.



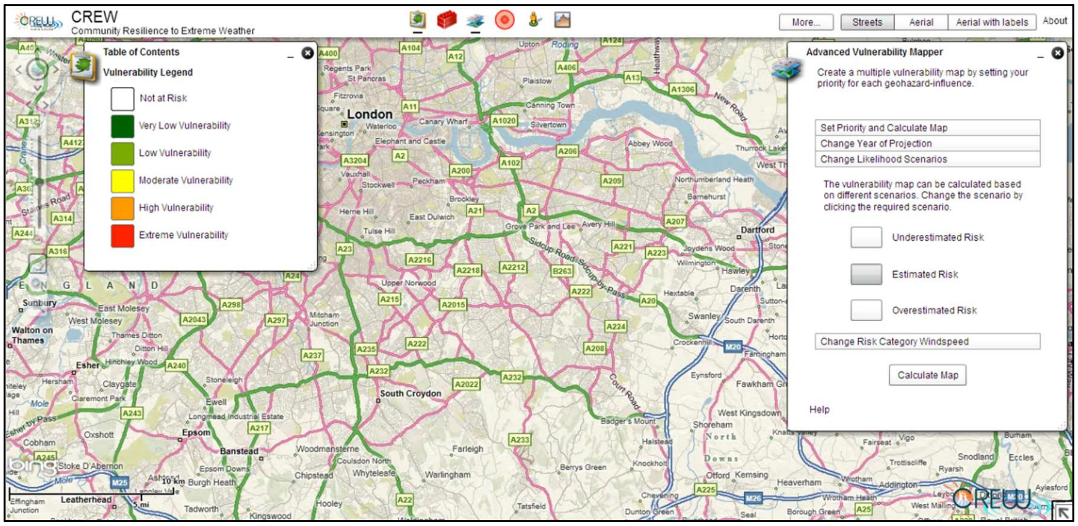
The widget Advanced Vulnerability Mapper is opened by clicking on the icon on the top bar of the application. In the first panel the weightings of the different geohazards can be adjusted.



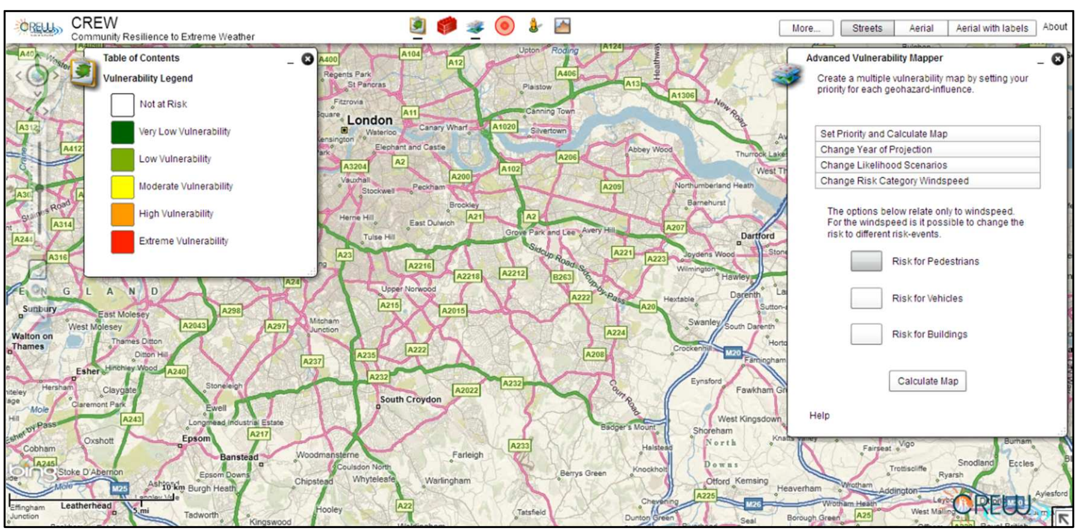
In the second panel of the widget is it possible to make a selection of the year of projection. For the CREW project are datasets calculated and prepared for ‘Now’, ‘2020’ and ‘2050’.



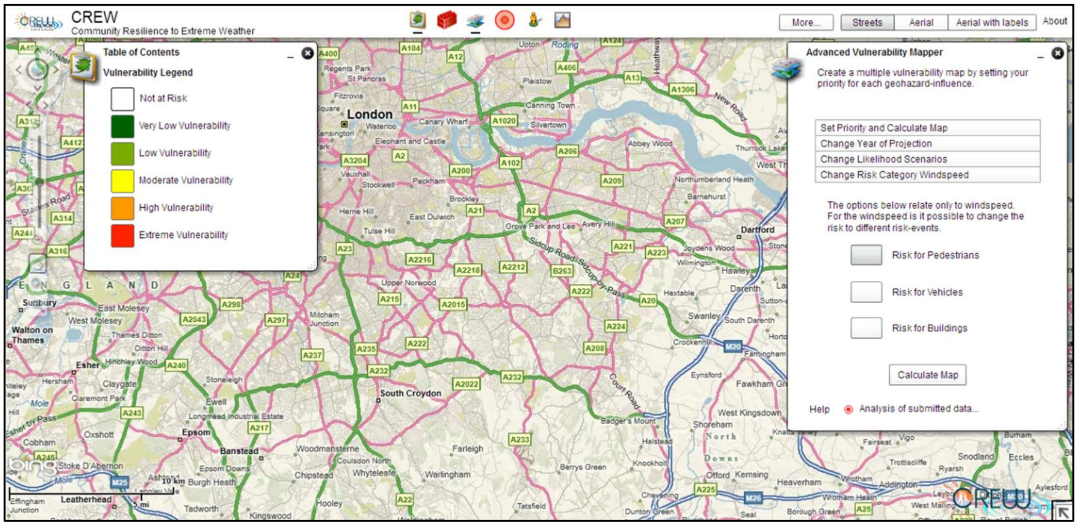
The third panel present the options for making a selection of the likelihood of the scenarios. The likelihood scenarios are underestimated risk, estimated risk and overestimated risk. These scenario risks correspond to the 10^{th}, 50^{th} and 90^{th} percentile of the created datatsets.



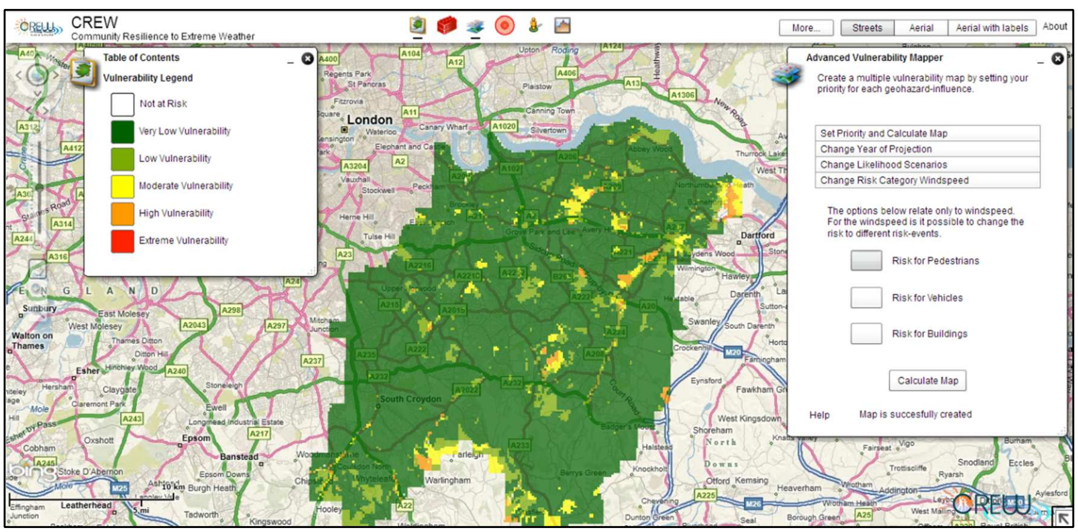
The fourth panel provides the option to select a risk category for windspeed. The risk categories are based on the thresholds of pedestrians, vehicles and buildings.



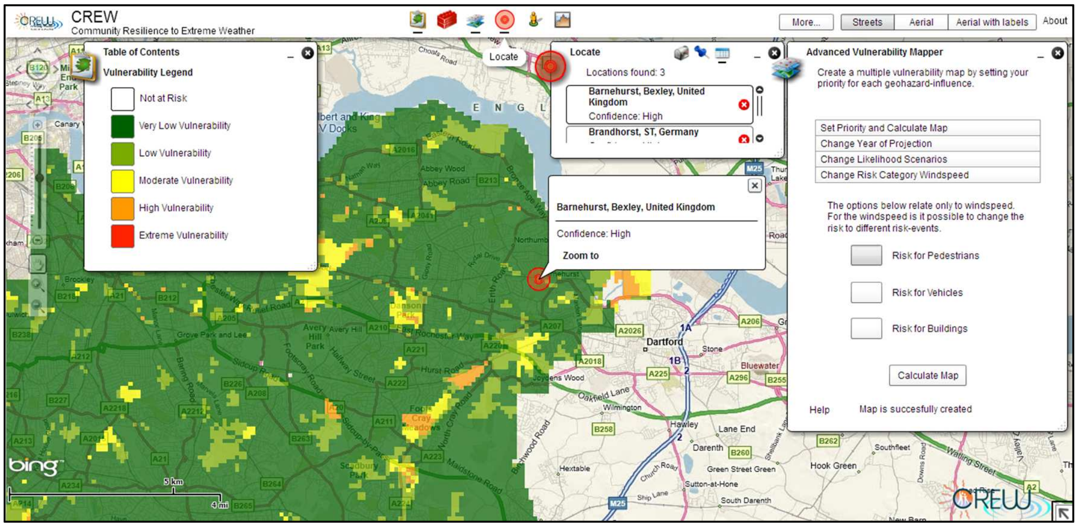
On the bottom of the widget the status is continuously given of the geoprocessing service that runs on ArcGIS Server.



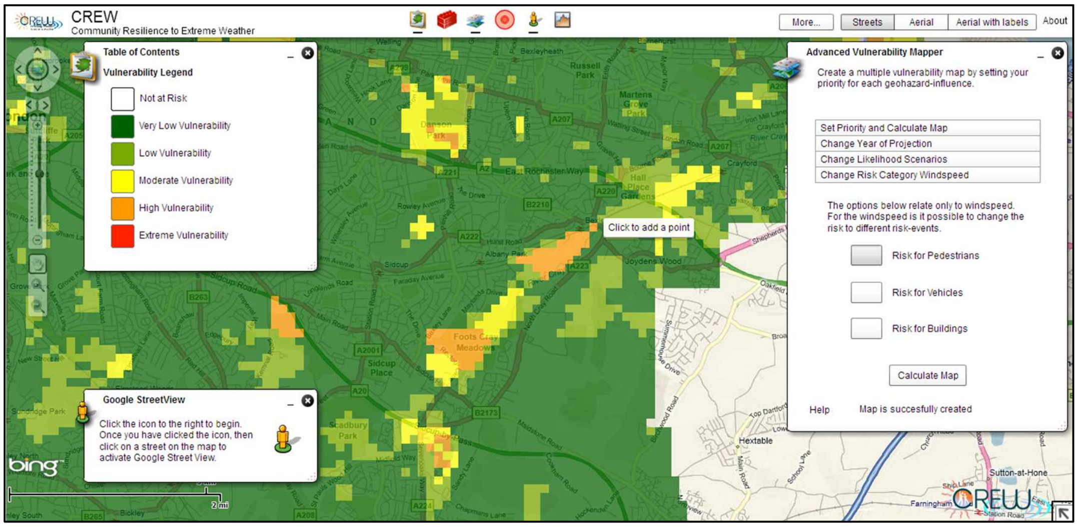
If the status listener receives the update that the map successfully is created; the new created virtual data product is added to the map as a new layer.



A series of applets, or ‘widgets’, were developed to add depth and context to the results. This widget provides the option to search for a location in the study area.

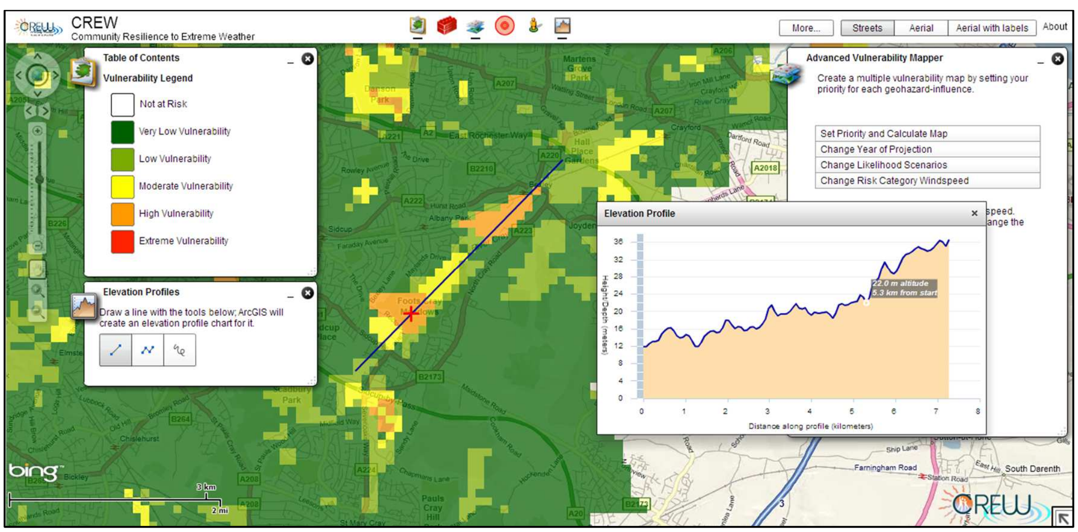


Another widget is included to integrate the ability to use Google Streetview to aid navigation around the study area. Click on the Google Streetview icon and place it on the map where needed.

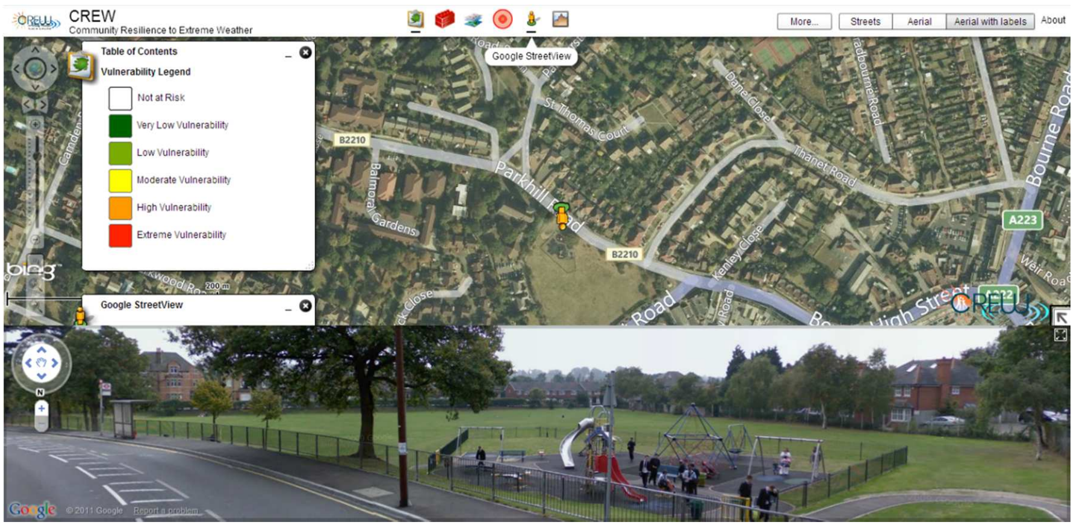


The Google Streetview navigation screen is placed on the bottom of the screen, whereby in both screens the navigation of the location can be controlled.

A different widget is included which provide depth and context to the results by providing the user to create a elevation profile chart. This widget uses an ESRI geoprocesing servcive to build the elevation profile chart.



Lastly, this figure shows the strengths of developing prototypes in the ArcGIS Flex environment, where both Bing maps for the basemap and Google StreetView are integrated in one application.



Appendix E Questionnaire

A key stakeholder questionnaire was conducted to derive feedback on the prototype application. This questionnaire is presented to the wider CREW advisory board and the Cranfield University

Questionnaire for CREW Web-based GIS Application

Please can you outline the nature of your professional interest in this topic area?
What sort of decisions or support actions relating to extreme weather impacts are you responsible for taking?

General questions
Some general comments on the overall application.

	Very poor	Poor	Fine	Good	Excellent
To what extent do you find the interface user-friendly?	○	○	○	○	○
Does the web-based GIS application load quickly?	○	○	○	○	○
How do you rate the functionality of the map zoom and pan tools?	○	○	○	○	○
How do you rate the fact that this application is presented as a web tool?	○	○	○	○	○

The icons along the top of the website launch different applications; to what extent does this improve the user-friendliness?
The mapping tool allows so-called 'widgets', each with different functions - is this intuitive and useful?

A key to the research is to present composite, combined risk. Do you see this as useful?
Is the idea of combined risk beneficial to your work, if so why?

The legend currently shows a combined vulnerability scale with six classes; how many classes would you like? *Please circle*

The colours used in the legend range from green to red; is this also your preference?
Where Green = Low vulnerability, Red = Extreme Vulnerability

- ☐ Yes
- ☐ Other: ________________________________

Advanced Vulnerability Mapper

A further advanced application tool makes it possible to combine all the created outputs of the CREW project.

	Very poor	Poor	Fine	Good	Excellent
How do you rate the application interface?	○	○	○	○	○
What is your opinion of the way the horizontal sliders allow changes to the influence of the different geohazards?	○	○	○	○	○
How do you rate the way the interface uses buttons for making specialised selections in the different panes?	○	○	○	○	○

Calculation of vulnerability map

This concern the response times of the online modelling tool.

	3 seconds	10 seconds	30 seconds
How long are you willing to wait to calculate the map?	○	○	○
How long are you willing to wait to calculate the map?	○	○	○
How long did take to calculate the map?	○	○	○

To what extent does the Advanced Vulnerability Mapper application meet your expectations?
From a scientific or policy decision support context

Google Streetview Application
Google Streetview is integrated to aid navigation around the study area.

	Very poor	Poor	Fine	Good	Excellent
How do you rate the functionality of the street-view application?	◯	◯	◯	◯	◯
How do you rate the position of the street view window on-screen?	◯	◯	◯	◯	◯
How do you rate the position marker on the map that tracks your Google street view position?	◯	◯	◯	◯	◯

The elevation profile widget gives you the possibility to create an elevation profile chart. To what extent does this widget add value to the calculated results?
Elevation could be used say in conjunction with the flood models.

What type of tools would you like to see added?
What additional functionality would improve the application?

- ☐ Demographic tools
- ☐ Temporal layers (e.g. weather forecasting)
- ☐ Popup windows with detailed additional insight information
- ☐ Other: ____

Appendix F Responses Questionnaire

This appendix shows the results of the responses of the conducted questionnaire.

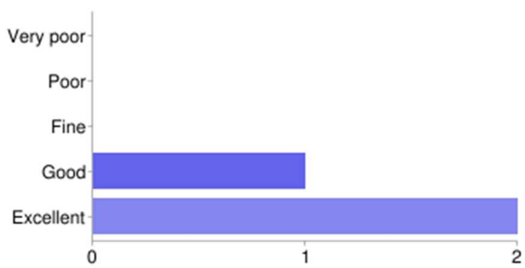
3 responses
Can you outline the nature of your professional interest in this topic area?

Testing the website to find where improvements could be made;

Natura hazards;

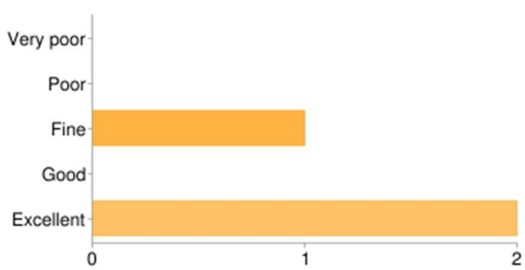
I have had an input into the CREW project (from Cranfield University)

General questions - To what extent do you find the interface user-friendly?



Very poor	0	0%
Poor	0	0%
Fine	0	0%
Good	1	33%
Excellent	2	67%

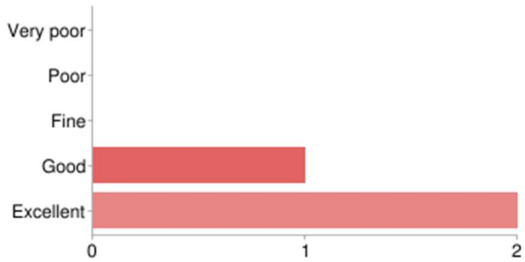
General questions - Does the web-based GIS application load quickly?



Very poor	0	0%
Poor	0	0%
Fine	1	33%
Good	0	0%

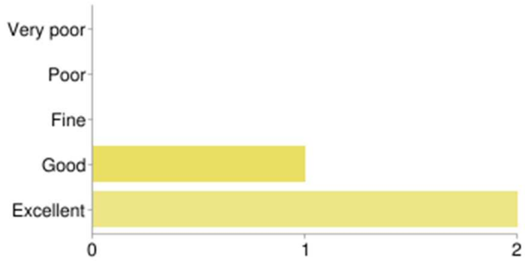
Excellent	2	67%

General questions - How do you rate the functionality of the map zoom and pan tools?



Very poor	0	0%
Poor	0	0%
Fine	0	0%
Good	1	33%
Excellent	2	67%

General questions - How do you rate the fact that this application is presented as a web tool?



Very poor	0	0%
Poor	0	0%
Fine	0	0%
Good	1	33%
Excellent	2	67%

The icons along the top of the website launch different applications; to what extent does this improve the user-friendliness?

A good idea but when the ToC widget is open it obscures the help text on the neighbouring buttons i.e. the vulnerability mapping buttons.

I do not know what the symbols mean. So I am not sure what icon to use first. It would be a great idea to add some text

Easy to use, the tool tips make it obvious what each widget does. Doe the simple and advanced vulnerability mapper have to be separate widgets or could the advanced options just be available on the bottom of a single vulnerability widgit?

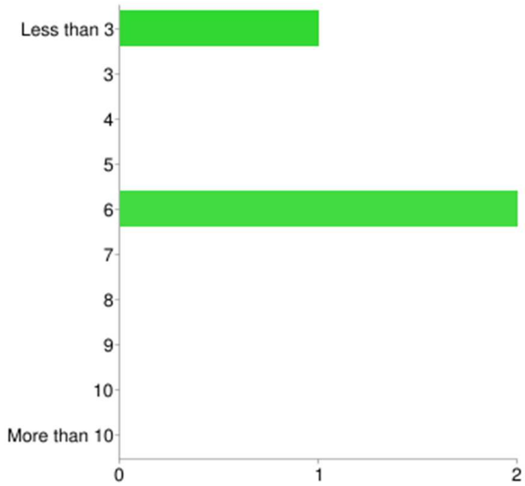
A key to the research is to present composite, combined risk. Do you see this as useful?

Yes

I am not sure about the combined idea. GIS-wise very nice and probably very powerful. In terms of decision making, I am not sure. How does a decision-maker, politician makes a decision based on the combined risk of an event? Moreover, how does these risks have been calculated? An introduction on this topic would be nice.

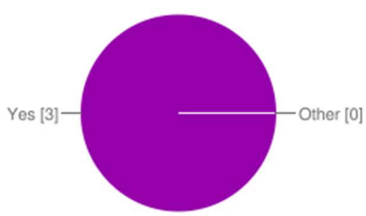
Definitely. The ability to look at each risk independently and in combination is extremely important.

The legend currently shows a combined vulnerability scale with six classes; how many classes would you like?



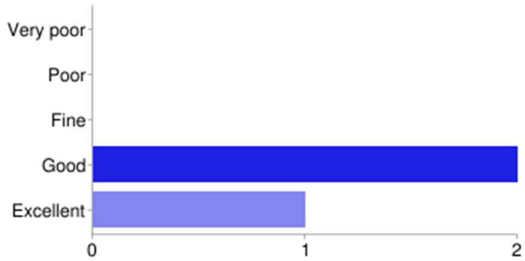
Less than 3	1	33%
3	0	0%
4	0	0%
5	0	0%
6	2	67%
7	0	0%
8	0	0%
9	0	0%
10	0	0%
More than 10	0	0%

The colours used in the legend range from green to red; is this also your preference?



Yes	3	100%
Other	0	0%

Advanced Vulnerability Mapper - How do you rate the application interface?

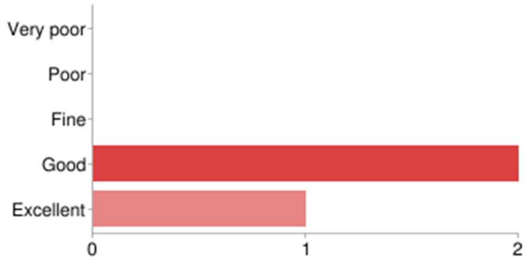


Very poor	0	0%
Poor	0	0%
Fine	0	0%
Good	2	67%
Excellent	1	33%

Advanced Vulnerability Mapper - What is your opinion of the way the horizontal sliders allow changes to the influence of the different geohazards?

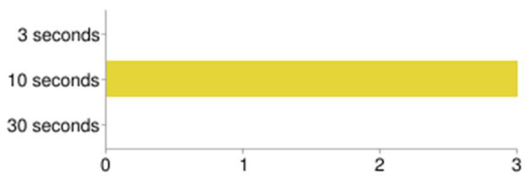
Very poor	0	0%
Poor	0	0%
Fine	1	33%
Good	1	33%
Excellent	1	33%

Advanced Vulnerability Mapper - How do you rate the way the interface uses buttons for making specialised selections in the different panes?



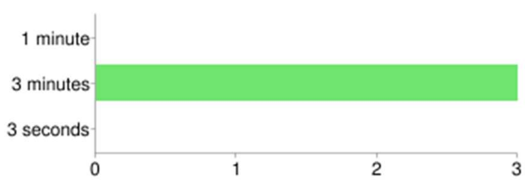
Very poor	0	0%
Poor	0	0%
Fine	0	0%
Good	2	67%
Excellent	1	33%

Calculation of vulnerability map - How long are you willing to wait to calculate the map?



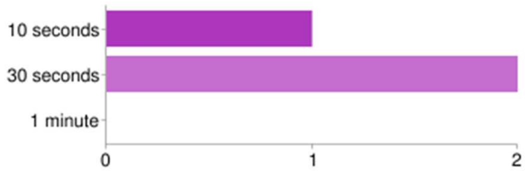
3 seconds	0	0%
10 seconds	3	100%
30 seconds	0	0%

Calculation of vulnerability map - How long are you willing to wait to calculate the map?



1 minute	0	0%
3 minutes	3	100%
3 seconds	0	0%

Calculation of vulnerability map - How long did take to calculate the map?



10 seconds	1	33%
30 seconds	2	67%
1 minute	0	0%

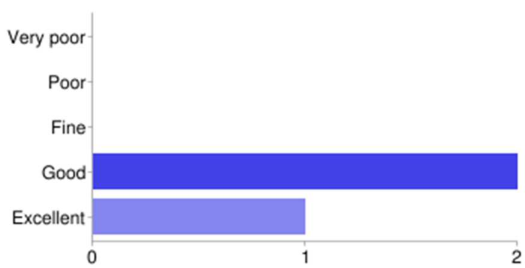
To what extent does the Advanced Vulnerability Mapper application meet your expectations?

The concept is good. However, there is a problem with the execution. If i click on the buttons more than once I get a message warning me to only click once otherwise two maps will be produced. Once into this loop I can't get out it even by closing the widget and restarting the advanced vulnerability mapper.

From the GIS perspective, excellent. I have concerns about the science behind it and the usefulness of the tool. Please consider the following concerns: (1) I have no idea where the databases or models come from; (2) I do not have any information on what rationale was used to combine the models;(3)Is there an assessment of the risks associated with the interpretation of the models?; and (4) the scale of the processes behind each risk are very different, how do you account for the variability in these processes?

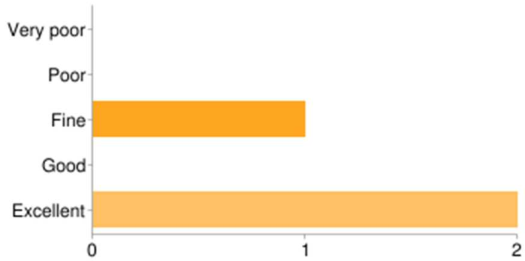
...

Google Streetview Application - How do you rate the functionality of the street-view application?



Very poor	0	0%
Poor	0	0%
Fine	0	0%
Good	2	67%
Excellent	1	33%

Google Streetview Application - How do you rate the position of the street view window on-screen?



Very poor	0	0%
Poor	0	0%
Fine	1	33%
Good	0	0%
Excellent	2	67%

Google Streetview Application - How do you rate the position marker on the map that tracks your Google street view position?

Very poor	0	0%
Poor	0	0%
Fine	1	33%
Good	1	33%
Excellent	1	33%

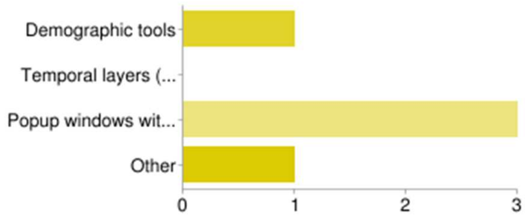
The elevation profile widget gives you the possibility to create an elevation profile chart. To what extent does this widget add value to the calculated results?

Elevation profile even worked in Russia!!

n/a

It is dependent on the accuracy of the height information. I think it may be of minimal use regarding analysis of the flood results. Some thoughts on street view. The window position is good but it would be nice to be able to resize the window slightly or have the option to dock in a different location. Also when moving the marker it would be beneficial to see what areas have street view available rather than just placing the pointer and receiving the no street view available message.

What type of tools would you like to see added?



People may select more than one checkbox, so percentages may add up to more than 100%.

Demographic tools	1	33%
Temporal layers (e.g. weather forecasting)	0	0%
Popup windows with detailed additional insight information	3	100%
Other	1	33%

Number of daily responses