Developing a Risk Assessment Approach for Forest Fire at the Rural-Urban Interface

Developing a Risk Assessment Approach for Forest Fire at the Rural-Urban Interface: Potential of the Wildfire Threat Analysis Framework

Final report

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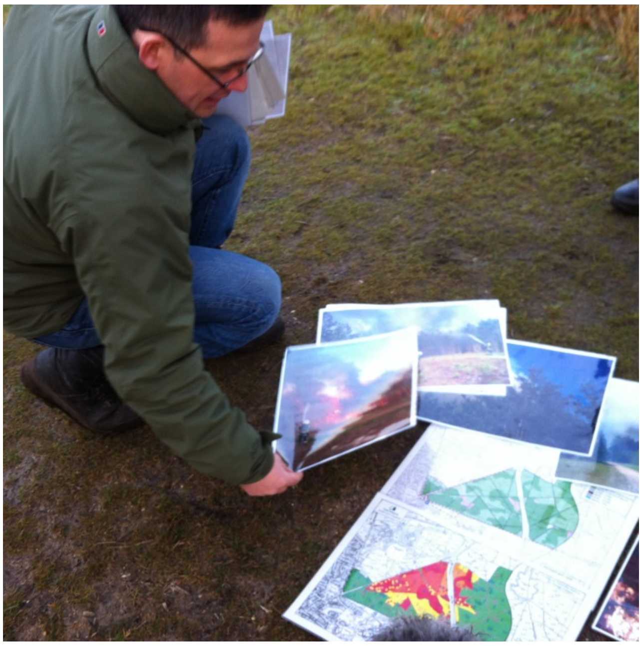

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Glossary

AHP	Analytic Hierarchic Process
BUI	Build-up Index
DC	Drought Code
DCLG	Department for Communities and Local Government
DMC	Duff Moisture Code
FC	Forestry Commission
FCE	Forestry Commission England
FDP	Forest Design Plan
FFMC	Fine Fuel Moisture Code
FMP	Forest Management Plan
FR	Forest Research
FRS	Fire and Rescue Service
FRSD	Fire and Rescue Service Directorate
FS	Forest Services
FWI	Fire Weather Index
IRMP	Integrated Risk Management Plan
IRS	Incident Recording System
ISI	Initial Spread Index
KCL	Kings College London
LCM2007	Land Cover Map 2007
MCE	Multi-criteria evaluation
MoD	Ministry of Defence
NERC	Natural Environment Research Council
NFI	National Forest Inventory
RoI	Risk of Ignition
PFE	Public Forest Estate
PURE	Probability, Uncertainty and Risk in the Environment
VaR	Values at risk
WTA	Wildfire threat analysis

Hierarchy of spatial information used in this project:

Layers	Map layers of spatial information without any aggregation; *e.g*. LCM2007; Ambulance stations.
Components	Themes derived by aggregating layers; *e.g.* Land cover, proximity to roads, emergency services, biodiversity.
Sub-modules	Larger groupings derived by further aggregating components within the Values at Risk module: *i.e*. Health and wellbeing, Ecosystem services and Property and infrastructure.
Module	The three top-level parts of WTA, produced by weighted combinations of components or sub-modules; *i.e.* Risk of Ignition, Hazard and Values at Risk.

Executive summary

The report covers a scoping study on risk assessment for forest fire at the rural-urban interface undertaken by the University of Manchester, working alongside Forestry Commission England (FCE) and Forest Research (FR). The research was funded by the Natural Environment Research Council (NERC) under the Probability Uncertainty and Risk in the Environment (PURE) Associates Programme.

The scoping study tests the applicability of the Wildfire Threat Analysis (WTA) technique from New Zealand to a UK context and at a local scale. WTA treats wildfire threat as the cumulative combination of three aspects: ignition potential (risk of ignition), potential fire behaviour (hazard of fire spread), and values put at risk as a result (assets, including life and well-being). These are represented by three GIS modules, each comprising a set of layers of geographical information, organised into components and sub-modules.

The threefold WTA framework mapped reasonably well onto two existing risk assessment frameworks used in the UK. In the National Risk Register, risk is a function of likelihood and impact. Risk here approximates to threat in WTA, and likelihood to risk of ignition together with hazard. NRR impact is captured partially by the values at risk inventory, and partially by magnitude of the hazard. Crucially, it also requires a better understanding of the relationship between intensity of the fire hazard and degree of damage produced.

In the Crichton risk triangle used for flooding, and by the IPCC for climate change related risks, risk is seen as a function of hazard, exposure of assets to the hazard and also their vulnerability. Risk here again approximates WTA threat, and hazard to WTA's risk of ignition together with hazard. Exposure equates to the chance of WTA values coming into contact with fire, thus in a way reflecting the extent of the area affected by fire under the hazard module. Vulnerability is an attribute of values at risk, describing the potential harm to people or assets if they are exposed to fire. It has no direct counterpart in the WTA framework, so we modified values at risk to include social vulnerability, but did not include vulnerability of ecosystems services or infrastructure.

Appropriate spatial information was collected for an 11 km by 12 km case study area on the Berkshire, Surrey and Hampshire borders, centred on Crowthorne Wood and Swinley Forest. The three local Fire and Rescue Services (FRS) have attended nearly 1000 vegetation fires in four years in this area, including a major, politically significant fire in Crowthorne Wood in Spring 2011 (the 'Swinley Forest' fire).

Two of the three GIS modules, that is, risk of ignition and values at risk, were developed using a 25m cell size, which is appropriate to the local scale at which management is undertaken. The hazard module could not be constructed due to lack of fire weather data at the time, but simulations of fire spread for the Crowthorne 2011 fire were done by King's College London. Values at risk from wildfire spread were grouped into three sub-modules: human health and wellbeing; property and infrastructure; and ecosystem services.

The UK's Incident Recording System (IRS) records vegetation fires attended by the approximately 50 regional FRS and was an extra source of information used in the risk of ignition module. A panel of experts were consulted through two stakeholder meetings on the appropriateness of the WTA framework and the choice of layers. The experts were asked to evaluate individual GIS layers within each of the three modules and to assess issues such as the variation in risk of ignition with land cover type. Opinions were also gathered on how to threshold layers, for instance, into classes representing distance from access points.

The expert panels were then asked to weight the relative importance of the resulting components within each module. The weights were applied and the resulting maps were presented for further evaluation and feedback. An overall risk of ignition map was established for the study area. In combining the three values at risk sub-modules, maps showing values at risk for human life were weighted more heavily than infrastructure, which, in turn, was given greater weight than ecosystem services.

The outcome of the wildfire threat analysis exercise was a set of agreed maps showing risk of ignition and values at risk across the study area. These had been refined through intensive discussion with groups of end-users during follow-up meetings. Potential applications of the maps include: for Local Authorities, guiding local development plans; and for Fire Services, informing Integrated Risk Management Plans (IRMPs), including the deployment of emergency services in the event of a fire. For the Forestry Commission (FC), Ministry of

Defence (MoD) and other land managers, it targets resources for public fire awareness and other fire prevention measures and fuel management measures such as thinning or replanting.

Work remains to be done on development of a hazard module showing potential fire spread at this local scale. Kings College London (KCL) recently developed 2km Fire Severity sub-indices for the Met Office under a parallel PURE Associates grant. This is still too coarse for a 25m local WTA but would be appropriate at the national scale. The Fine Fuel Moisture Code 2km data could be incorporated into a regional or national risk of ignition module to give the more meaningful probability of sustained ignition. The other fire severity sub-indices could be used with other layers to create a national or regional scale worse-case wildfire hazard map. A nested approach may be the most appropriate, developing a coarser scale WTA to identify national wildfire hotspots, where a more intensive local finer scale WTA (as here) is required.

Further ecosystem services should also be added to the values at risk module. Finally, work is also required to test whether WTA works at the coarser regional and national scales appropriate to strategic risk assessment by national agencies. For risk of ignition, this is likely to require replacing stakeholder weighting with mathematical modelling. More accurate risk of ignition models will be possible, however, if the geo-reference recorded in IRS is standardised to the estimated point of ignition.

1. Introduction

1.1 About this report

This report summarises a scoping project, *'Developing a risk assessment approach for forest fire at the rural-urban interface: potential of the wildfire threat analysis framework'*. It was carried out by the University of Manchester in partnership with Forest Services (FS), Forest Enterprise (FE) and Forest Research (FR), which are subsidiaries of the Forestry Commission England (FCE) and the Forestry Commission itself (FC). The project ran for 6 months (December 2013 – May 2014) and was funded by the Natural Environment Research Council (NERC) under their Probability, Uncertainty and Risk in the Environment (PURE) Knowledge Transfer Associates programme (Grant reference PA13-035).

The aim of the project was to test the applicability of wildfire threat analysis (WTA), both for fit to current UK risk assessment frameworks, and for use in strategic decision making by forest managers and planners at the woodland-urban interface. The research refined the proposed framework, scoped the appropriateness of the layers and assessed the availability of data and sources of uncertainty.

This report has been produced for the benefit of the major stakeholder organisations, *i.e.* those whose representatives took part in workshops and meetings organised for the project. It describes the steps undertaken and the issues that arose at different stages of the process, leading to development of the Risk of Ignition and Values at Risk maps. It also offers practical applications and recommendations for further research.

1.2. UK wildfire

Analysis of Incident Recording System (IRS) statistics for Great Britain by FCE shows that in the four financial years 2009/10 to 2012/13, over 211,000 fires burned an estimated 71,000 ha and required over 181,000 person hours to suppress (14 years 7 months), with 65,000 fires alone in FY2010/11 (Gazzard, 2014). Further statistics and mapping by land cover and size of damage area using the first two years of IRS data for England can be found in Finlay *et al* (2012). An overview of some key issues in wildfire risk management in the UK can be found in McMorrow (2011) and Moffat and Pearce (2013).

1.3 Policy drivers and responses to wildfire risk

The financial, environmental and societal cost of damage caused by wildfires in England is already high. Fire suppression costs for a single large moorland fire in the Peak District was £1M (Aylen *et al.* 2007). Annual costs to GB's Fire Services are estimated at up to £55 million per annum (R. Gazzard, cited in Moffat and Pearce, 2013), and are set to increase.

The first UK Climate Change Risk Assessment (CCRA1) recognised that more frequent wildfires are expected to occur due to warmer and drier conditions (DEFRA, 2012). The National Adaptation Plan (2013: 55) includes policy actions for wildfire. It anticipates that Local Resilience Forums (LRFs) will re-consider the risk of severe wildfires in their Community Risk Registers, and Fire and Rescue Services (FRS) in their Integrated Risk Management Plans (IRMP). A further key driver, is that wildfire was included for the first time in the National Risk Assessment in 2012 (NRA12) and the public version, the National Risk Register (Cabinet Office 2013). The UK therefore has an urgent need for improved policy and operational approaches to manage wildfires.

Within the FC, increased forest fire risk is already recognised and planning is underway under the banner of climate change adaptation. Ray *et al.* (2010) acknowledged that increased frequency of forest fires would change the composition, structure and age profile of English woodland and would require new approaches to woodland management. More recently, evidence on the risks posed to the forestry sector by climate change was evaluated for the CCRA1 (Moffat *et al.,* 2012). FCE (2012) also carried out its own invited Climate Change Risk Assessment for the CCRA1. The report outlines the role of the FC's Climate Change Strategy Group and the Climate Change Action Plan for the Public Forest Estate (PFE). The Action Plan will use the PFE Forest Design Plans (FDP) as the main instrument to improve habitat resilience, involving for instance, greater use of continuous cover management, planting for stands of mixed species and mixed age, and planning for forest fire and other risks (Forestry Commission, 2012: 9). There is a potential role within FDPs for decision support tools such as wildfire threat analysis.

European policy is also a driver for the FC. The UK Forestry Standard (UKFS) recognises wildfire as one of the threats to be included in the contingency plans required under the Environmental Liability Directive (204/35/EC) (Forestry Commission, 2011). These plans are important because the 'polluter pays' principle, which underlies the Directive, makes the FC financially liable for environmental damage on land managed by them.

Forest Management Plans (FMP) are used to monitor, assess and propose management plans for Forest Management Units at a scale appropriate to the complexity of the unit. At site scale, operational plans are used, specifying in detail how management proposals should be carried out on the ground.

Wildfire risk assessment tools at appropriate scales are needed for all four instruments; contingency plans , FDPs/FMPs and their resulting operational plans. The Forestry Commission's (2014) practice guide to build wildfire resilience uses a range of toolkits based on Forest Management Plan principles including wildfire risk assessment process and templates. This practice guide has been used in a recent GIS-based fire management zoning of the Public Forest Estate in the Wild Purbeck Nature Improvement Area. Wildfire threat analysis could evaluated there as an alternative decision support tool.

1.4 The Wildfire Threat Analysis framework

The WTA approach was developed for Canada (*e.g*. Beck and Simpson, 2007) and successfully implemented in New Zealand (Gibos and Pearce 2007, Majorhazi 2002; Intergraph, no date). Wildfire threat is analysed as a cumulative combination of three GIS modules:

- **RISK** – Risk of ignition (RoI), or ignition potential; *i.e*. How likely is a fire to start at this point?
- **HAZARD** – Potential fire behaviour, or hazard of fire spread; *e.g.* Once ignited, how quickly and intensely will it burn at this point?
- **VALUES** – Values at risk (VaR), or assets put at risk as a result of the fire; *i.e.* What assets will be exposed at this point, for instance life, property or ecosystem services?

It is important to realise that Risk, Hazard and Values are considered separately in WTA, and combined only at the end. A hierarchy of spatial information is used in WTA and the terms used in this report are defined in the Glossary.

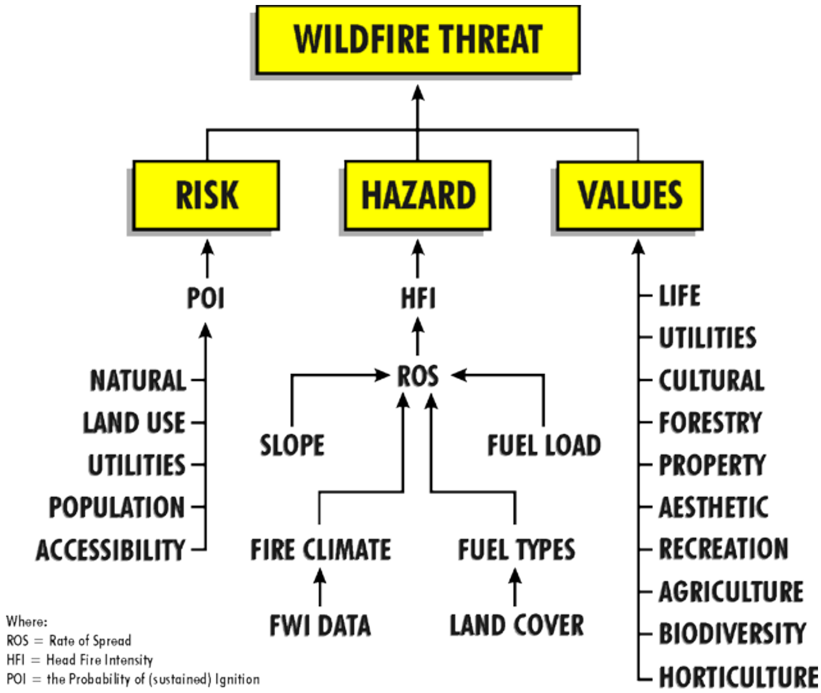


Figure 1: Wildfire Threat Analysis, comprising three modules (Risk of Ignition, Hazard and Values at Risk), which in turn are built of a number of components, each composed of GIS layers (Moffat and Pearce, 2013).

Each module is made up of a set of layers of geographical information (Figure 1). The layers within a module are aggregated in various ways to produce components, which represent a contributory factor such as land use or accessibility. The component maps are then combined within a module to give a map; one map for each module. In a full WTA, every grid cell will therefore have a separate number for Risk, Hazard and Values. Combining the three maps gives the Threat.

Discussions and collaboration between FC, FR and Scion (the New Zealand forest research agency) suggested that wildfire risk in New Zealand and the UK are comparable, and identified the potential for the WTA framework currently used in NZ to be adapted for UK conditions (Moffat and Pearce, 2013).

WTA has its critics; for instance, there is no module for fire response (Wilson, 2004). The term 'threat' denies any positive outcomes from fire, whereas fire can reset the ecosystem in positive ways and reduces fuel for the next fire.

Miller and Ager (2012) and Stratton (2006) provide good reviews of alternative frameworks for wildfire risk assessment. Specific examples include: Atkinson *et al*. (2010); Badia *et al.* (2002); Bonazoutas *et al.* (2005); Chuvieco *et al.* (2010) and (2013); Contreras and Kienberger (2011); Lampin-Maillet *et al.* (2010); and Tedim (2012). Challenges are reviewed in Finney (2005) and Thompson and Calkin (2011).

1.5 Fit to existing risk assessment frameworks

The fit of the threefold WTA framework to two risk assessment frameworks used in the UK is shown in Figure 2.

1.5.1 National Risk Register

In the National Risk Register (NNR) framework, risk is a function of likelihood and impact (Cabinet Office, 2013):

LIKELIHOOD + IMPACT = RISK

NRR likelihood equates to WTA's risk of ignition combined with hazard of fire spread, since it is the likelihood of a fire starting and developing to a certain size. The NRR is only concerned with 'severe wildfires'. Likelihood is inversely related to magnitude; larger fires occur much less frequently than smaller ones. What this does not take into account is that experience in the USA and Mediterranean shows that zero tolerance to small fires, or lack of land management, allows fuel to build up and allow mega-fires (Tedim *et al*., 2013), so the likelihood of a severe wildfire is affected by fire suppression and land management in the longer term.

NRR impact is partially related to WTA's values at risk. NRR impact is, however, more than simply values at risk. Impact must also involve WTA hazard, because impact requires us to know not just which assets are at risk, but also the severity of the hazard imposed and the resulting response. Similar to a dose-response relationship in medicine, it requires we need to know how fireline intensity (WTA's hazard, the physical heat 'dose') actually affects the assets (WTA's values at risk) to create an impact (the damage response). This last step – an understanding of how fireline intensity produces an ecological or sociological response – is poorly understood for UK conditions. For instance, in fire ecology, the relationship between fireline intensity and post-fire 'burn severity' (the degree of damage to vegetation and soil immediately after the fire) is only partially understood. We cannot assume that a certain fireline intensity (from WTA hazard) will always produce the same degree of charring, since factors such as fire history can cause it to vary. With this in mind, a useful additional layer would be burn severity recorded in the field or by remote sensing immediately after the fire (Chafer, 2013; Cocke *et al*., 2005). Long-term ecological response is even harder to predict (Keeley, 2009). Equally, communities and individuals will respond differently according to their social vulnerability, for instance age, health or income (Tedim, 2012). Indicators of social vulnerability are incorporated in this project within values at risk (section 2.3.2). For these reasons, WTA's values at risk equates only approximately to NRR impact, and WTA's threat to NNR risk.

It is also necessary to define how long after the fire the impact is to be estimated. NRR is designed for emergency response, so we should perhaps think more in terms of shorter term impacts. Some impacts are immediate (*e.g.* removal of green vegetation and charring of the soil surface), whereas others develop over longer time spans (*e.g*. a change in species composition). An immediate post-fire negative impact can become a positive one, given long enough. For example, a percentage of the carbon stock is lost when vegetation burns, but is replaced slowly as vegetation regenerates, which may capture carbon at a faster rate than the pre-fire vegetation. V*ice versa*, a negative impact may develop over time, as in the case of psychological impacts, or bronchial illnesses triggered by smoke (Finlay *et al*. 2012).

Finally, we need to define whether it is only immediate impact within the fire perimeter that concerns us, or also off-site impacts such as the transport disruption caused by smoke. The WTA hazard module considers only direct fire hazard and does not model smoke plume dispersal.

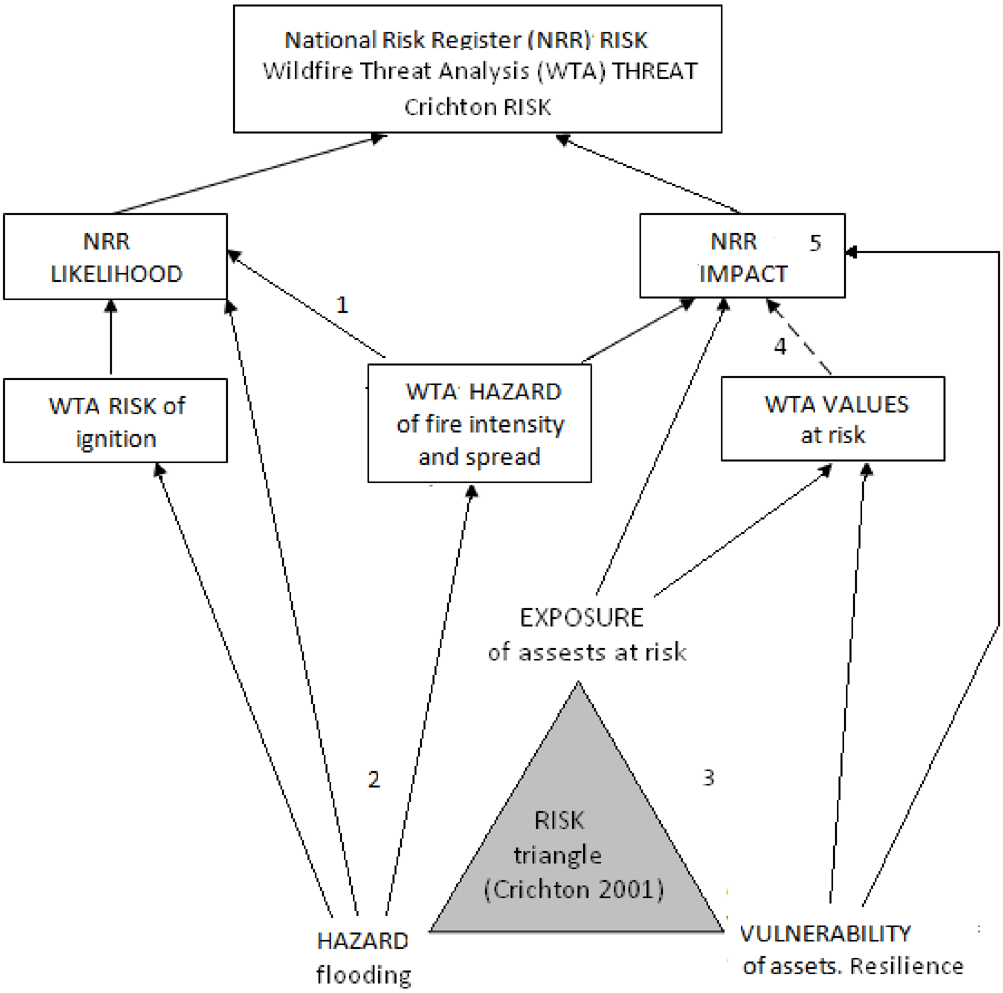
1.5.2 Crichton risk triangle

The Crichton (2001) risk triangle was developed for use in the insurance industry and is widely used in estimating risks from flooding (*e.g.* Kazmierczak and Cavan, 2011). The same framework is adopted in the UK's Climate Change Risk Assessment, based on that of the Intergovernment Panel on Climate Change Fifth Assessment (2014, Figure SPM.1). The framework sees risk as a function of hazard, exposure (assets at risk) and their vulnerability:

HAZARD + EXPOSURE + VULNERABILITY = RISK

Flood hazard in this framework is treated as a single phenomenon (presence of flood water), whereas WTA places greater emphasis on fire as a physical process and divides the process into the two stages of ignition and spread. Crichton's risk triangle, instead, places greater emphasis on the socio-economic impacts further down the causal chain, splitting these into exposure and vulnerability. Exposure of assets reflects the possibility of WTA's values becoming affected by hazards; i.e. the human, ecosystem and infrastructure assets coming to contact with flood or fire. Vulnerability, as noted above, mediates the impact of the flood/fire hazard on those assets (Tedim, 2012; Contreras and Kienberger, 2011). Vulnerability is decreased by community, ecosystem or infrastructure resilience to the hazard event. In the modified version of WTA used in this project, some indicators of social vulnerability of communities are included as layers in values at risk (section 2.3.2), but we did not include vulnerability of ecosystem services or infrastructure and property.

The risk triangle maps well onto the NRR framework. Hazard (a flood of a given magnitude) equates to likelihood. Exposure with vulnerability together equate to impact.



1. Likelihood depends on magnitude (Hazard of fire intensity and spread). Inverse relationship between likelihood of an event and its magnitude; smaller events occur more frequently. NRR Likelihood therefore specifies 'severe' wildfires.
2. WTA's focus is on fire as a physical process, so it splits fire down into risk of starting and spreading. Crichton simplifies hazard into a single component. The focus is farther down the causal chain, on socio-econmic factors, which it splits into exposure and vulnerability.
3. Crichton's Exposure + Vulnerability = NRR Impact
4. WTA Values at risk + WTA Hazard +[Vulnerability] = NRR Impact. Relationships poorly understood for UK conditions. Only social vulnerability used in this project.
5. Impact varies over short to longer time scales

Figure 2: Fit between three UK risk assessment frameworks: National Risk Register (NRR), Wildfire Threat Analysis (WTA) and Crichton flood risk triangle.

1.6 The 2011 'Swinley Forest' fire

On 2nd May 2011, FCE's Crowthorne Wood experienced a major wildfire, which started to the east in Swinley Forest on Crown Estate land and lasted over week. It was the largest and most resource-intensive fire ever fought by Royal Berkshire FRS, requiring almost 300 firefighters including those from six other FRS (Oxborough & Gazzard 2011). Oxborough and Gazzard (2011) describe the extreme fire behaviour caused by high fuel loading, and the lessons learned from the fire. The description which follows is based on their paper, supplemented by further information from stakeholders during the project and preliminary work by Aylen *et al*. (2011) on costing the fire's impacts.

Ladder fuels in dense young pine thickets allowed surface fire to travel into the crown and cause a flash-over that jumped 5 and 10m wide fuel breaks, travelling through 7 hectares in 20 minutes. At its height, over 50 pumping appliances were used on one day. Weather conditions encouraged rapid fire spread; temperatures of >30°C, relative humidity of <40%, wind speeds of around 35 kph and changeable wind direction. Of the total 110 ha affected, 55% (approximately 60 ha) was due to damage by fire and forestry clearing operations, such as bull-dozing and mulching by FCE during the fire to create or reinforce firebreaks along tracks.

The incident resulted in a total loss of woodland of 40 hectares and replanting costs of over £150K. National infrastructure and assets were also affected, including closure of a major A-road for five days, disruption to Broadmoor High Security Hospital and to the Transport Research Laboratory. Seven houses were evacuated; three schools were closed; local businesses incurred losses up to £70K. Aylen *et al*. (2011) estimates fire fighting costs at £543,000 – almost half the total social cost of the incident. Transport disruption to cars, goods vehicles and public service vehicles, estimated at £229,300, accounts for a further quarter. This fire is classified as a 'near miss' event, because it could easily have caused even greater social disruption to surrounding communities and threatened critical infrastructure in the surrounding area, had the wind not changed in time (section 1.8).

Lessons learned include the need to consult FRS more when planning new urban development in the rural-urban interface, and for all stakeholders (*e.g.* FRS, FC, Crown Estate) to improve strategic and tactical planning for preparedness, prevention, response and recovery (Oxborough and Gazzard, 2011). WTA could assist with both.

1.7 Case study area

An 11 by 12 km area centred on Crowthorne Wood (managed by FCE) and Swinley Forest (by Crown Estates) was chosen as the case study for the WTA. As was demonstrated in section 1.6, it is a good example of rural-urban interface (RUI) where wildfire is a serious threat. The case study area is shown in Figure 3. The coordinates were: top left corner: X=483000, Y=170000; bottom right corner X=494000, Y=158000. It includes many different land uses and multiple landowners. It allows a 500m buffer around the main area of interest to accommodate edge effects which would be created if certain spatial modelling techniques were used.

In order to understand and manage the risk of serious fire occurring again in and around the Public Forest Estate the responsible government department (FCE) needs to be able to quantify risks, hazards and impacts of wildfire which, in turn, will inform FCE policy and operational managers. FCE needs a strategic, spatial tool which can assist FC policy and help operational managers improve the resilience of forests and woodland by quantifying specific wildfire risks, hazards and impacts. Such a tool could also be applied by planners and developers in order to assist their decisions on the location of new housing and the redevelopment of existing built-up areas.

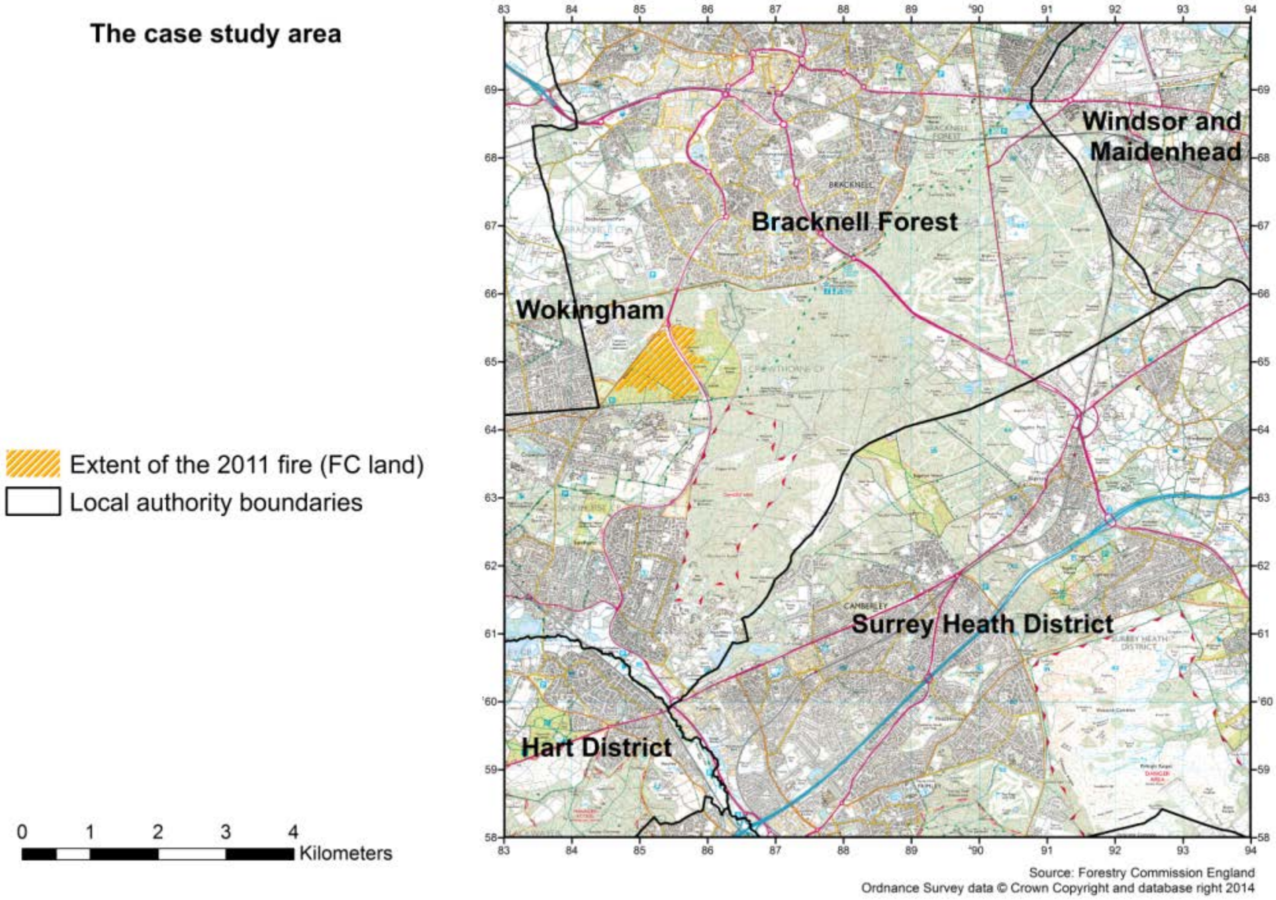


Figure 3: The case study area, spanning the borders of Berkshire, Surrey and Hampshire.

1.8 Hazard module and fire behaviour simulations for the 'Swinley Forest' fire

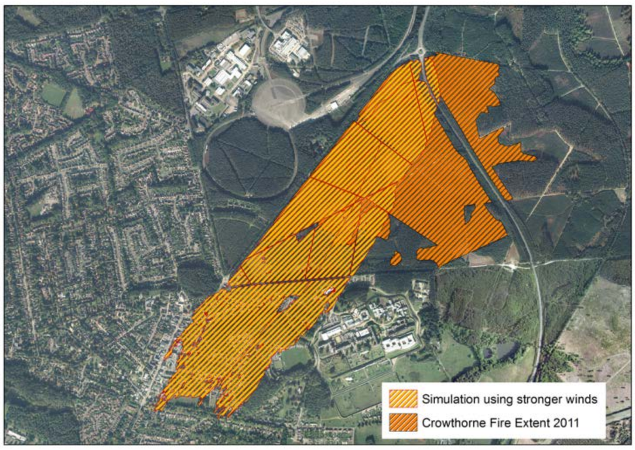
The hazard module could not be constructed due to lack of long-term fire climate severity indices at a suitable spatial resolution and within the time frame of the study.

For the new Zealand WTA, fire climate severity maps were available (Pearce *et al*., 2011). Fifteen years of New Zealand fire weather records were used from 77 weather stations to calculate the five sub-indices making up the Fire Weather Index (FWI); Fine Fuel Moisture Code (FFMC), Duff Moisture Code (DMC), Initial Spread Index (ISI), Build-Up Index (BUI) and Drought Code (DC). The mean and top values during the 15 fire seasons were mapped to show variation in fire climate severity across New Zealand.

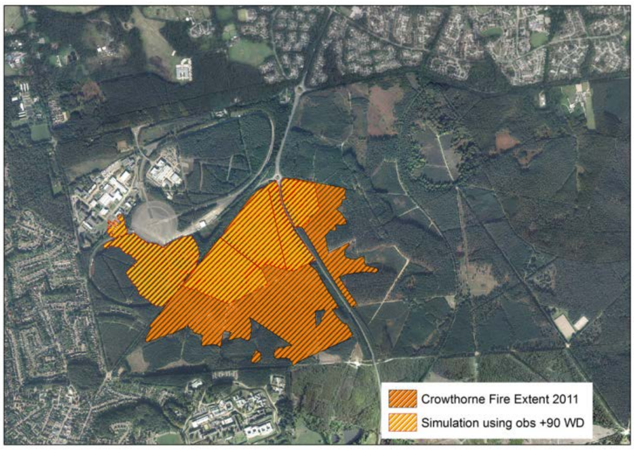
These sub-indices have recently been calculated for the UK at 2km spatial resolution in a parallel PURE KTA project by Kings College London (KCL) for the Met Office. They were not available in time for our project, and the 2km resolution was too coarse for the fine spatial scale (25m) used here. It was beyond the resources of our project to calculate it from the weather history of past fires in the study area. However, the KCL indices would be appropriate for a national Hazard map (see section 9, point 1).

As an alternative, preliminary simulations of fire spread for the Crowthorne 2011 fire were carried out by Tom Smith at King's College London using the Prometheus fire spread model (Alberta Government, 2012; Tymstra *et al.,* 2010). Prometheus uses a digital terrain model (DEM), a fuel layer and fire weather data (as opposed to longer term fire climate) to calculate fire behaviour and spread in a pre-determined way (FireGrowthModel.ca, no date).

The simulations show that if the wind had been stronger, it would have driven the fire south-westward, bringing it to the doorstep of Broadmoor Hospital and into houses in the village of Crowthorne (Figure 4a). If the wind direction had shifted 90° towards the north-west, it would have gone into Transport Research Laboratory land, where new housing and a care home are planned (Figure 4b). A 270° degree shift would have driven it eastwards into Swinley Forest proper and on towards Bagshot (Figure 4c).



(a)



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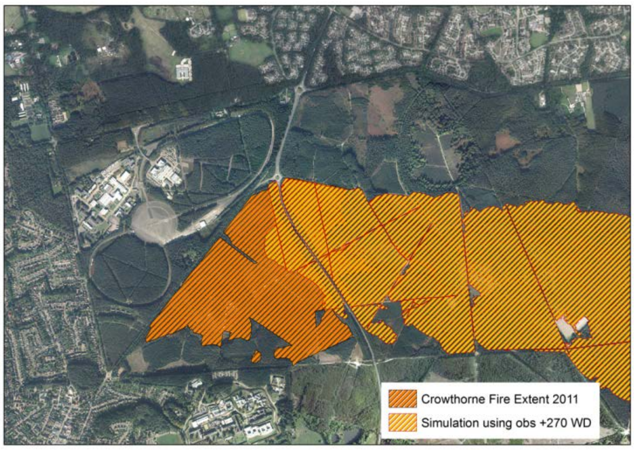


(c)

Figure 4: Preliminary Prometheus model simulations of fire spread, courtesy of Dr Tom Smith, King's College London; (a) stronger winds with observed wind direction; (b) observed wind strength but shift in wind direction 90°; (c) observed wind strength but 270° shift in wind direction shortly after ignition.

1.9 Project approach

Wildfire Threat Analysis involves the following stages, broadly aligned with usual stages in multi-criteria evaluation (MCE) (McMorrow and Lindley, 2006; Majorhazi, 2002):

1. **Defining** the map layers and compiling the base maps required
2. **Scoring** the features in each map
3. **Weighting** the different map layers/components against each other within the Risk of Ignition module of separately for Values at Risk
4. **Mapping** and **evaluating** the results from stakeholder feedback. This includes selection of the most appropriate method of presentation and adjusting the weighting of components and the method of presentation as necessary
5. **Applying** the results to fire management.

We employed the Delphi method, to establish the views of stakeholders. Delphi is a structured communication technique relying on a panel of experts (Rowe and Wright, 2001). The focus of the exercise was two rounds of consultation; in this case, two workshops (in February and April 2014) involving representatives from 11 organisations (see Appendix 1). The experts were chosen for their detailed but varied knowledge of aspects of wildfire in the area. The panel included foresters, fire fighters, emergency planners, property owners, infrastructure managers and environmental experts. There was a high degree of stability in group membership and the panels were the same size at each round. Participants were variously asked to work as individuals, or together, or in sub-groups to offer informed answers to questions during two rounds of enquiry.

The process of eliciting knowledge was supported by a range of structured exercises and worksheets to focus discussion and force trade-offs between competing outcomes. In this way, judgements became explicit and precise. For example, in one exercise, participants were given a budget of points to allocate according to the importance of factors, forcing them to make relative valuations of one factor against another. In another instance, a series of Likert scales were used to prompt formation of a consensus on a range of issues.

Questions for evaluation at these workshops built upon the structure suggested by New Zealand's WTA. After each round, we provided a summary of views expressed, with reasons given for judgments. In this way, the experts were encouraged to re-appraise and revise earlier responses in the light of the replies of others. During this process the range of the answers decreased and the group converged towards a consensus. Thus, in effect, the maps of Risk of Ignition and Values at Risk are a result of co-production of knowledge with the local stakeholders. The two workshops were followed by a series of one-to-one or small group meetings with representatives of five of these organisations (based on their availability).

There was a clear progression of topics across the meetings. As demonstrated in Figure 5, the first workshop focused on defining and scoring data. The second meeting moved on to scoring and weighting. The individual follow-up meetings discussed the weighting, mapping and application of the results. So, at each of these stages, the focus was slightly different. This may be seen as a deviation from the standard Delphi method which emphasises a static consensus on one issue. Nevertheless, the overlap in themes during these workshops meant a key feature of the Delphi process was retained whereby participants are allowed to review opinions given at previous stages of consultation.

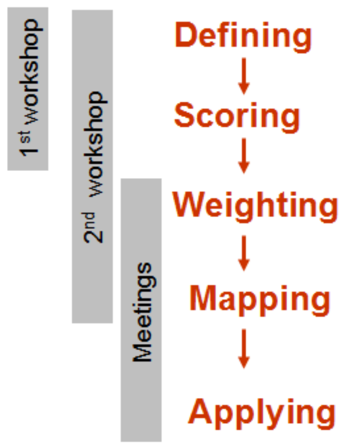


Figure 5: Alignment of the stages of the WTA process and the stakeholder involvement.

These stages of defining layers, scoring, weighting and mapping are described in the subsequent sections of this report (sections 2-7). The final stage– applying the relevant judgements - has not been reached within this scoping project; however, the stakeholders offered ideas on the potential applications of the maps developed and these are summarised in section 8.

2. Defining the layers

This stage included a compilation of the available spatial information pertaining to the Risk of Ignition and Values at Risk. The entry point was the WTA layers used in New Zealand. But our process was to large extent guided by the data available here in the UK. For example, land use information is not available in the UK context. Conversely, some layers that were not present in the New Zealand WTA were added.

Some of these new layers were based on an analysis of the spatial distribution of fires in IRS. Other layers were suggested by workshop participants. The data sources used for the layers included open sources of spatial data (e.g. Natural England, English Heritage, National Grid); Ordnance Survey (MasterMap, boundary data); and location-specific data from FCE (detailed land cover data, some information on electricity lines and gas pipelines). The 'data catalogue' in Appendix 4 provides more details.

A draft 'data catalogue', listing data sources available, was sent to the stakeholders in advance of the first workshop. They were encouraged to comment on data already collected and suggest alternative sources of information for data that was missing, or indicate where more accurate information could be obtained.

The first workshop opened with a presentation on factors within the Risk of Ignition. Here the participants were encouraged to comment on data sources relevant to factors affecting risk of ignition, both in a structured group discussion (following questions included on slides) and by completing question sheets individually.

The next session within the workshop focussed on Values at Risk. Stakeholders were divided into three thematic groups (according to their organisation, or role in their organisation). These specialist sub-groups applied their expert judgements to ecosystem services, property and infrastructure, and health and well-being. These sub-groups were asked to allocate a limited budget of resources – in truth, a limited number of 'sticky dots' - to prioritise layers of information. This constrained choice forced each sub-groups to focus on the relative importance of particular values and the data series used to represent these values. They were also encouraged to provide information about any additional data and information sources.

Notes from the workshop, the question sheets and the sheets from group exercises were analysed. Additional data searches were carried out and more data layers acquired. The second round data included, for example, data provided by Bracknell Forest Council, the Ministry of Defence and additional open source data e.g. the National Forest Inventory (NFI). During the second workshop, the updated data sources were presented to the stakeholders and again comments were encouraged on the relevance of layers to the likely Risk of Ignition and Values at Risk through scoring exercises (section 4). This iterative process established some clear and well-founded priorities – the importance of the value of life relative to the environment, for example.

2.1 Use of Incident Recording System (IRS) data

One advantage of applying Wildfire Threat Analysis in the UK is the availability of the national IRS fire statistics database, managed by the Department for Communities and Local Government (DCLG) Fire and Rescue Service Directorate (FRSD). It collates the detailed information collected by the regional FRS on *all* incidents reported to them. IRS contains information on outdoor fires, and within this, fires where the primary source is vegetation. For the study area, vegetation fire categories from IRS in order of frequency were:

- Tree scrub (33%);
- Heathland/moorland (25%);
- Scrub land (15%);
- Grassland (10%);
- Domestic garden (6%);
- Park (5%);

- Roadside (3%);
- Woodland/forest - conifers/softwood (1%);
- Wasteland (1%); Railway (<1%);
- Woodland/forest - broadleaf/hardwood (<1%);
- Canal (<1%).

The IRS data for the case study area was obtained via FCE. In the four financial years April 2009 to March 2013, 964 incidents were recorded by the three FRS covering the 11x12 km study area (Royal Berkshire, Surrey and Hampshire FRS). These incidents were primarily small fires of under 5m^2 (54%), with 69% under 10 m^2, but also including larger areas of damage, *e.g*. the Crowthorne Wood ('Swinley Forest') fire in 2011. Circles in Figure 6 are proportional to damage area recorded in IRS.

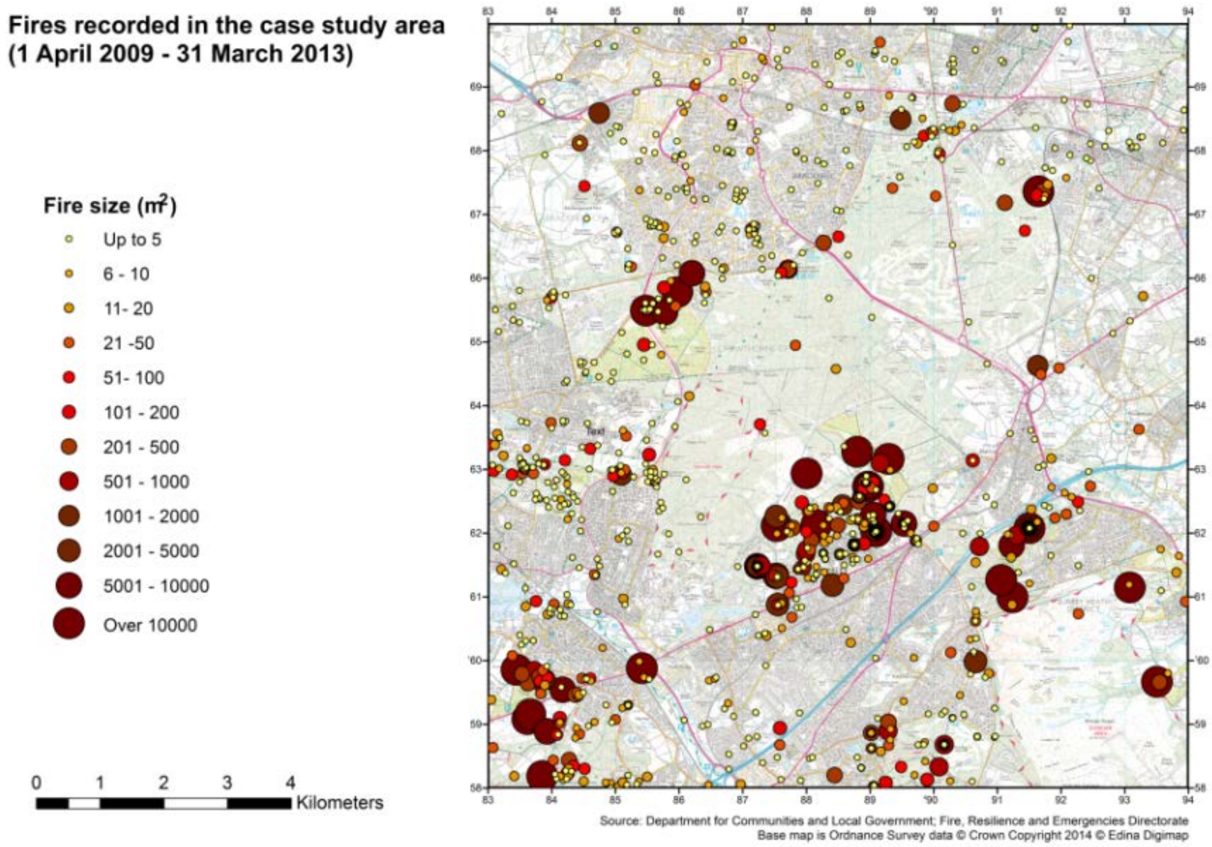


Figure 6: Vegetation fires recorded by the IRS system in the area between April 2009 and March 2013. Circles are proportional to damage area as recorded in IRS.

There are sources of uncertainty associated with IRS data:

- *Spatial accuracy of IRS points:* the IRS geo-location of the fire is recorded as a single point by the Incident Commander following the incident. A point may be the location where the fire was first observed, the rendezvous point where the fire appliances were parked, or even the location where the call-out originated. This partly explains the concentration of vegetation fires around built up areas as well as roads and paths (see sections 2.2.3 and 2.2.4)

- *Thematic accuracy of IRS information:* the data used for the analysis here includes only fires recorded as vegetation fires. However, if a fire started in vegetation but progressed to affect a property, it would be recorded as property fire. As a result, there is some under-reporting of vegetation fires within IRS. Property type was only used to identify vegetation fires. It was not used to analyse land cover types on which fires occur. Here,the Land Cover Map 2007 (LCM2007) was used instead (section 2.2.1).

2.2 Risk of ignition layers

The Risk of Ignition layers to be included in the WTA were discussed with the stakeholders during both workshops. The research team proposed a set of layers which might be included and discussed the associated sources of uncertainty with the participants. The experts gave their feedback through a group discussion, structured around questions included on slides and individually on 'scoring sheets'.

2.2.1 Land cover map

WTA recommends using land use information. In the absence of up-to-date spatial information on land *use* for the UK, land *cover* maps were used instead. For instance, land cover might be grassland, but land use might be recreation, agriculture or horticulture.

The LCM2007 (CEH, 2011) was initially used, but following a recommendation at the first stakeholder workshop, the NFI map (Forestry Commission 2011)[1] was used as a supplementary source of information, providing more details on land cover in many of the areas classified by LCM2007 as woodland. Broadleaved and coniferous woodland classes were selected from LCM2007 and used to "clip" the NFI layer. The non-woodland LCM2007 classes were retained for the remainder of the area, with some adjustments (Table 1). This created some gaps where LCM2007 woodland polygons were present, but there was no NFI data. For these areas, the LCM2007 woodland classes were used. The LCM2007 classes were matched to NFI classes, and the latter were then used in the final classification (Table 2).

Table 1: Matching the non-woodland LCM2007 land cover classes to NFI classification

LCM2007 class	NFI class
No data	No data
Arable and horticulture	Agricultural land
Grassland – improved	Grass
Grassland – rough	Grass
Grassland – neutral	Grass
Heather	*Additional class*
Heather grassland	*Additional class*
Inland rock	Bare ground/rock
Freshwater	Open water
Suburban	Urban/building
Urban	Urban/building

[1] Data for NFI was collected in 2010, so was deemed appropriate to reflect the pre-fire situation in May 2011.

Table 2: Final land cover types in the combined map

Woodland	Non-woodland
Broadleaved	Grass
Conifer	Agricultural land
Felled	Other vegetation
Ground prepared for new planting	Bare ground/rock
Mixed – predominantly Broadleaved	Urban/building
Mixed – predominantly Conifer	Quarry
Young trees	Power lines
Low density	Open water
Assumed woodland	Forest road or track
Shrub land	Heather
	Heather grassland

All LCM2007 grassland classes were considered together, as the predominant type in the case study is improved grassland area with very small coverage of the remaining two types of grassland. In other parts of the UK, it would be important to retain the three LCM2007 grassland classes, as they are associated with different fuel type and load and density of ignition sources related to different land uses.

Suburban and urban LCM2007 classes were considered together and replaced by the NFI urban/building class. Heather and heather grassland from LCM2007 were, however, added to the NFI classification, because it was important to retain these two land cover classes which would otherwise simply be classified in NFI as 'other vegetation'. In all, this resulted in 21 land cover types (*Figure 7: Land cover types in the study area*).

There are a variety of data issues relating to the LCM2007 which introduce uncertainty:

- In the production of LCM2007, parcels less than 0.5ha and linear features less than 20m were dissolved into the surrounding landscape. The raster data have been derived from the vector dataset to produce a 25m product (CEH, 2011); therefore it may omit small-scale mosaics of habitats.
- LCM2007 was created by classifying summer-winter composite images captured by satellite sensors with 20-30m pixels. The published accuracy for LCM2007 is 87% against ground truth data (CEH, 2011), so some misclassification remains.
- As LCM2007 is based on satellite images, it captures only the top surface of vegetation (canopy level or equivalent) so that variations in ground cover below may be not captured. This is important for RoI, because it is normally the fine fuel at ground level which is ignited.
- NFI is also derived from aerial/satellite images. The NFI is limited to forestry areas, which means that this dataset does not provide coverage for all woodland areas (these were left as LCM2007 classes in our methodology).
- Age of the maps: The LCM2007 map is based on satellite images from 2007. The NFI is based on information from 2010 and earlier, so there is a chance that the differences between these two datasets are associated with the temporal change (e.g. change from woodland to felled woodland or ground prepared for planting could be explained by the actual change in land cover)

Recommendations:

- FCE has carried out an analysis of land cover, using the LCM2007 and NFI datasets for forestry areas; they used NFI as the initial dataset, supplemented it with LCM2007 and cross-checked against the OS MasterMap (whereas we started with LCL2007 and supplemented it with NFI). In the future, development of a land cover map relevant to the risk of ignition at larger scales (county/ region/ national) could follow this approach initially tested by FCE.
- Land cover is *not* the same as land use. Land covers reflects the uppermost fuel type. But, use of land by people can only be approximated from land cover. Developing a land use map would be useful for WTA. It was suggested by the stakeholders that local authorities could be reliable sources of land use information, for example about the green spaces and recreation areas.
- The risk of ignition is lower for close-mown grass on golf courses than it is for rough grassland such as *Molinia* sp. Therefore, different types of grassland should be treated separately for study areas where their areal coverage is larger.
- More detailed mapping of land cover could include specific data on land use, tree age, species and density in forest sub-compartments on FCE land. More detailed mapping would also be possible for the Crown Estate and Ministry of Defence land as well as for land belonging to other organisations who keep detailed information on type of vegetation. This data could be usefully built in to offer additional information on risk of ignition. For instance, the age of trees is relevant (younger conifers are more flammable than older trees) as is the management regime (thinned/not thinned); and vegetation condition (trees affected by pests and diseases have dead material which can burn more easily).

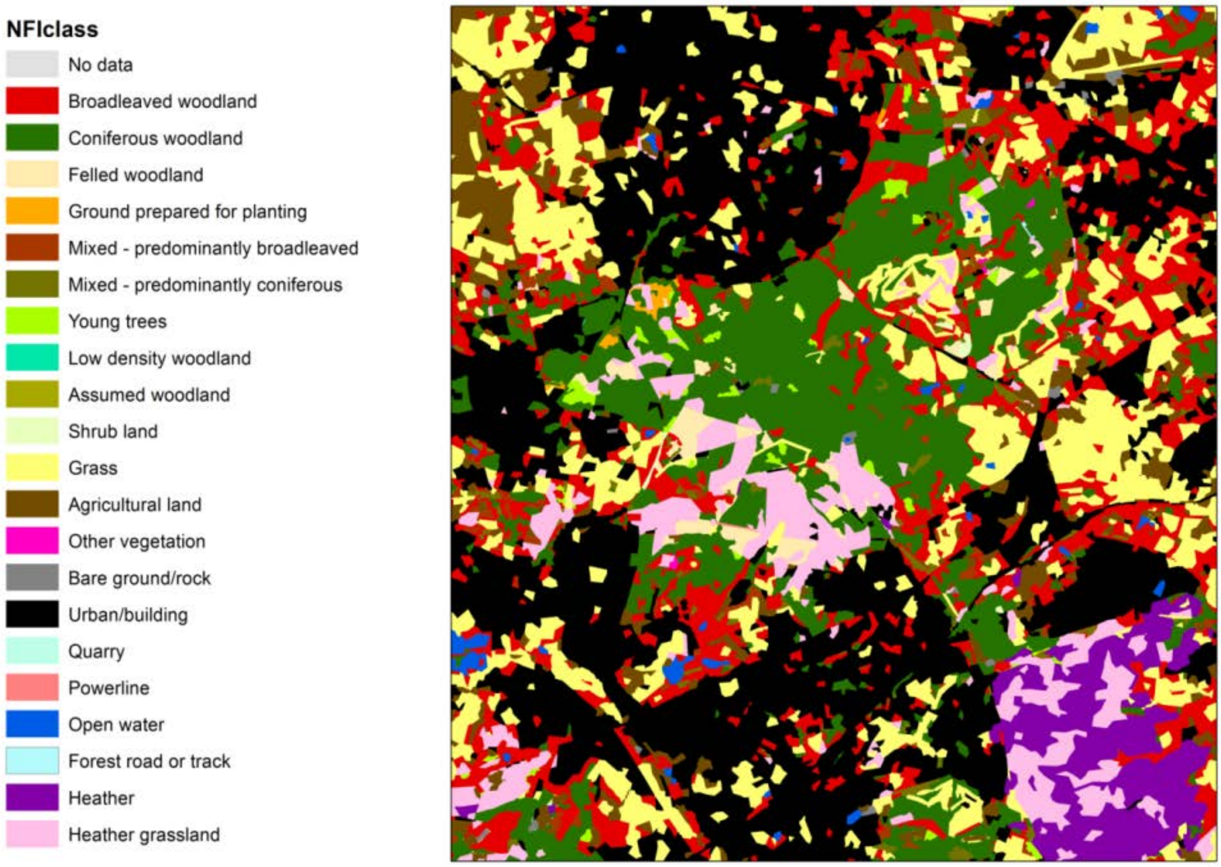


Figure 7: Land cover types in the study area, using a combination of LCM2007 and NFI

2.2.2 Land accessible to the public

This component was included in order to reflect the layers of 'land use' and 'recreation' originally included in the WTA framework. The following layers reflecting different types of accessible land were used:

- Land accessible under CROW sections 15 and 16 (Natural England)
- Registered Common Land (Natural England)
- Open Country (Natural England)
- Country Parks (Natural England)
- Doorstep Greens (Natural England)
- Parks and gardens (Bracknell Forest Council; only for Bracknell Forest area)
- MoD land (MoD)

In truth, most of these are likely to be accessible to the public, but one or two types may be inaccessible. More information about these layers can be found in the Data catalogue (Appendix 4).

Issues and sources of uncertainty:

- The designation of the land as publically accessible does not automatically translate into its greater use by the public.

Recommendations:

- Local authority data on recreation areas could be used in the future to identify areas of heavier use.
- Visitor surveys, similar to the one carried out for Thames heaths SPA, could be employed in order to identify the intensity of use of various areas.

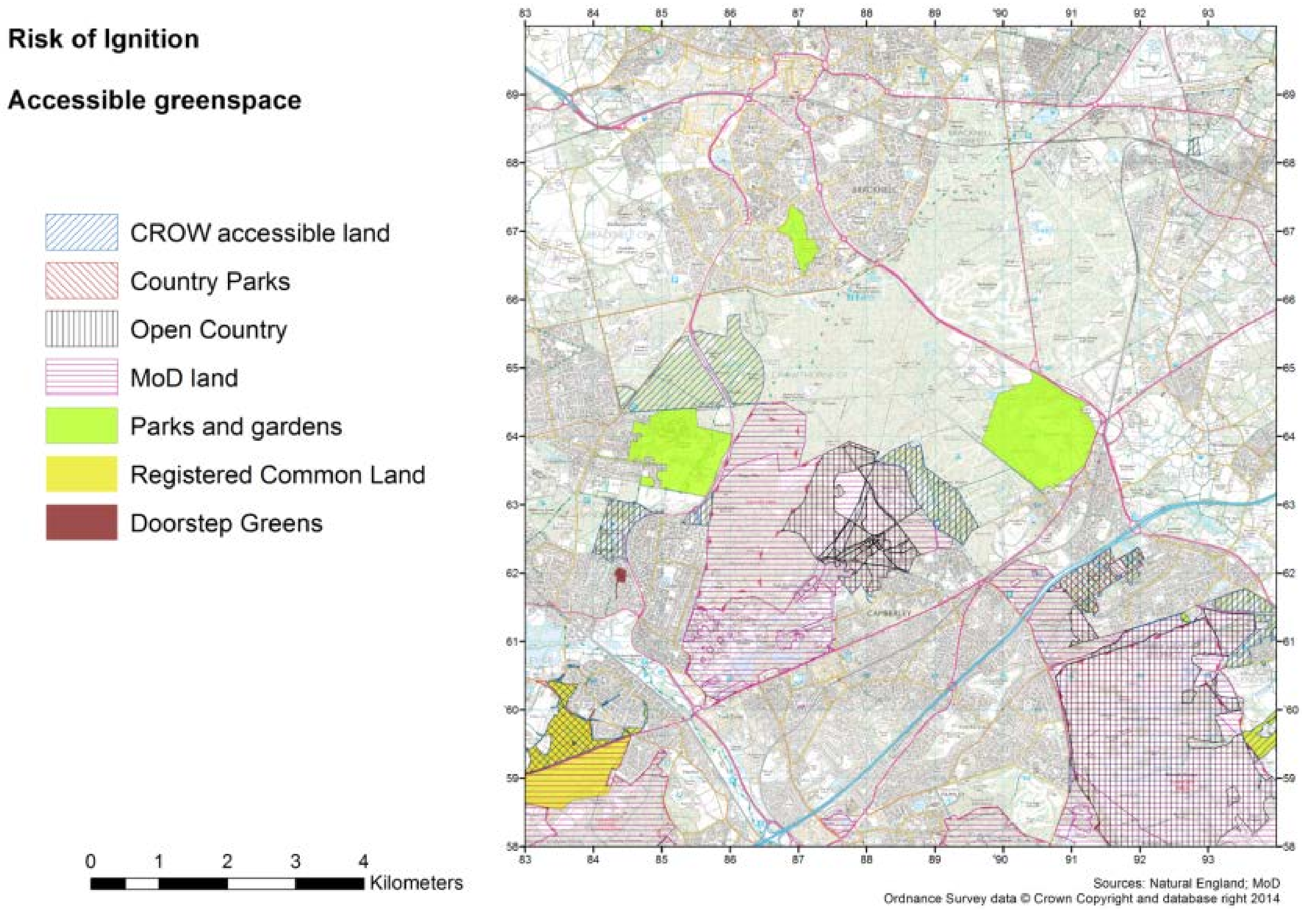


Figure 8: Categories of land accessible and inaccessible to the public.

2.2.3 Proximity to built-up areas

The visual assessment of the distribution of IRS points from Figure 9 suggested that vegetation fires tend to concentrate around the boundary between the urban/suburban areas (as classified according to LCM2007). This was confirmed by analysing the distance decay of incidents as fire sites become more remote from built-up areas (Figure 10).

Issues and sources of uncertainty:

- Limitations of the IRS dataset – see section 2.1
- This assumes that the main cause of ignition is people leaving nearby. However, additional sources could be visitors to the area from further afield or deliberate arsonists. Nonetheless, the visitor surveys (Liley *et al.*, 2005; Fearnley and Liley, 2014) suggest that the vast majority of visitors to the Thames Basin Heaths SPA have come from the immediate neighbourhood or travelled only a short distance by car (the distance from roads is covered in the next point).

Recommendations:

- Other sources of information about urbanised areas could be used in order to define these areas better than according to Land Cover Map

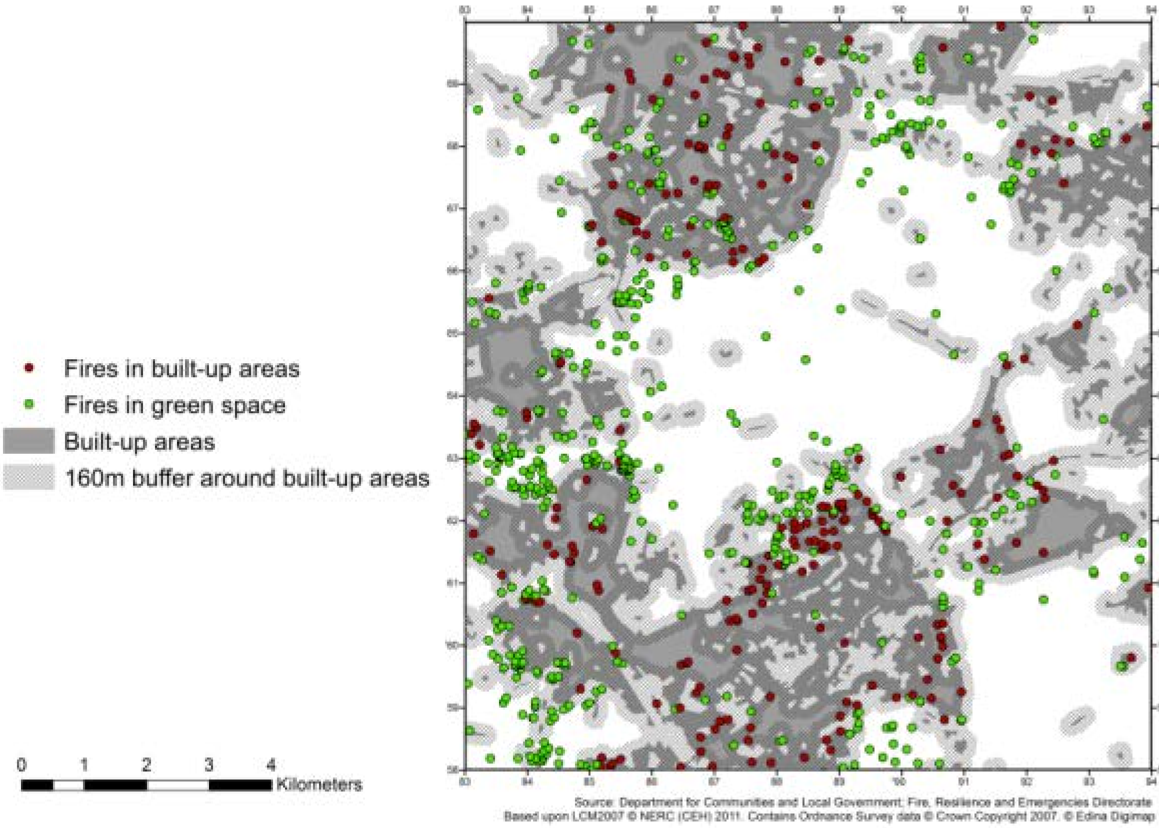


Figure 9: Distribution of IRS points within built-up areas and those on greenspace. Most green space fires occur within 160m of the built-up area.

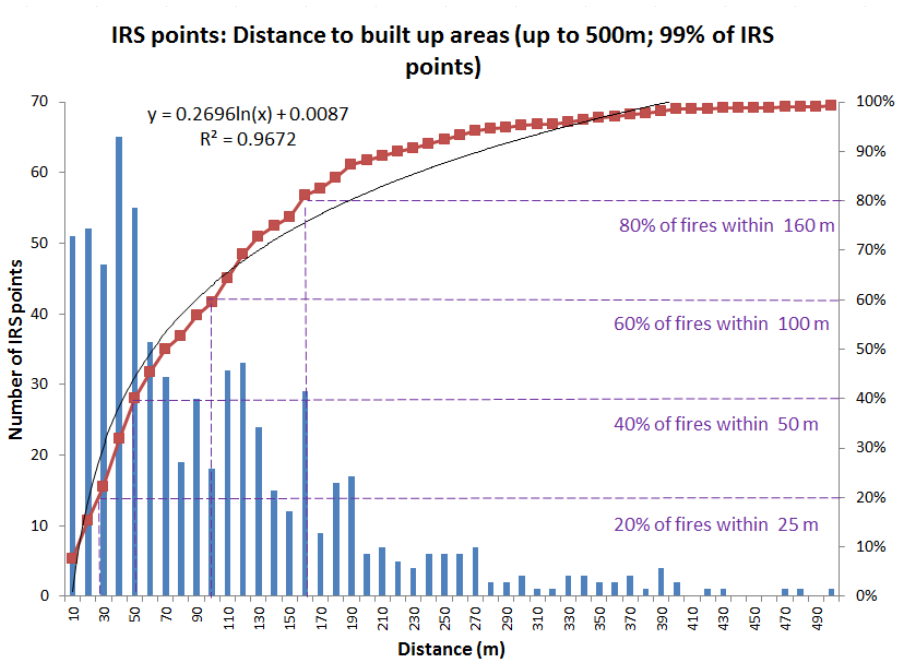


Figure 10: Frequency of IRS points with increasing distance from the built-up area (blue bars). The distance is limited to 500m to reduce the impact of outliers, but still contains 99% of the IRS points. Red squares correspond to the cumulative frequency of IRS points. The black line shows the best fit equation for the cumulative frequency curve, developed with 70% of the IRS point. The R^2 value describes how well the line matches the curve. Remaining 30% of points were used to test the equation. Purple lines show quantiles; in this case, five classes each containing 20% of the IRS points.

2.2.4 Proximity to access routes

It was observed that the IRS points also concentrate around paths and roads (Figure 11) in the same way that recorded fires clustered close to built-up areas. During the first workshop, stakeholders were asked whether they would prefer roads and paths to be treated separately or together as a factor contributing to the risk of ignition. The majority opted for separate factors. Also, it was collectively decided that motorways should not be included in "roads" as the risk of ignition around them would be different due to restrictions on stopping. Motorways are considered separately under 'dangerous infrastructure and installations', see point 2.2.6.

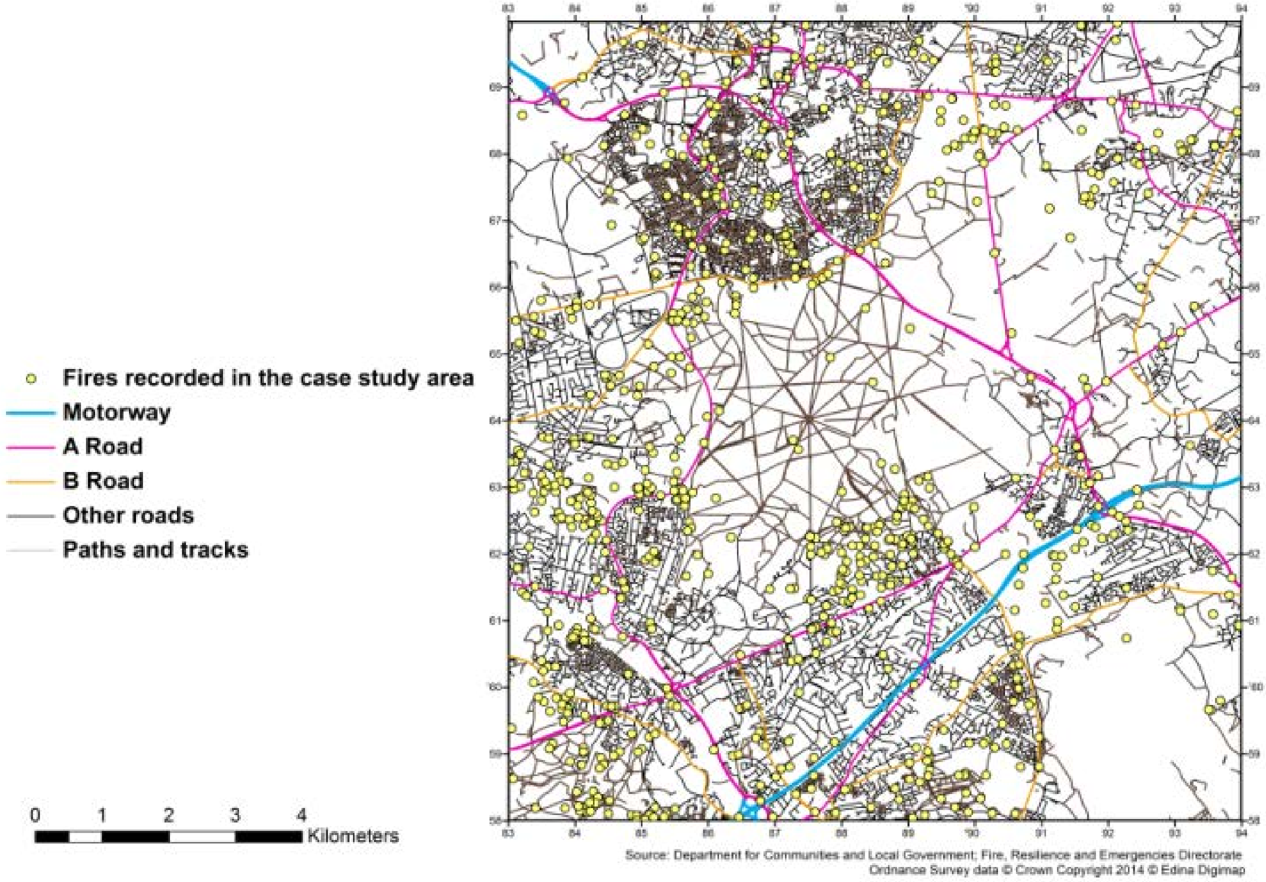


Figure 11: Distribution of IRS points in relation to roads and paths

Figure 12 and Figure 13 show the distance decay in frequency of IRS points with roads and paths, respectively.

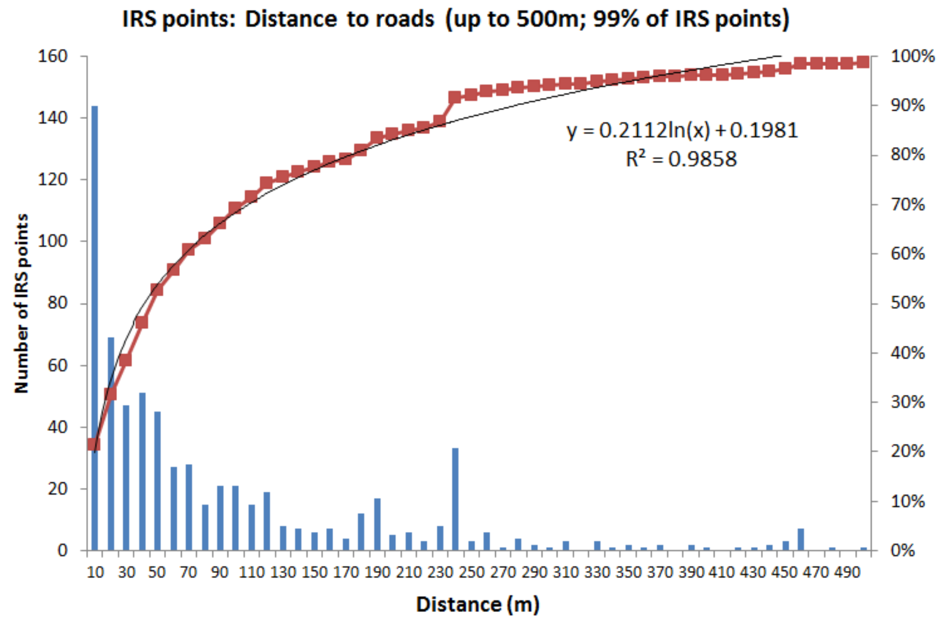


Figure 12: Frequency of IRS points with increasing distance from roads (blue bars). The distance is limited to 500m to reduce the impact of outliers, but still contains 99% of the IRS points. Red squares correspond to the cumulative frequency of IRS points. The black line shows the best fit equation for the cumulative frequency curve, developed with 70% of the IRS point. The R^2 value describes how well the line matches the curve. Remaining 30% of points were used to test the equation.

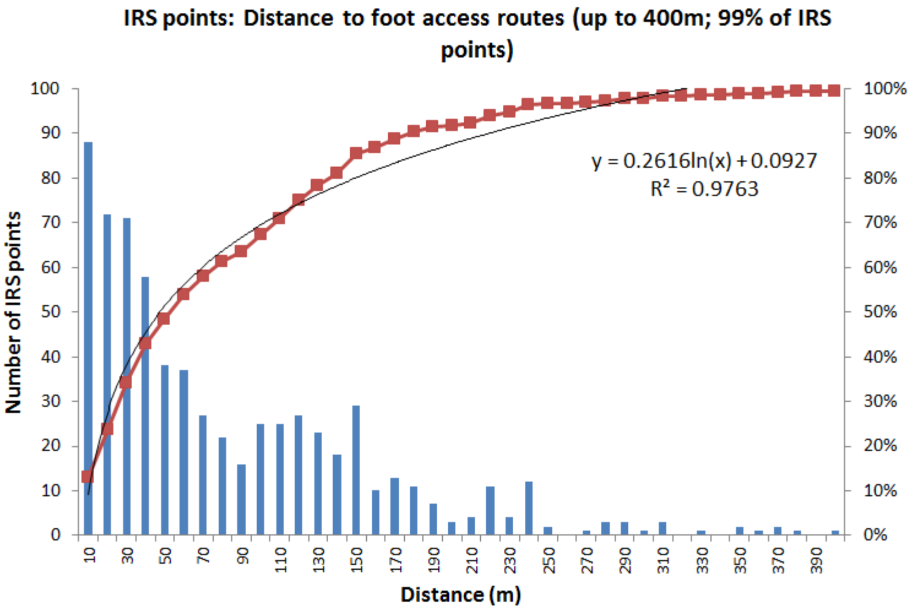


Figure 13: Frequency of IRS points with increasing distance from paths (blue bars). The distance is limited to 400m to reduce the impact of outliers, but still contains 99% of the IRS points. Red squares correspond to the cumulative frequency of IRS points. The black line shows the best fit equation for the cumulative frequency curve, developed with 70% of the IRS point. The R^2 value describes how well the line matches the curve. Remaining 30% of points were used to test the equation.

Issues and sources of uncertainty:

- The quality of the IRS dataset – see section 2.1
- The assumption is that opportunities to stop and leave the car, and thus the risk of ignition, are distributed equally along roads. In reality, the risk of ignition would be more likely to concentrate around official car parks and unofficial parking spaces.

Recommendations:

- Access points leading directly to green space could be recorded and the concentration of IRS points around them estimated. This could be done, for instance, by looking for intersection of paths with the built-up area boundary. Data on access points to SPAs in the area was not considered sufficient, as it did not cover the entire case study area and was only relevant to some sites of nature conservation.
- Similarly, car access points, *i.e*. official and unofficial car parks could be recorded.

2.2.5 Population density and characteristics

The New Zealand version of WTA uses population density as a factor contributing to risk of ignition. In our case study area, no obvious association was found between the number of IRS points and population density (Figure 14). Various spatial analysis methods were used, including, first, the ArcInfo function 'Near', between the centroid of the output area (abbreviated OA; a census 2011 unit containing around 300 people) and IRS points. Second, the 'Near' function was used between the OA boundary and the IRS points. Third, the number and density of IRS points per OA was calculated. The absence of a relationship using any of these methods could be due to the small size of the case study area and the short distances between the populated areas of high density in this rural-urban interface. Some pattern might emerge if the size of the study area were increased.

Despite the lack of associations, the stakeholders consulted during the individual meetings were in favour of including population density as one of the factors in risk of ignition, simply following the logic that wildfires are caused by people, so the more people in the area, the higher the likelihood of the fire occurring.

Similarly, no obvious associations were found between fire distribution and two population characteristics; first, material deprivation (a proxy for the per cent of people in long term unemployment or who never worked, measured at OA level) (Figure 15); and second, levels of crime (Crime Domain of Indices of Multiple Deprivation at the Lower Super Output Area level – a larger census 2011 unit of 1000-3000 people on average). This is in contrast to the findings of a study in South Wales (Jollands *et al.,* 2011), where the 20% most deprived areas were nine times more likely to experience wildfires than the 20% least deprived areas. This discrepancy could be associated with the fact that the crime and unemployment levels in our case study area are generally low, and the distances between contrasting areas too small to produce sufficient variety in spatial distribution. The stakeholders spoke about their experience of some 'less desirable' estates bordering green space, where fires are likely to be more prevalent, but at the same time were against the assumption that higher levels of crime equated to a higher probability of arson. In the end, a collective decision was made not to include the material deprivation and crime factors in Risk of Ignition for this case study.

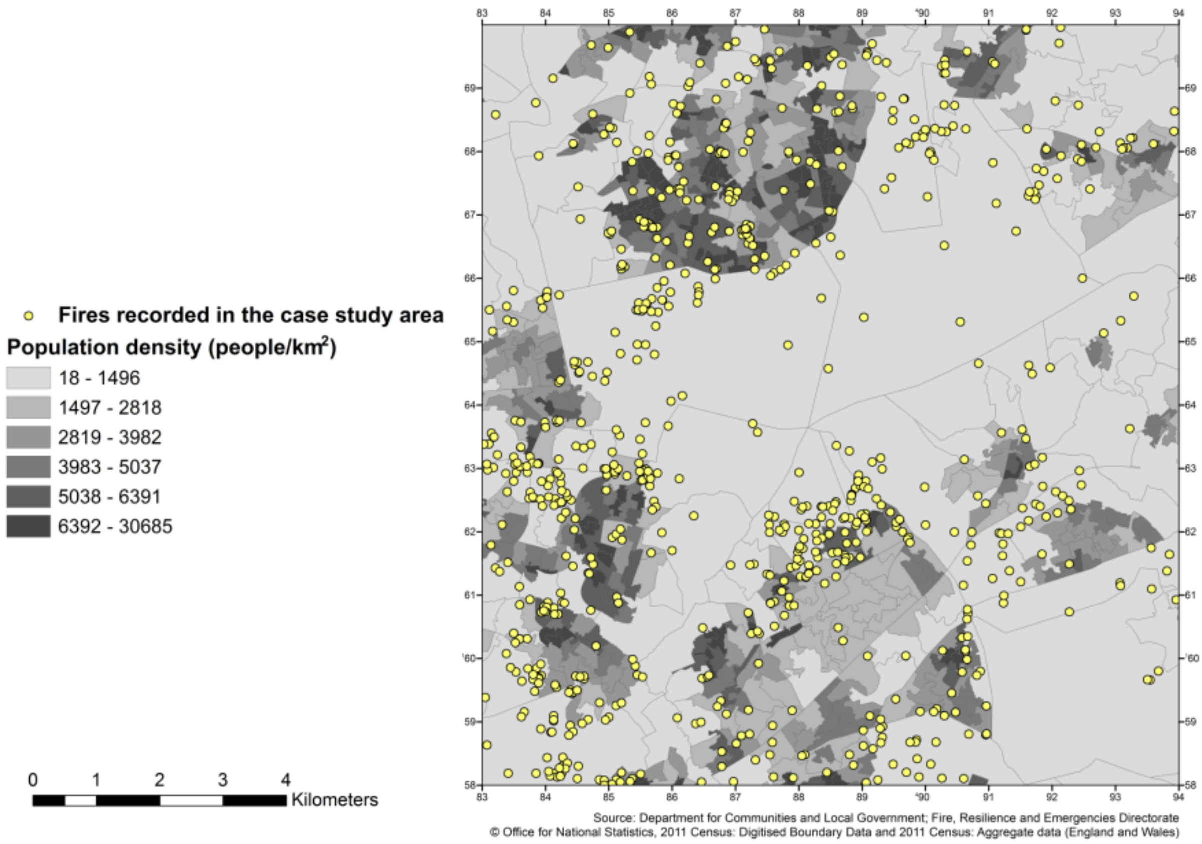


Figure 14: Lack of association between population density for 2011 census Output Areas (approx 300 people) and the spatial distribution of IRS points

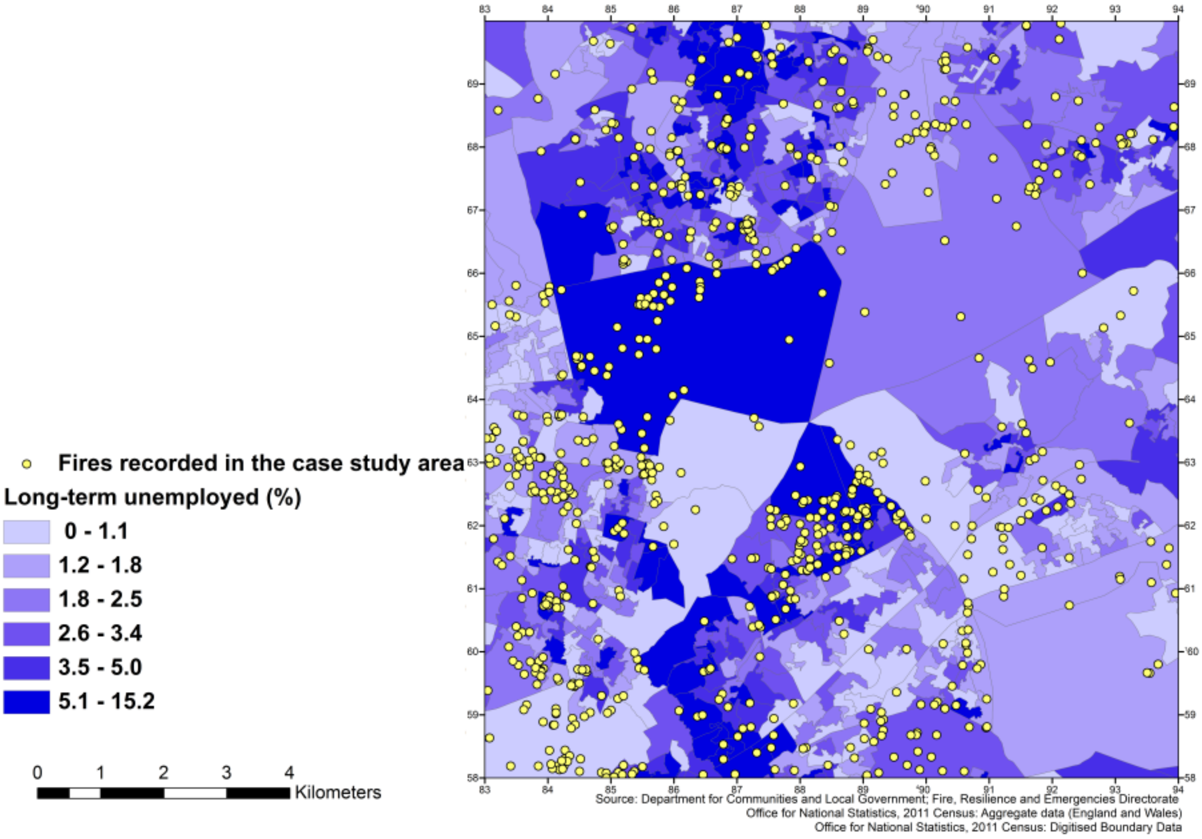


Figure 15: Lack of association between the levels of material deprivation (proxied by long-term unemployed for 2011 census Output Areas) and the spatial distribution of IRS points.

Issues and uncertainties:

- The case study area is not representative in terms of the range of crime and unemployment levels.
- It is also potentially too small (or the OAs/LSOAs too big) to show variability in spatial distribution of points between areas of different characteristics.

Recommendations:

- It would be interesting to carry out an investigation into the association between the spatial distribution of fires and the levels of deprivation and crime at a county/regional/national level.

2.2.6 Infrastructure and installations

New Zealand's WTA contains 'Utilities' as one of the factors potentially increasing the risk of ignition. This component includes powerlines and railways. Our data on powerlines for the case study area was spatially very sparse. It only included overhead and underground powerlines on FCE land in Crowthorne Wood, and one high voltage electricity line obtained from the National Grid website. There was no spatial association between the distribution of fires and powerlines or railways.

The stakeholders' views on whether to include these installations were mixed: during the first workshop the impact of powerlines and railways on the risk of ignition was seen as negligible. However, it was observed that firing ranges on the MoD land increase the risk of ignition: the military training causes a number of fires which are sometimes put out by the military or sometimes FRS attend. We also discussed whether motorways could be seen as a source of ignitions, for instance through discarded cigarette ends, sparks from maintenance or accidents involving vehicles.

In the end, the infrastructure and installations seen as potentially dangerous in terms of wildfire were as follows:

- Motorways
- Railways
- Powerlines
- MoD firing ranges (considered as the extent of 'danger area' according to the OS map).

Issues and uncertainties:

- The spatial data on powerlines data is currently very limited.

Recommendations:

- In the future, utilities companies should be involved in the WTA process as entities familiar with the risk of ignition potentially caused by their assets, and to provide the spatial data needed.

2.2.7 Adapted Risk of Ignition module

Figure 16 summarises the changes made to New Zealand's WTA Risk of Ignition module to adapt it to the case study area conditions and data availability. Land use has been substituted by land cover. Accessibility is represented as the proximity to different types of roads, paths and built up areas. Recreation has been captured to an extent in the form of land accessible to the public. Powerlines and railways are represented by infrastructure and installations, together with motorways and firing ranges.

Due to lack of suitable data, we did not include natural causes of ignition (e.g lightning strikes), nor the probability of sustained ignition (section 2.2.8). Suspected cause is recorded in IRS but is not confirmed by fire investigations, except in the rare case of injury or damage to structures. Anecdotally, lightning rarely causes wildfires in the UK because it is usually accompanied by rain.

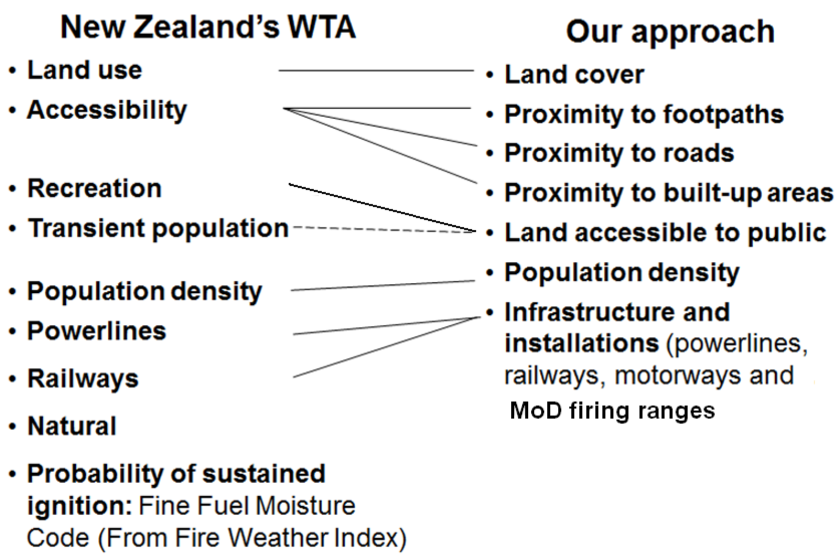


Figure 16: Risk of Ignition module adapted to UK conditions and data availability.

2.2.8 The role of Fire Weather Indices in RoI

In the New Zealand WTA, the FFMC severity map was then used to rescale the weighted sum of all other WTA RoI layers to give probability of sustained ignition across New Zealand, rather than simply risk of an ignition. FFMC fire climate severity mapping at a suitably fine scale was not available for the project (section 1.8). However, the 2km KCL indices would be appropriate for a national RoI map (see section 9, point 1).

2.3 Values at risk

2.3.1 Our approach

The New Zealand WTA framework lists a number of values at risk (Figure 1). We grouped them into three sub-modules to better reflect the UK frameworks and acknowledged gaps:

- *Human health and well-being*: this theme also aimed to include people's vulnerability.
- *Property and infrastructure*: this theme reflects the notion of 'critical infrastructure' in the Cabinet Office Civil Contingency Secretariat's Strategic Framework and Policy Statement on Improving the Resilience of Critical Infrastructure to Disruption from Natural Hazards (Cabinet Office, 2010).
- *Ecosystem services*: the New Zealand's WTA does not yet explicitly capture ecosystem services, but the approach is used here to reflect DEFRA's prevailing paradigm and the UK National Ecosystem Assessment (NEA, 2011).

2.3.2 Human health and well-being

In the New Zealand WTA, human health is only captured as 'life' (measured as population density) and 'transient life' (measured as the intensity of tourist use). These two proxies are exactly the same as those used in the risk of ignition module. In our approach, we combine population density with population characteristics which could make people more vulnerable to wildfires*, i.e*. characteristics deemed to result in greater physical and psychological harm and relatively higher economic impact on individuals in the event of fire, than would be expected for the average population (Finlay *et al.,* 2012) (Table 3).

Table **3***: Characteristics that may make population more vulnerable to wildfire*

Indicator (layer)	Spatial unit	Map component
% children under 4	OA	Age
% people over 75	OA	
% temporary and mobile structures among households	OA	Vulnerable dwellings
% Lone parent households	OA	Evacuation problems
% people living in communal establishments	OA	
% single pensioners	OA	
% non-UK born people with less than 1 year residence	OA	
% rented households	OA	Income
% people in long term unemployment and never worked	OA	
Average income	LSOA	
% people whose daily activities are limited by an illness	OA	Health
% people who describe their health as very bad or bad	OA	

2.3.3 Property and infrastructure

Following advice from the first stakeholder workshop, we grouped the property and infrastructure assets around the Cabinet Office's Strategic Framework and Policy Statement (2010) nine national infrastructure sectors and sub-sectors. The alignment of our approach with the Cabinet Office framework is shown in

Table ***4***. The absence of relevant data meant that we were unable to consider the aspects of food and finance.

Table 4 Transport and infrastructure themes and their match to Cabinet Office Strategic Framework (2010)

Cabinet office	Our approach	Data coverage
Transport	Transport	Partial (Figure 17)
Utilities (energy, water, communications)	Utilities - energy	Partial (Figure 18)
	Utilities- water	None
	Utilities - communications	Full (Figure 19)
Emergency services	Emergency services	Full (Figure 20
Health	Health and social services	Partial (Figure 21)
Government	Other property (incl. civic buildings)	Partial ((Figure 22)
Finance	*No data*	None
Food	*No data*	None

Constructing the 'transport and infrastructure' component required a compilation of a large number of datasets. The component included railways (OS MasterMap), major and minor roads (OS MasterMap), mapping of the Average Annual Traffic Flow on major roads (Department for Transport data), and data on bus routes and bridges provided by Bracknell Forest Council (Figure 17). Despite initially emphasising the importance of knowing how intensely a given road is used (traffic flows), stakeholders opted for the classification of roads into Strategic Road Network and local roads, reflecting the split in responsibility between different bodies.

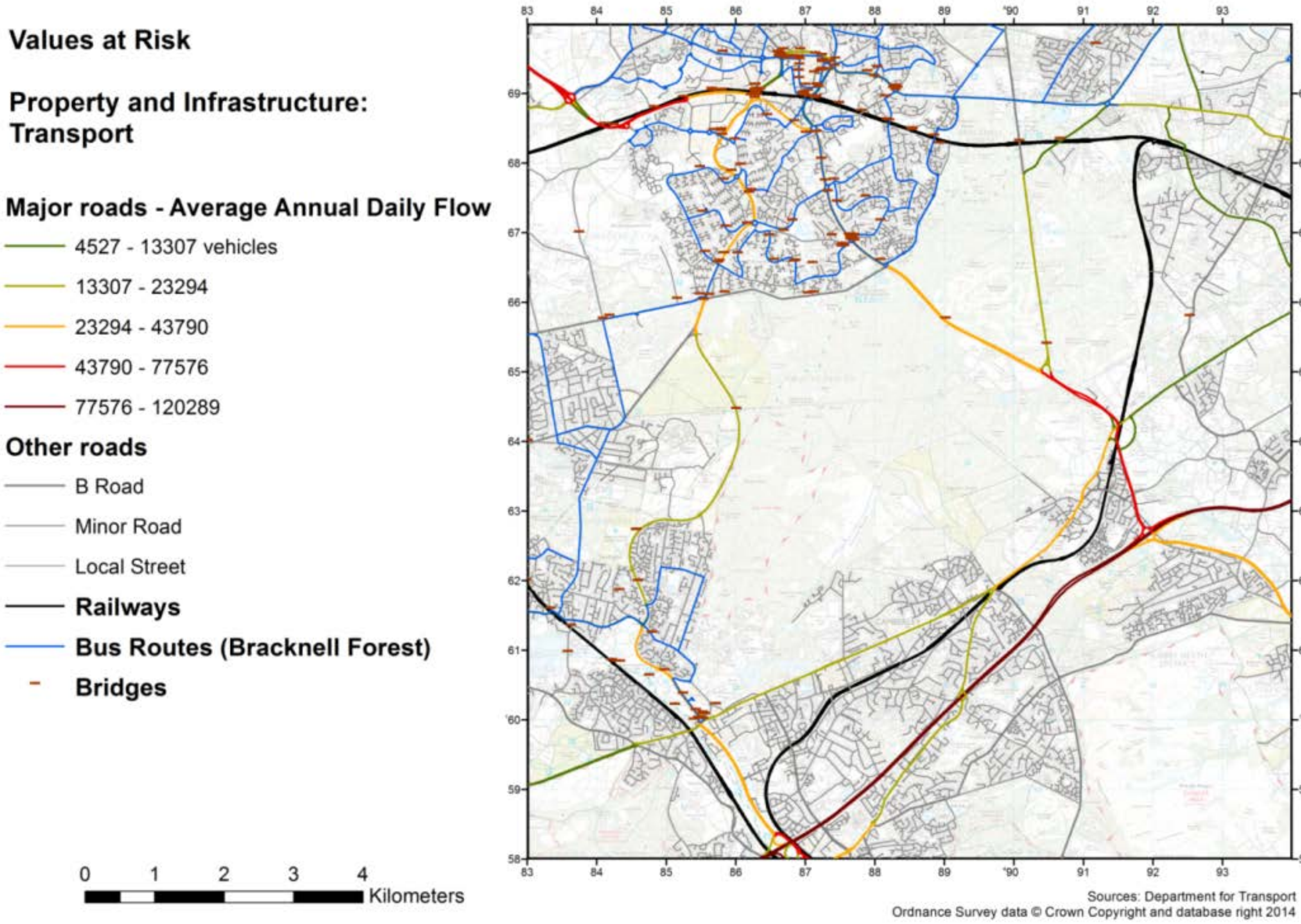


Figure 17: Transport layer

The energy component required data from OS MasterMap (electricity towers and pylons), from the FCE for Crowthorne, and sub-stations and petrol filling stations from Bracknell Forest (Figure 18). The data on communications (Figure 19) was mainly compiled using open data sources on internet; however, their reliability and consistency in terms of data age could be questioned (see data catalogue, Appendix 4). The information about the location of emergency services (Figure 20) was also mainly obtained from the internet, i.e. the county fire service and police service websites (postcodes of location) and from Bracknell Forest.

The location of health and social services (Figure 21) was obtained from the Care Quality Commission website, Department of Health, Department of Education, and Health and Social Care Information Centre. The spatial accuracy of these datasets is the postcode centroid. This was supplemented by local authority data provided by Bracknell Forest

The commercial and other non-commercial buildings component (or 'other property' in Table 4) was compiled using open sources of information (Office for National Statistics census unit level data on house prices and density of VAT based enterprises), supplemented by the data from Bracknell Forest (Figure 22).

Issues and sources of uncertainty:

- Data paucity for critical infrastructure: the location of water assets and many of the electricity assets were unknown.
- Confidential character of data: information on finance, food services or government servers is not known.
- Spatial accuracy of locations varies: from the exact location to the proxy of postcode centroid.

- Point *versus* polygon: many assets are represented as points, whilst the footprint of buildings and their grounds would be more accurately represented by a polygon. The density of VAT-based enterprises is represented as polygons, mapped at the LSOA level, rather than showing their exact locations.

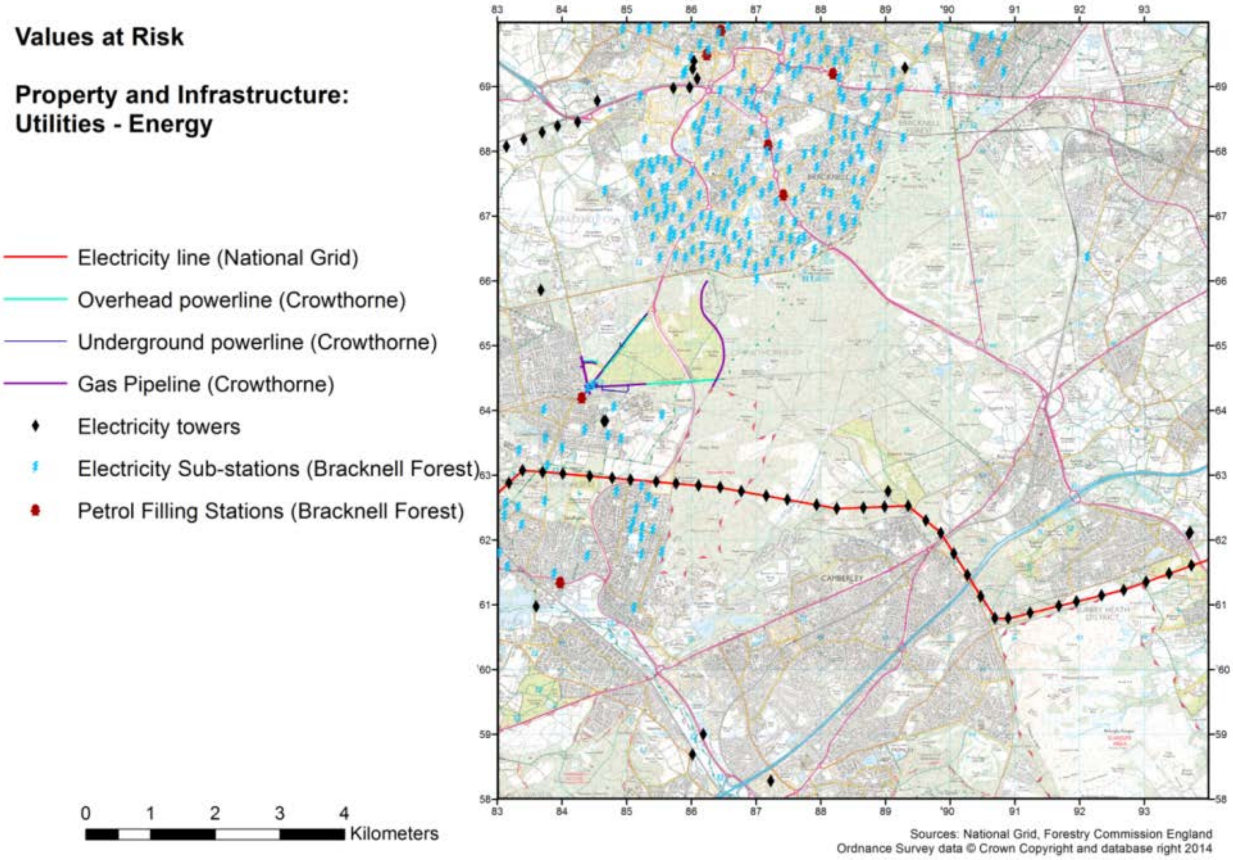


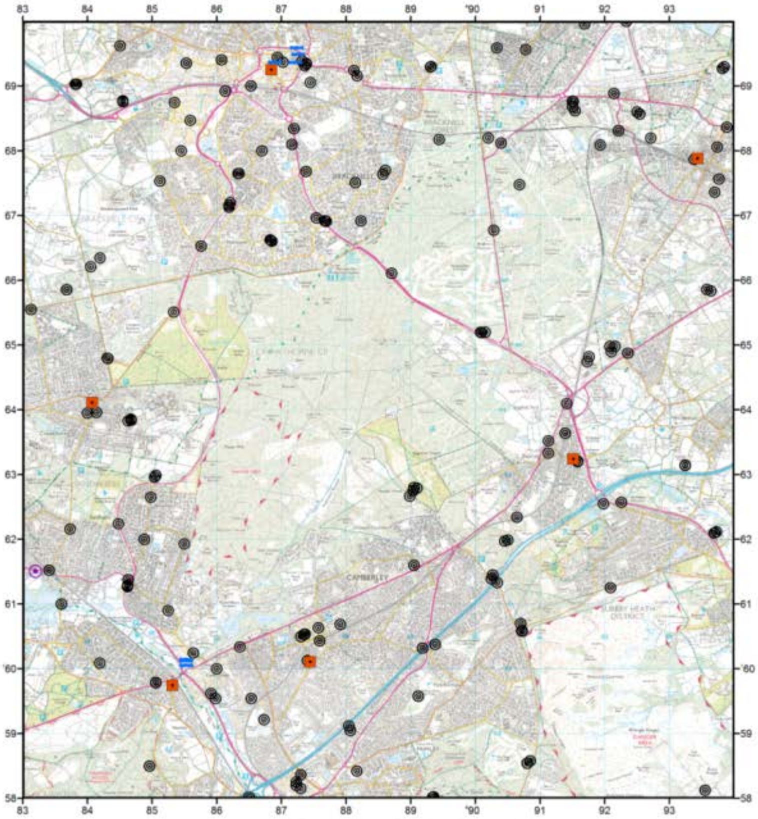
Figure 18: Utilities – energy.

Values at Risk

Property and Infrastructure: Utilities - communications

- Radio transmitters
- BT telephone exchanges
- Mobile communication masts
- Sign gantries (Bracknell Forest)

0 1 2 3 4 Kilometers



Sources: Ofcom; http://maps.thinkbroadband.com/; http://www.samknows.com/
Ordnance Survey data © Crown Copyright and database right 2014

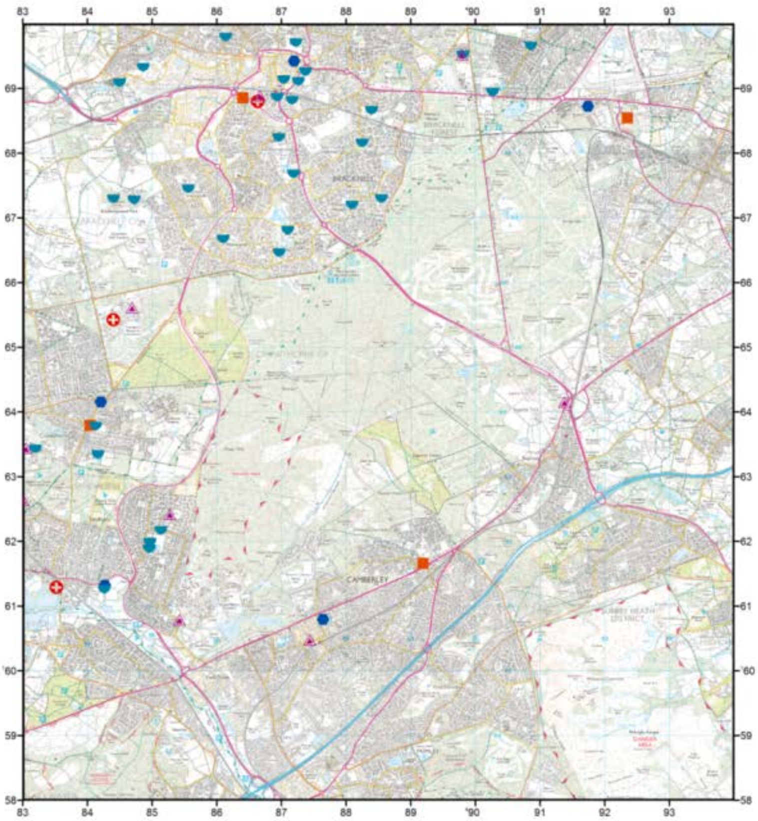
Figure 19: Utilities - communications

Values at Risk

Property and Infrastructure: Emergency services

- Fire stations
- Police stations
- Ambulance stations
- Rest centres (Bracknell Forest)
- Broadmoor sirens (Bracknell Forest)

0 1 2 3 4 Kilometers



Sources: Office for National Statistics; English Heritage's National Heritage List for England data © English Heritage;
Office for National Statistics, 2001 Census: Digitised Boundary Data (England and Wales) Downloaded from: http://edina.ac.uk/census
Ordnance Survey data © Crown Copyright and database right 2014

Figure 20: Emergency services

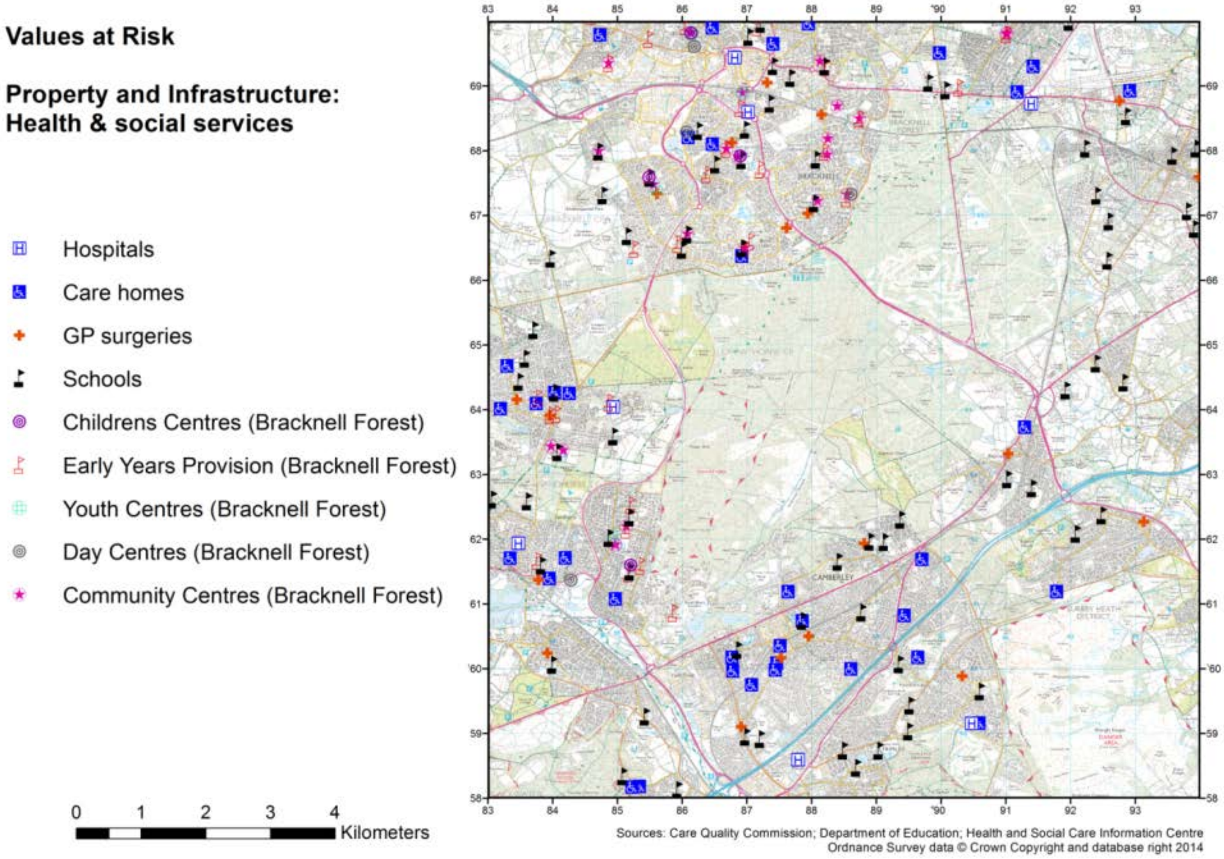


Figure 21: Health and social services

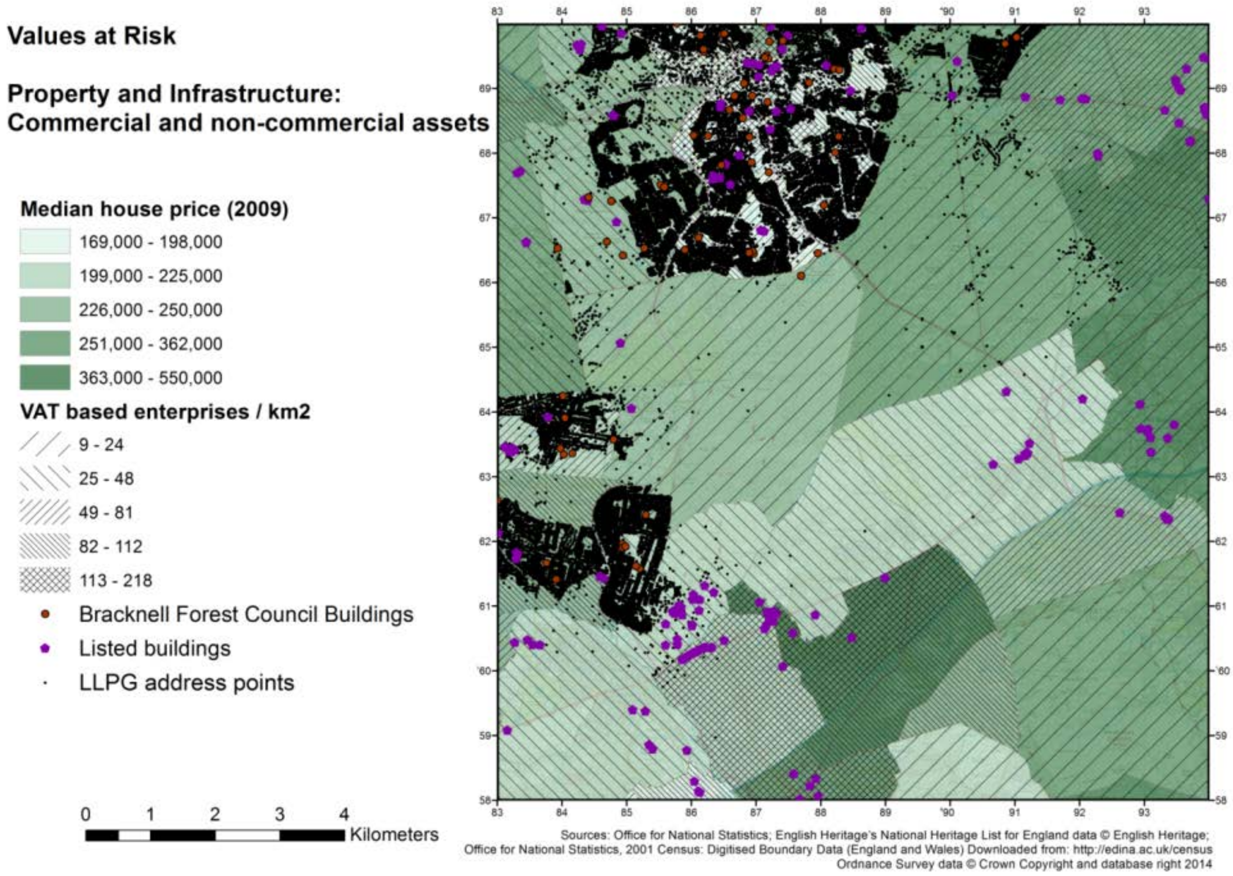


Figure 22: Commercial and other non-commercial property

Recommendations:

- Collaboration with local authorities, water and electricity companies and other stakeholders could help to address data gaps. Ideally, the WTA would be provided as an interactive tool where stakeholders could add their own data.

2.3.4 Ecosystem services

Ecosystem services can be divided into four categories following the Millennium Ecosystem Assessment (MEA, 2005):

- *Cultural*: for the rural-urban interface, the proxy for provision of cultural ecosystem services used here was designated areas for recreation.
- *Supporting*: biodiversity could be seen as a supporting ecosystem service, and nature conservation areas were used as a proxy.
- *Provisioning*: since there is little food production in our case study area, the timber value was used.
- *Regulating*: in the light of a changing climate, the carbon-storage function of vegetation was used (predominantly forests).

Within the limited timeframe of the project, it was necessary to be guided by data availability. We therefore compiled data for selected cultural and supporting ecosystem services, based on the designations for recreation/access and nature conservation. The data presented on Figure 23 and 24 was mainly obtained from the Natural England's website (open source) and supplemented with data provided by Bracknell Forest (parks and gardens; local wildlife sites). More information can be found in the Data Catalogue (Appendix 4).

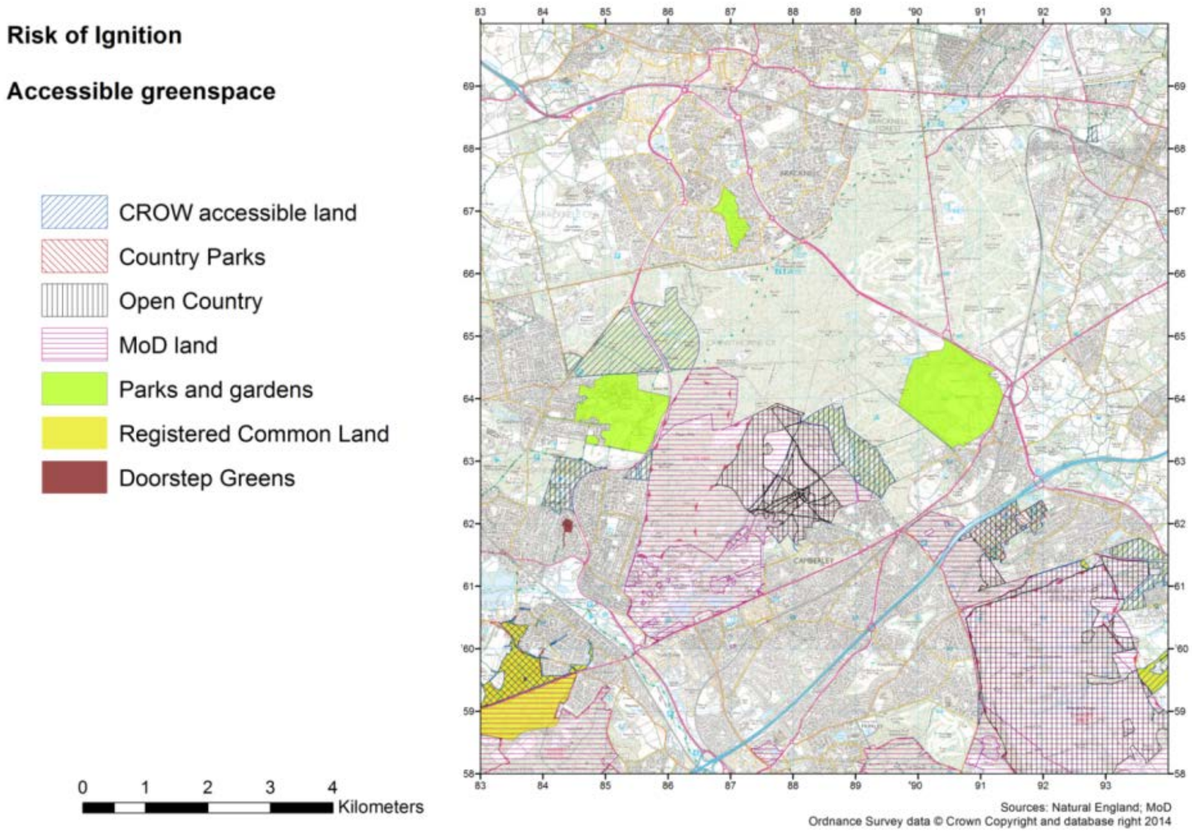


Figure 23 Areas designated for recreation – a proxy for cultural ecosystems services in the rural-urban interface. NB MoD land was removed after the second workshop as it was land not openly accessible to public.

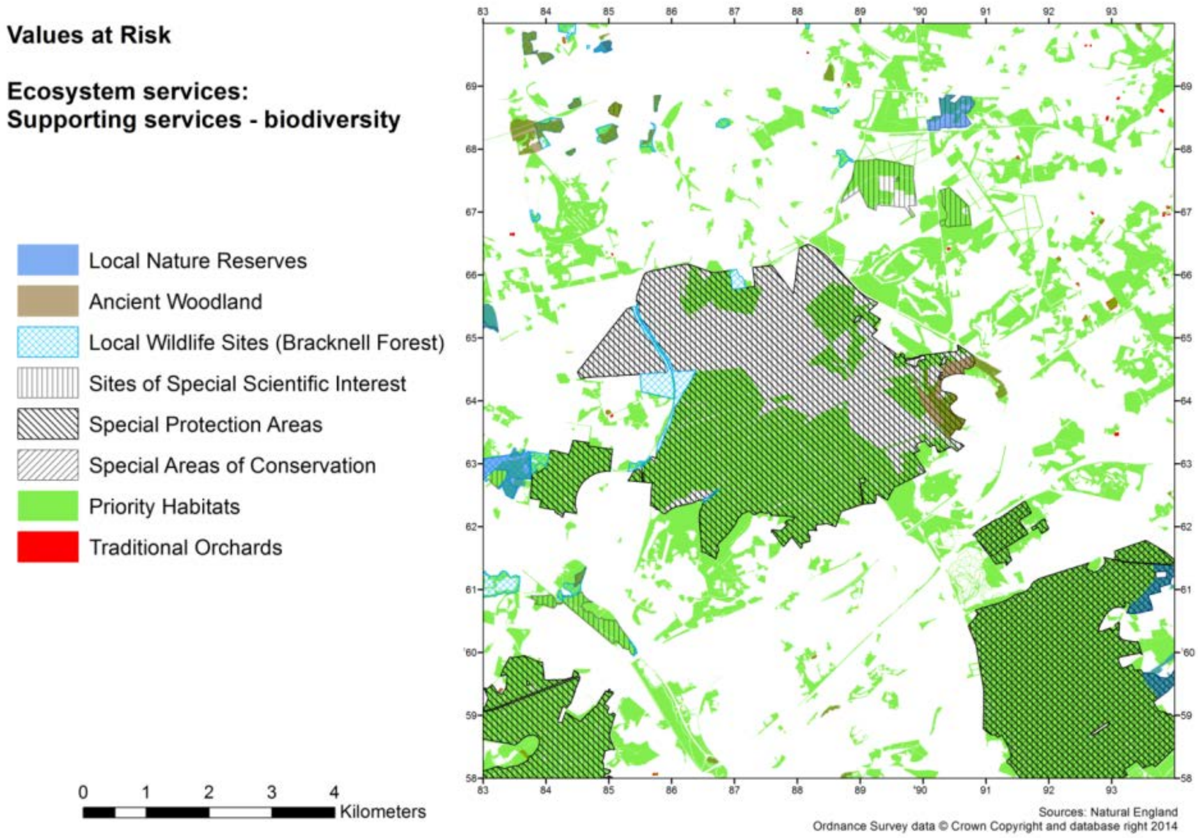


Figure 24 Areas designated for nature conservation – a proxy for supporting ecosystems services

Uncertainties:

- Should areas where different designations overlap be regarded as more valuable to recreation or nature conservation than areas where only one designation is present? If so, then scores should be added. If not, then the highest score should be used.
- Data paucity regarding, for example, sustainable alternative natural green space as places providing cultural and supporting ecosystem services.
- Information paucity regarding the cultural and supporting ecosystem services provided by areas that are not designated, e.g. forest, golf courses, private gardens.
- Timeframe of assessment for impacts; as discussed in section 1.5.1, should we be considering the immediate impact of fire, or the long term change? Not enough is known about the relationship between intensity of fire and its impacts for UK conditions, especially long-term impacts. Long term impacts could be positive, even if it is seen as devastating in the short term. This particularly affects the immediate loss of carbon stock in a fire which is offset by longer term carbon gains from regenerating vegetation.
- Should we be considering only direct impact by flames and smouldering combustion, or also off-site impacts such as smoke?

Recommendations:

- Include the intensity of use as one of the potential ways of estimating the value of cultural ecosystem services.
- Use local stakeholder knowledge to identify hotspots of cultural and supporting ecosystem services provision.

- Carry out a collaborative assessment of the carbon stock and timber utilising available modelling tools, such as the FC's 'Forecast System' (for FC land), 'Carbine' (for other forest areas with some information about the sub-compartments, e.g. the MoD land),and Blue Sky's LiDAR data on tree top heights, from which the biomass could be deduced. Work with the Valuing Nature Network.
- Draw on GIS approaches to ecosystem service mapping developed by JNCC, for instance opportunities and benefits mapping (Medcalf *et al.*, 2014 a -d).
- Record vegetation and soil burn severity immediate after a fire (Chafer, 2013; Cocke *et al.*, 2005).

2.4 Updated WTA framework

As a result of selecting appropriate layers, an updated version of the WTA framework is presented in Figure 25. It is appropriate to conditions in the study area, data availability and UK policy context. The process of modification was most intense at the beginning of the project, but some discussions about which layers to include or exclude were carried out at the sector-based meetings with stakeholders in May. A significant omission is the hazard module for reasons discussed in section 1.8.

Within the Values at Risk module there are three sub-modules, Health and wellbeing, Ecosystem services and Property and infrastructure. Within these modules and sub-modules are the components actually used. The components are in turn constructed from individual layers of spatial information.

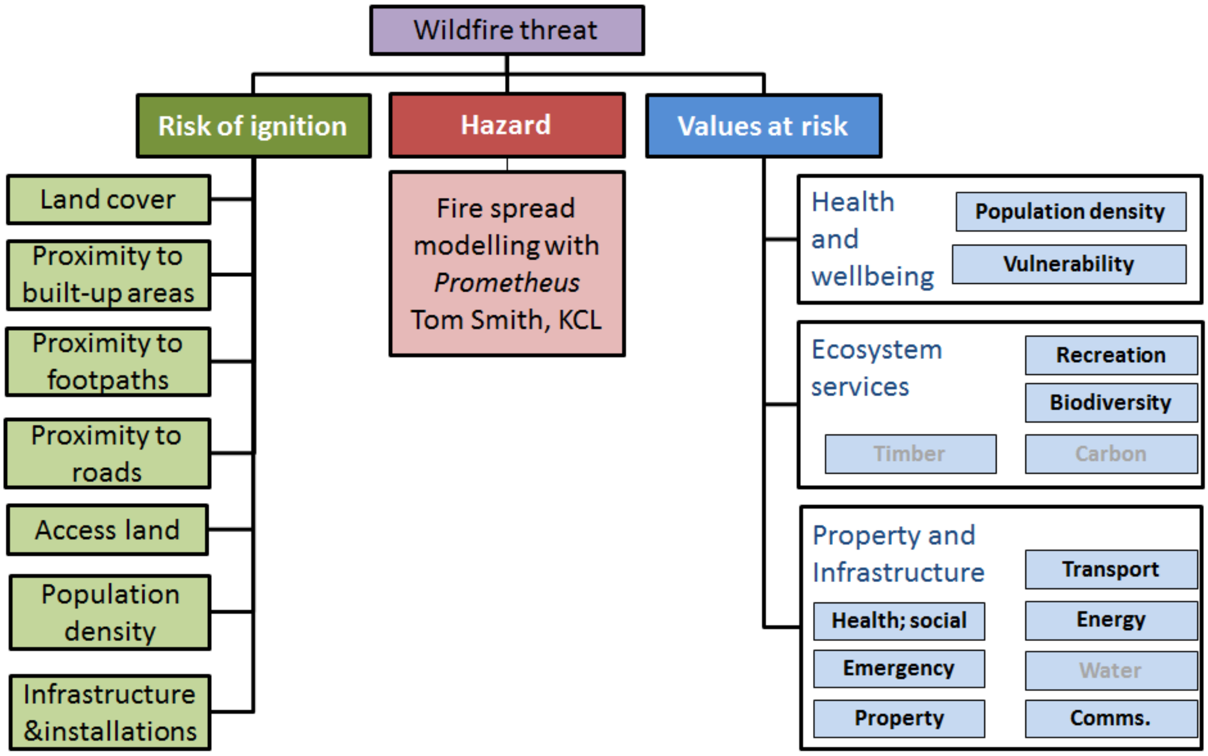


Figure 25: Modified WTA framework. Grey text indicates data desirable but unavailable within the project timeframe.

3 Scoring risk of ignition layers

3.1 Scoring Land cover

3.1.1 Using expert judgement to score the risk of ignition for land cover classes

During the first workshop, stakeholders were asked to rank the hybrid LCM2007 (Figure 7) classes according to the risk of ignition with respect to; (i) fuel type implied by the land cover class, and (ii) its likely land use and therefore relative density of ignition sources. Classes present in the study area were: Broadleaf woodland, Coniferous woodland, Arable & Horticulture, Grassland, Heather, Heather grassland and Urban & suburban.

At the first workshop, it was suggested that the LCM2007 dataset should be combined with the NFI dataset. After merging these two datasets (section 2.2.1), we then asked the FCE experts to assign a risk of ignition score to each of the resulting 21 hybrid classes using a 5-point scale. The scores were then applied to the hybrid land cover map and the results shown to participants at the 2nd workshop. They were asked to individually comment on the scoring and, where relevant, suggest different scores. This exercise resulted in a slight amendment to the scores assigned by the experts from FCE.

During all the scoring exercises, stakeholders were reminded to score the risk of ignition of land cover types for Spring conditions. Timing and size of IRS fires in the study area suggests that Spring has the highest fire risk during the year. The Crowthorne Wood ('Swinley Forest') fire of 2011 also occurred in Spring.

Table 5 presents the level of risk of different land cover classes according to expert judgement (section 3.1.1) compared against the that using the empirical method based on IRS points distribution (section 3.1.2).

Issues and sources of uncertainty:

- Expert judgement can be biased by the somewhat artificial distinction between risk of ignition and hazard of fire spread. Large, spectacular fires may be remembered more vividly than small fires. The risk of ignition may also be perceived as higher in areas where fire spreads more easily.
- People can also be biased towards land cover types that have a large number of fires simply by virtue of their large areal extent.
- Bias can be introduced by not focusing on just the Spring season because amount of fine fuel, its and moisture content change with the seasons. So too may density of ignition sources.
- Land cover classes are treated as uniform, or else the assumptions are made on their character are assumed to apply equally over the whole of its area (also known in Geo-information Science as 'ecological fallacy'). So, for example, 'grass' covers all types of grass from improved and mown to long and unmanaged; 'young trees' could mean either conifers or broadleaves, when confers have more fine fuel so a higher risk of ignition. 'Ground prepared for planting' could mean different types of preparation (mulching, cover with harvesting residues, ploughing). Considerable variation in risk of ignition could therefore occur within a single hybrid land cover class.
- Management regimes and age of vegetation are not adequately captured by the hybrid land cover map. Some information on age is included (Young trees and Low density woodland), but age of heather is not, yet old 'leggy' heather is known to present a greater fire risk than younger heather. The difference in risk of ignition between thinned and un-thinned woodland, or mown/grazed and unmown/ungrazed grassland can also be considerable.

Recommendations:

- Information about the land use and management regime of land cover types such as woodland and grassland would greatly improve the accuracy of risk of ignition scores.
- It is recommended that information about tree species, management regime (thinned/ not thinned), pests and diseases and spacing is incorporated into any land cover map prior to presenting it to experts for judgement. This level of information exists in FCE's sub-compartment database in Forester GIS. It would be useful to know which of this information is the most important to help gauge risk of ignition.

3.1.2 Using IRS point data to score risk of ignition for land cover classes (empirical method)

There are 964 IRS points in the case study area of 132km^2 over a four year period. The number of IRS vegetation fires present in each of the 21 combined NFI/LCM2007 classes was recorded. This is referred to as 'observed IRS number'. The number of 'expected' IRS points in each land cover class was calculated, based on the proportion of this land cover class by area in the case study area, i.e. a measure of expected fire density:

Number of expected IRS = (Total number of IRS points in study area * Area occupied by land cover class) / Total study area

Put another way:

Number of expected IRS = Total number of IRS points in study area * % of study area covered by the land cover class

For example, Broadleaved woodland covers 18.98 km^2 (14.48%) of the total 132 km^2. If IRS points were evenly distributed:

Number of expected IRS points for Broadleaf woodland = (964 * 18.98) / 132 = 138.6 points

Or 964 * 14.48 = 138.6 points.

The expected number of IRS points was calculated for three cases: (i) all the IRS points; (ii) very small fires only (damaged area<5m^2); and (ii) larger fires only (damaged area>5m^2). The risk score is based on the equation:

Score, x = (number of observed IRS points – number of expected IRS points) / number of expected IRS points.

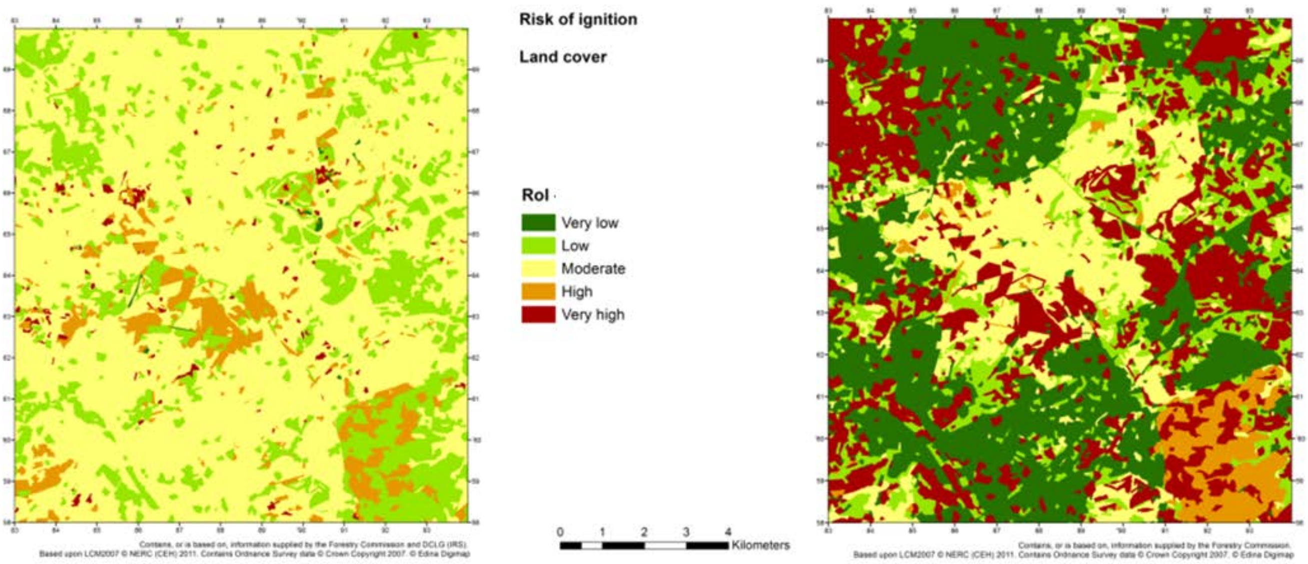
The denominator allows for class size. It considers the difference between observed and expected as a proportion of the number expected by area. Small *absolute* changes in small classes become large *relative* changes. Alternative scoring systems which do not favour small classes can also be used. The scores x were divided into five risk of ignition classes, where positive values are higher risk than negative:

1. Very low: x <= -1.0
2. Low: -1.0 < x <-0.2
3. Moderate: -0.2 < x <0.2
4. High : 0.2 <x <1.0
5. Very high: x => 1.0

Table 5 and Figure 26 summarise the results of the risk scoring for the empirical and expert judgement methods using all the IRS points regardless of size of burned area. There is a significant discrepancy here for reasons for explained in 'issues and sources of uncertainty' below. Results did not differ when just small or just large fires were used.

Table 5: Risk of ignition in different land cover classes

Land cover class (hybrid LCM2007 and NFI)	Number of observed IRS points	Expected number of IRS points (based on % of land cover type in the study area)	Observed – expected	(Observed – expected) / expected	Risk of Ignition (1-very low; 5 – very high)	
					Empirical scores	Expert judgement
Broadleaved	159	138.63	20.37	0.15	3	2
Conifer	176	164.54	11.46	0.07	3	3
Felled	6	9.99	-3.99	-0.40	2	3
Ground prepared for new planting	3	1.38	1.62	1.17	5	3
Mixed – predominantly Broadleaved	22	8.48	13.52	1.59	5	2
Mixed – predominantly Conifer	16	9.05	6.95	0.77	4	2
Young trees	10	5.41	4.59	0.85	4	4
Low density	0	0.02	-0.02	-1.00	1	2
Assumed woodland	0	0.05	-0.05	-1.00	1	2
Shrub land	0	0.99	-0.99	-1.00	1	4
Grass	102	144.12	-42.12	-0.29	2	5
Agricultural land	48	55.81	-7.81	-0.14	3	4
Other vegetation	0	0.29	-0.29	-1.00	1	5
Bare ground/rock	1	1.91	-0.91	-0.48	2	1
Urban/building	336	321.09	14.91	0.05	3	1
Quarry	1	0.04	0.96	26.88	5	1
Powerline	0	0.13	-0.13	-1.00	1	4
Open water	2	5.68	-3.68	-0.65	2	1
Forest road or track	0	0.08	-0.08	-1.00	1	2
Heather	12	39.83	-27.83	-0.70	2	5
Heather grassland	70	56.43	13.57	0.24	4	5



(a) (b)

Figure 26: Risk of ignition as assessed by: (a) empirical scoring based on the distribution of IRS points between different land cover classes; and (b) expert judgement.

Issues and uncertainty

- The analysis is based on a simple intersection of points (IRS fires) and polygons (LCM2007); the uncertainty related to the actual location of the IRS point is not considered (section 2.1).
- The formula used to compare expected and observed number of IRS points: The empirical scoring method uses *relative* difference, so it overestimates risk for land cover classes that occupy a small proportion of the case study area. For example, class 16 (quarry), the risk is very high. This arises because for a class so small in size, only 0.04 IRS points are expected, whilst 1 point was observed (see Table 5), so exceeding the expected number 25-fold. On the other hand, looking at the *absolute* difference in the number of expected and observed points would give the same weight to the difference between 350 (obs) and 351 (exp) points as to 1 (observed) and 2 (expected).
- It assumes that the same risk score applies to the whole of the class, regardless of geographical position of the land cover type.
- As stated in section 2.2.1, land cover map information relates only to the top layer of vegetation (canopy). The fires that were recorded in a given land cover type could have happened at the ground level (e.g. road verges or grasses burning in woodland). This could explain the difference between the empirical and expert judgement of the risk of ignition in forests.

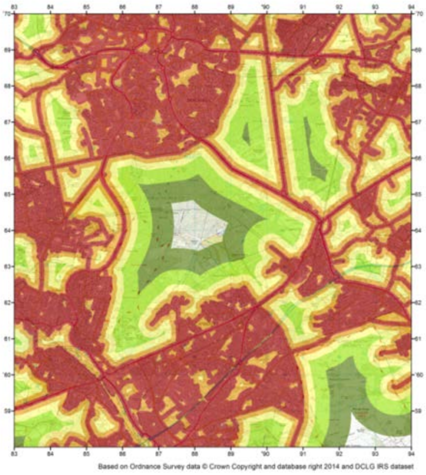
Recommendations:

- A variety of methods of analysis could be used to help overcome the bias associated with the false accuracy of IRS point. One approach would be to create a continuous surface of vegetation fire density using a technique called kernel density (Amatulli *et al.*, 2007).
- Mathematical modelling is an alternative to the multi-criteria evaluation with stakeholder scoring and weighting normally used for WTA (section 9, point 2).
- It could be useful to experiment with alternative ways of calculating empirical score which suit classes of all sizes. For instance, using simply the absolute difference between observed and expected; observed divided by expected; or observed divided by area, as in the 'ignition danger' index used by the Spanish Forest Service to compare relative fire occurrence between regions (Martínez *et al*., 2009). Alternatively, a combination of empirical and expert knowledge methods could be used to remove small classes that are not considered important for fire risk.

3.2 Scoring proximity to access routes and built-up areas

During the first workshop, the participants were asked to indicate the width of buffer around roads, paths and built-up areas that they would consider 'reasonable', *i.e*. one which could be applied in practical prevention and management of fires. Unfortunately, only a few workshop members completed the scoring sheets and the answers were inconclusive. After the workshop therefore, different empirical methods were tried for slicing the distance image into five classes; quantiles, natural breaks and equal intervals. Figure 27 (a)-(c) shows the results for roads.

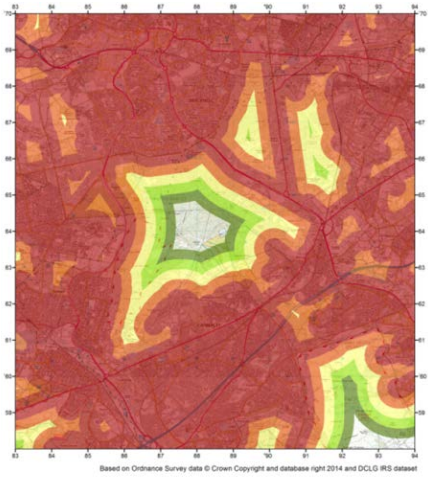
(a)



(b)

Thresholds used to divide distance into classes:

Symbol	Class	Distance (m)			Score
		Quantiles	Natural breaks	Equal interval	
	1st	10	69	274	5
	2nd	40	194	549	4
	3rd	91	374	823	3
	4th	230	777	1098	2
	5th	1372	1372	1372	1



(c)

Figure 27: Three different methods of slicing the distance image to express decreasing number of IRS points with increasing distance from roads: (a) quantiles; (b) natural breaks; (c) equal interval.

The stakeholders were then asked if they preferred any of these three ways of slicing the distance from access routes and built-up areas. The preferred option was quantiles (Figure 27 (a)). The natural breaks method was seen as too data/location-specific. Use of equal intervals suggested that there is no distance decay in the way that IRS points are distributed. The first quantile (the nearest to the feature) received the score of 5 (the highest risk of ignition), and the furthest – the score of 1 (the lowest risk of ignition). Areas beyond the furthest recorded IRS point were scored 0.

Mathematical equations were also developed to express the decay curve of IRS points with distance from built-up areas, car and foot access routes (as seen in Figures 10, 12 and 13). The equations were applied to the distance image to give a continuous estimate of IRS point frequency for every cell (Figure 28 shows distance from roads, for example). Stakeholders were presented with this way of representing the decreasing number of IRS points with distance as a continuous variable, but the preference was for slicing the distance image into classes. Nonetheless, it was observed that this method has its advantages, *i.e.* it eliminates the step change between the classes by assigning a probability of risk of ignition to every point on the map, and can be used in the alternative approach of mathematical modelling (section 9, point 2).

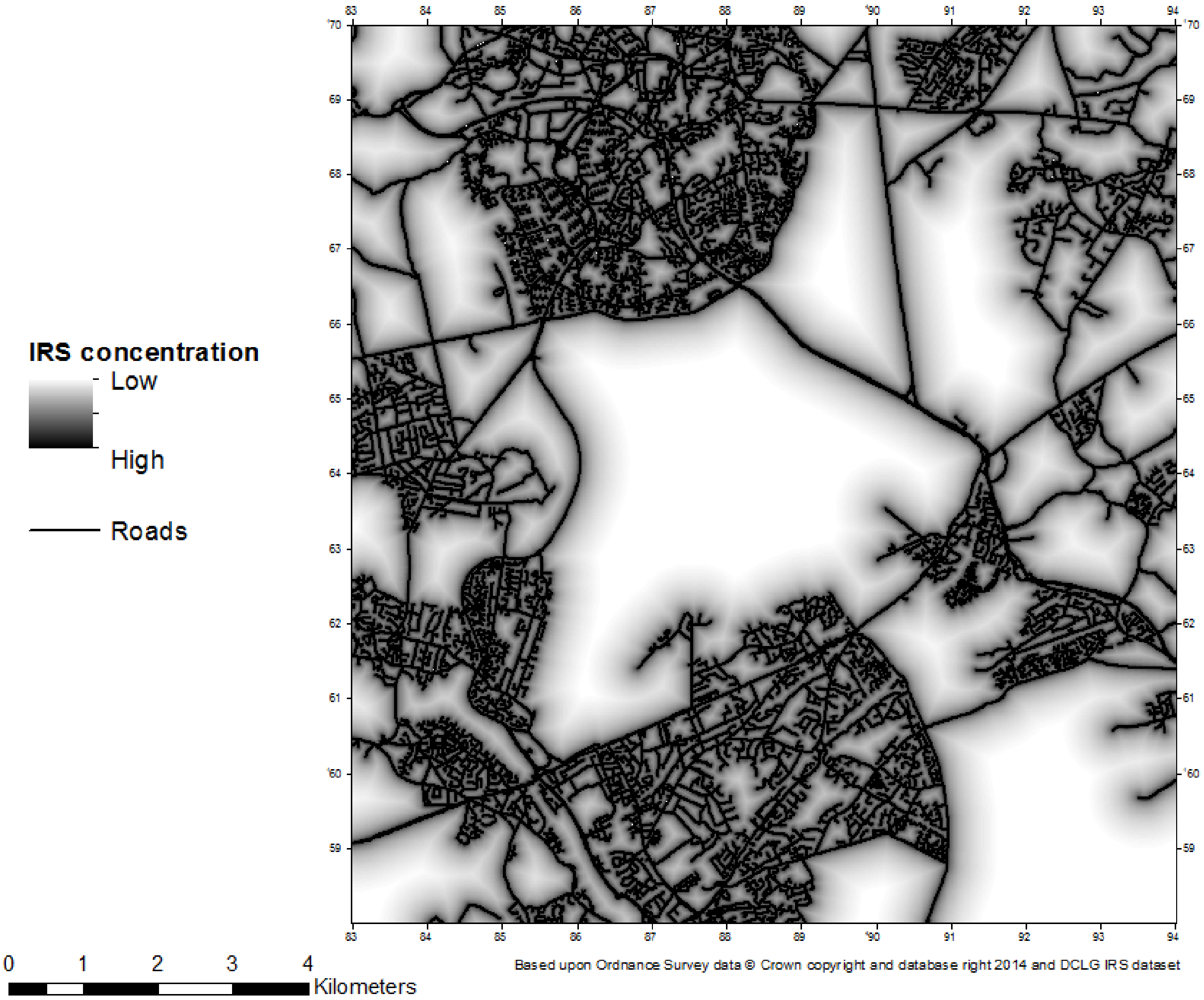


Figure 28: Concentration of IRS points predicted from the distance from roads equation in Figure 12.

Issues and sources of uncertainty:

- The quantile method of slicing the distance image may overemphasise the influence of access routes/built up areas in the distribution of fire points. As suggested in section 2.1, the exact location of the IRS points may be skewed toward access routes and built up areas because the location of the fire engine or the call-out point were recorded rather than the place of the actual fire.
- The five classes introduce rapid step change in the level of risk, which does not actually happen on the ground.
- The method assumes that the IRS points are distributed equally alongside roads, paths and built-up area boundary in the entire case study area, rather than concentrated in specific locations, for instance, due to path popularity or access points.

Recommendation:

- In the future, the probability of the IRS point being located at a given distance from access routes/built-up areas could be assessed based on the mathematical equation matched to the cumulative percentage of IRS points (Figures 10, 12 and 13). This would result in a smooth surface rather than abrupt/somewhat artificial 'steps' between classes, as seen in Figure 28.

3.3 Scoring land accessible to the public

The risk of ignition affecting different types of land accessible to the public was assessed by comparing the observed number of IRS points with the number that would be expected if the IRS points were distributed evenly across the case study area. Only the points present in green space (as opposed to built-up areas, see Figure 9), and the proportion of green space formed by the different types of land accessible to public were taken into consideration here.

The conclusions from this empirical assessment (carried out before the second stakeholder workshop) were as follows:

- Doorstep greens have eight times more IRS points than would be expected if the points were distributed evenly across the green space (very high risk of ignition),
- Country parks have six times more IRS points than expected (very high risk),
- CROW accessible land has four times more fires than expected (high risk),
- Registered common land has three times more fires than expected (high risk),
- Open country and local parks and gardens have a similar number of IRS points to those expected (1.4 and 1.1 times more) (moderate risk),
- MoD land has barely a third of the fires that might be expected.

Participants were asked to comment on these levels of risk during the second workshop. There was a broad agreement that the scoring emerging from the empirical analysis was acceptable. However, the stakeholders asked for 'doorstep greens' to be removed as land accessible to the public, arguing that these small pocket parks are more likely influenced by being surrounded by built-up areas rather than their character as accessible land. Also, their small area was potentially causing an overestimation of risk, due to the formula used, similar to the case of small land cover types (see section 3.1.2).

It was also noted that the MoD land is not accessible to general public (which would partially explain the low number of IRS points) and should be removed from the list of access land. The participants highlighted that MoD land can be divided into 'restricted access' and 'danger areas'. Post workshop, therefore, the team recognised this distinction by assigning *negative* scores to MoD land, with score of -2 for danger areas and -1 for restricted access areas.

During the meetings with individual representatives of stakeholder organisations in May, it was observed that including the land accessible to the public in the final RoI maps results in sharp boundaries on maps in locations whereas, on the ground, there is no difference in access to the land categorised as 'accessible' and not accessible. For example, in Figures 30 (a)–(d) the outline of Crowthorne Wood is clearly visible due to its CROW designation, yet the stakeholders commented that the adjacent Swinley Forest is equally accessible to public. It was suggested that the 'inaccessible' areas are mapped (i.e. the MoD land) to highlight the fact that people visit them less whilst the 'accessibility' is not emphasised. This is further explored in section 7.1.

3.4 Scoring population density

Population density was divided into 5 classes using standard deviation (SD) thresholds (Table 6). This method was chosen in order to reflect the deviation from the average population density within the case study areas and to show the areas where the greatest concentrations of people could be associated with the occurrence of fires. Figure 29 presents the population density categorised using standard deviation.

Table 6 Classification of population density using standard deviation thresholds

Population density	Class
More than 1.5 SD	5 – Very high risk
0.5 – 1.5 SD	4 – High risk
-0.5 – 0.5 SD	3 – Moderate risk
-1.5 - -0.5 SD	2 – Low risk
Less than -1.5 SD	1 – Very low risk

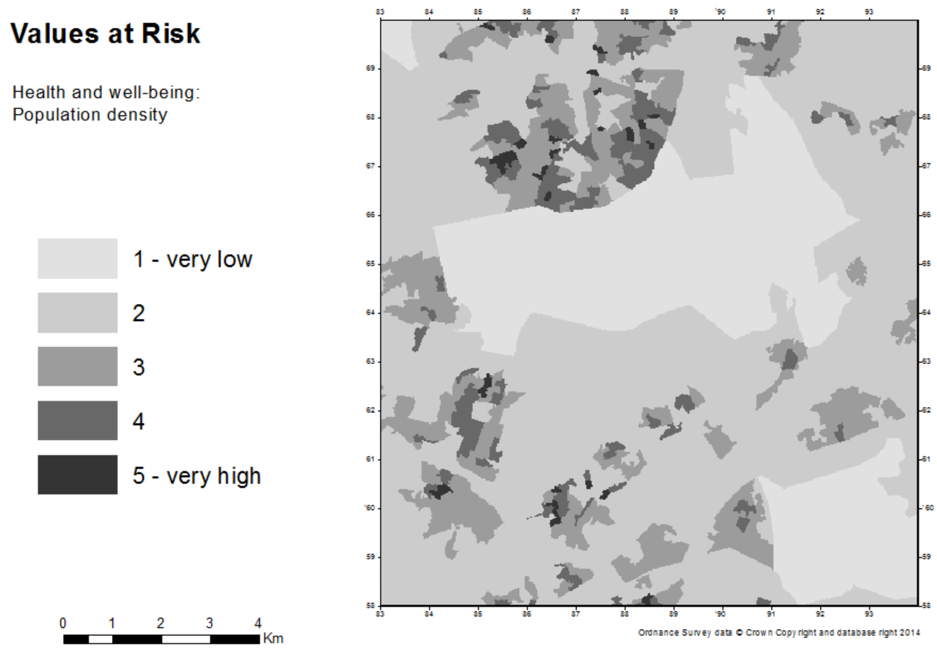


Figure 29: Population density in the case study area categorised using standard deviation.

Issues and sources of uncertainty:

- Standard deviation is only one possible method of classifying the data. Quantiles, natural breaks equal intervals and other methods could be used instead.
- The population density could be simply normalised on a scale 0-1, rather than divided into classes, and then added to other normalised layers to estimate risk of ignition.

3.5 Scoring infrastructure and installations

At the second workshop, stakeholders were asked to carry out a pairwise comparison of the risk of ignition posed by powerlines compared to railways. This is a technique known as Analytic Hierarchic Process (AHP), which uses the principle that it is easy to compare pairs than multiple of factors; the pairwise scores are then added to derive an overall score (normally referred to as weights) for each factor (Saaty, 1987). They were also asked to add any other infrastructure types or installations that could be potential sources of ignition, and assign scores from 1 to 5 to them. This resulted in the following scoring system: railways: 3; danger areas (MoD fire range): 3; powerlines: 2; motorways: 1.

4 Scoring Values at risk

The initial scoring was carried out at the first stakeholder workshop, where the participants were divided into three groups (property and infrastructure; ecosystem services; human health and well-being) and asked to allocate a “budget” of sticky dots to the layers they considered the most important. The results were presented back to the stakeholders during the second workshop (a scale from 1 to 5 was used, where 1 – low value of asset; 5 – high asset value), but using an amended framework for Property and Infrastructure.

4.1 Scoring property and infrastructure

Following the first workshop, the values were reorganised according to the Cabinet Office (2010) framework for critical infrastructure; transport, energy, communications, emergency services, health and social services and other property. The participants at the second workshop were invited to amend the scores within these groups (on a scale from 1 to 5). They were also encouraged to add any other assets and score them. See Appendix 3 for the list of layers and associated scores.

4.2 Scoring ecosystem services

Similarly, the long list of data sources in ecosystem services obtained in ten first workshop was divided into cultural ecosystem services and supporting ecosystem services and participants at the second workshop were invited to adjust the scores within these groups. They were also encouraged to list other sources of information and assign scores to them. The final list of scores is included in Appendix 3.

4.3 Scoring human health and well-being

During the first workshop, participants were asked to allocate sticky dots to different aspects of human vulnerability. However, they were hesitant to distinguish between people of different characteristics and came to the conclusion that there is only one value at risk: life. Consequently, population density was used as a proxy for human life exposed to fire hazard.

At the second workshop, groups of participants were asked again to score the map components which express vulnerability (age, health, income, evacuation issues and vulnerable dwellings) on a scale from 1 to 5, where 1 is low vulnerability, and 5 is high vulnerability. This time health emerged as the most important issue, whilst income was the least important. The final list of scores is included in Appendix 3.

5. Weighting

5.1 Weighting within Risk of Ignition module

At the second workshop, the participants were asked to do a pairwise comparison of the map components included in risk of ignition module in order to provide an overall AHP weighting. For each pair (e.g. land cover – proximity to footpaths) there were nine options ranging from ‘much more important’ (score 1) through ‘equally important’ (score 5) to ‘much less important’ (score 9). Participants worked in four groups (at separate tables). All possible pairs of components were listed on large sheets, one set per group. Participants were encouraged to discuss which aspect in each pair they considered as more important. The sheets were collected and the scores for each component summarised. A record of the discussion and the pairwise sheets can be seen in the separate report on the second workshop. The following weights were obtained, taking all four groups together:

- Land cover map: 5

- Proximity to built-up areas: 3.5
- Proximity to footpaths: 3
- Proximity to roads: 3
- Population density: 3
- Infrastructure and installations: 1

Issues and sources of uncertainty:

- Applying the weights assigned by participants to the components using a scale from 1 to 5 was based on ranking, rather than any continuous mathematical distribution. So, the highest score was translated into 5, the lowest into 1. The remaining were assigned proportionally, also taking into consideration the discussion during the workshop (thus involving a qualitative element).
- During workshop discussions, the participants said they did not see the validity of including population density and infrastructure and installations in the overall risk of ignition map. However, the pairwise comparison included all the 6 aspects listed above; potentially, if population density and infrastructure and installations were not included, the scores could be different. Furthermore, during the meetings with individual stakeholders in May and viewing the results of mapping, it was emphasised that population density and infrastructure and installations *should* be included in the risk of ignition map. This confirms that uncertainty associated with weighting components or excluding them from analysis is associated with the type of organisations and individuals involved in the assessment process and with the information they are shown. For instance, offering different versions of the final Risk of Ignition map actually made stakeholders change their mind about the weighting of components.

Recommendations:

- In the future, the iterative process of discussing the types of layers and components to be included in Risk of Ignition, and soliciting internal scores and weights should be more prolonged. Ideally, it would involve using an interactive GIS tool, where stakeholders could switch layers on and off in real time, change weights and change scores to see the effect on the final map and choose the option that best combines the empirical data with their professional experience section 9, point 11).

5.2 Weighting within Values at Risk sub-modules

Stakeholders understandably found it extremely difficult to weight one component against another within each of the sub-modules of values at risk. They felt that this would need specialist expertise and further information, such as relative economic losses, or time to recover from fire (resilience). Consequently, all the exemplar ecosystem services were weighted equally within the ecosystem services sub-module of values at risk. Similarly, all components of infrastructure and property were weighted equally. Population density was weighted equal to vulnerability in the human health and well-being sub-module.

5.3 Weighting between Values at Risk sub-modules

At the higher level of comparing between the three sub-modules – property and infrastructure, ecosystem services and human health and vulnerability – these initially considered equal (all weighted as 1). However, both the discussions during the two workshops, oscillating around the priorities guiding the FRS, as well as the original WTA approach, clearly suggest that the value of human life and well-being exceeds that of property and infrastructure. Property and infrastructure assets are considered to be more important than the environment. This reflects the Fire Services' stated order of priorities: from life, to property and finally environment. For this reasons, the final weights between the three Values at Risk sub-modules were 5 for human health and well-being, 3 for property and infrastructure and 1 for ecosystem services.

Issues and uncertainty:

- Human health and well-being is considered as 5 times more important than ecosystem services and 160% more important than property and infrastructure. This is an arbitrary scale, and further discussions with relevant stakeholders are necessary in order to refine the relative importance of these three sub-modules of values at risk.
- Only a sample of ecosystem services were mapped due to lack of time.
- Should WTA only consider values at risk directly affected by fire (within the fire perimeter), or should off-site effects, such as smoke, also be considered?
- Participants felt the length of time to recover was an important criterion in weighting values at risk. Over what period should impact be considered; days, weeks, months, years?
- Given the uncertainties, the approach adopted here is to map assets which could *potentially* be affected, *i.e.* an inventory role. It is not possible to consider actual economic impact without more information. A hazard module is needed to assess the physical severity of the fire. A better understanding of the relationship between wildfire hazard (fireline intensity) and impacts is needed. Information on relative costs of impacts will be required.

Recommendations:

- A wide group of stakeholders should be engaged in deciding the weights of values at risk.
- More ecosystem services should be added
- Information on relative economic impact of wildfire is needed. This also requires that the Hazard module is developed, as severity of fire will partially affect the degree of damage and the economic impact.
- It would also be useful to record burn severity immediately after a fire to help to develop a better understanding of how physical properties of the fire (from the Hazard module) are expressed as real post-fire impact. The burn severity information would also be helpful in assessing degree of longer term damage.

6. Mapping

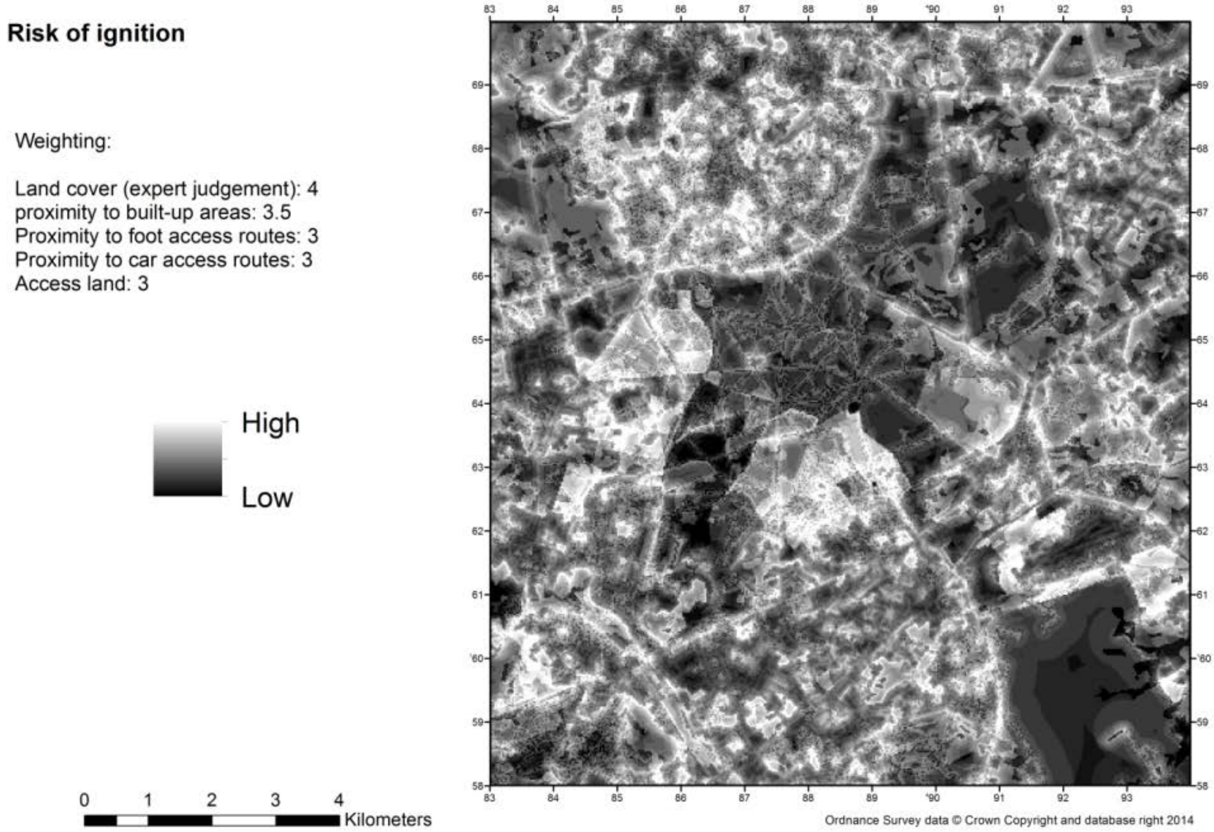
6.1 The final Risk of Ignition map

The components collected, scored and weighted in the previous steps had to undergo a final stage of processing in order to develop the final maps:

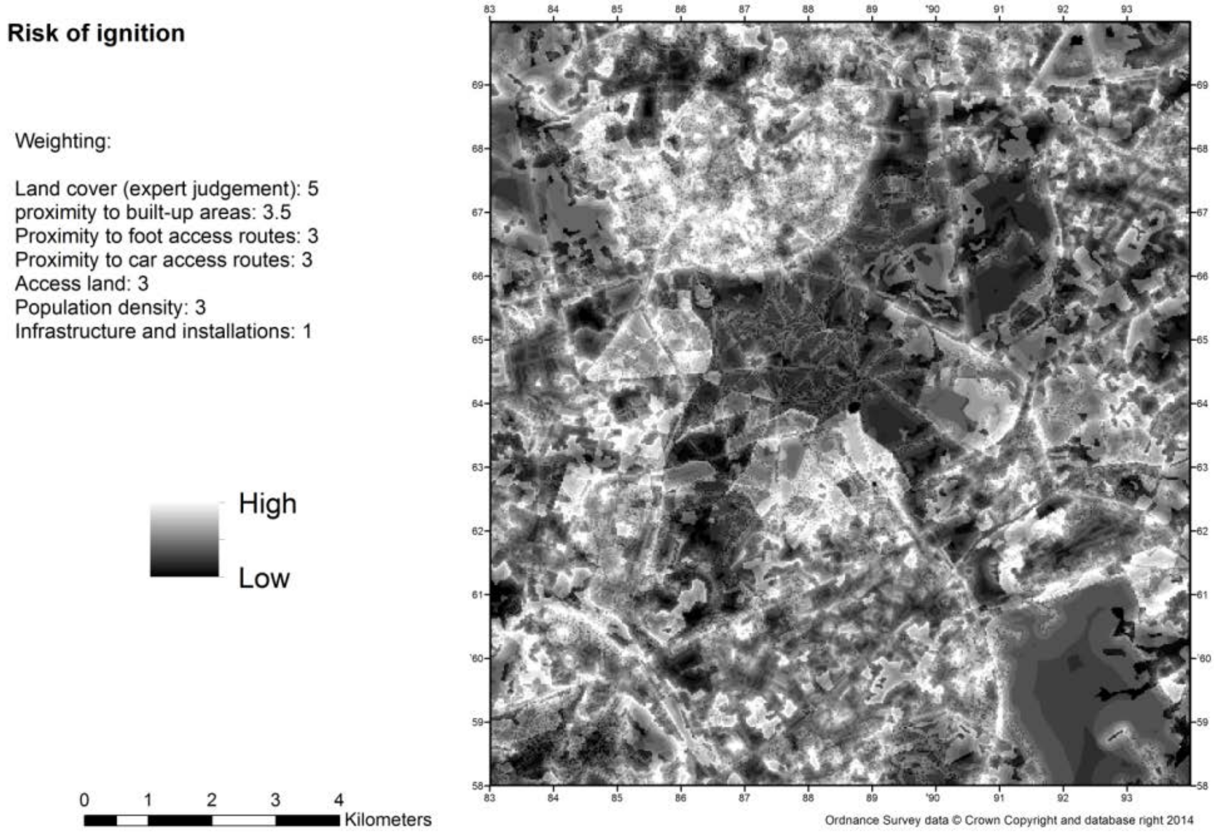
1) Assigning the scores to features, based on the 2nd workshop (see also Appendix 2)
2) Converting linear and point features into raster maps with a cell size of 25m, clipped to the extent of the case study area. Where no features were present, a score of 0 was given.
3) Multiplying the raster value by the weightings suggested by stakeholders.
4) Adding the multiplied rasters together.
5) Normalising the output risk of ignition map.

Based on the recommendations from the second workshop, several options for the final risk of ignition map have been developed. The absence of one definitive RoI map stems from the lack of consensus on the scores and weights to be assigned to different components. The four maps (Figure 30 a – d) were shown to the selected stakeholders during the sector-based meetings in May. Appendix 1 gives the details of the scoring and weighting used in each map.

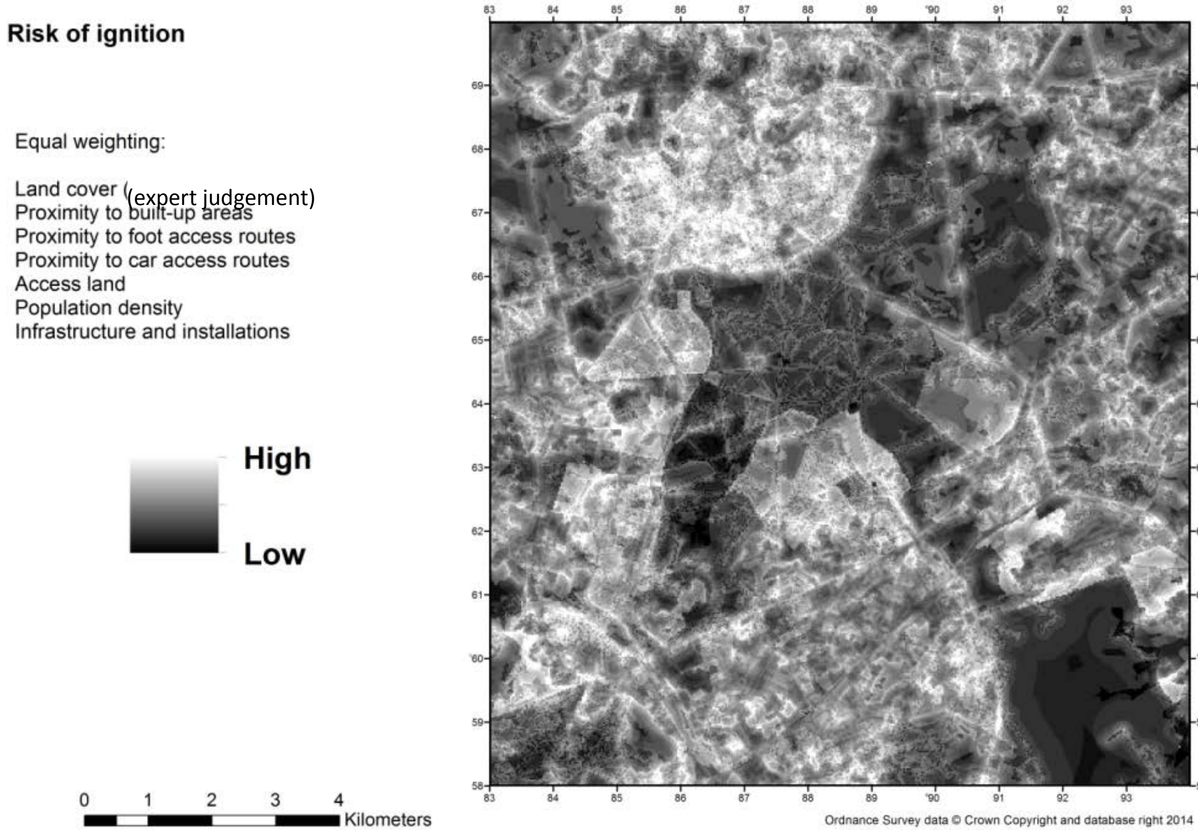
During these meetings, stakeholders expressed their preference for Figure 30b, but requested an amendment to the publically accessible land component. In their opinion, Crowthorne Wood, which had been classified as land accessible to public (as designated by Natural England) was in too stark contrast to the adjacent land. This does not have a statutory designation but is equally accessible. The suggestion was made to remove the positive values of the accessible land, and only leave the negative values of the inaccessible land, i.e. the MoD land. This was taken into consideration and the 'final' risk of ignition map, based on Figure 30b, is presented in Figure 31. Figure 32 overlays the IRS points on this 'final' risk of ignition map.



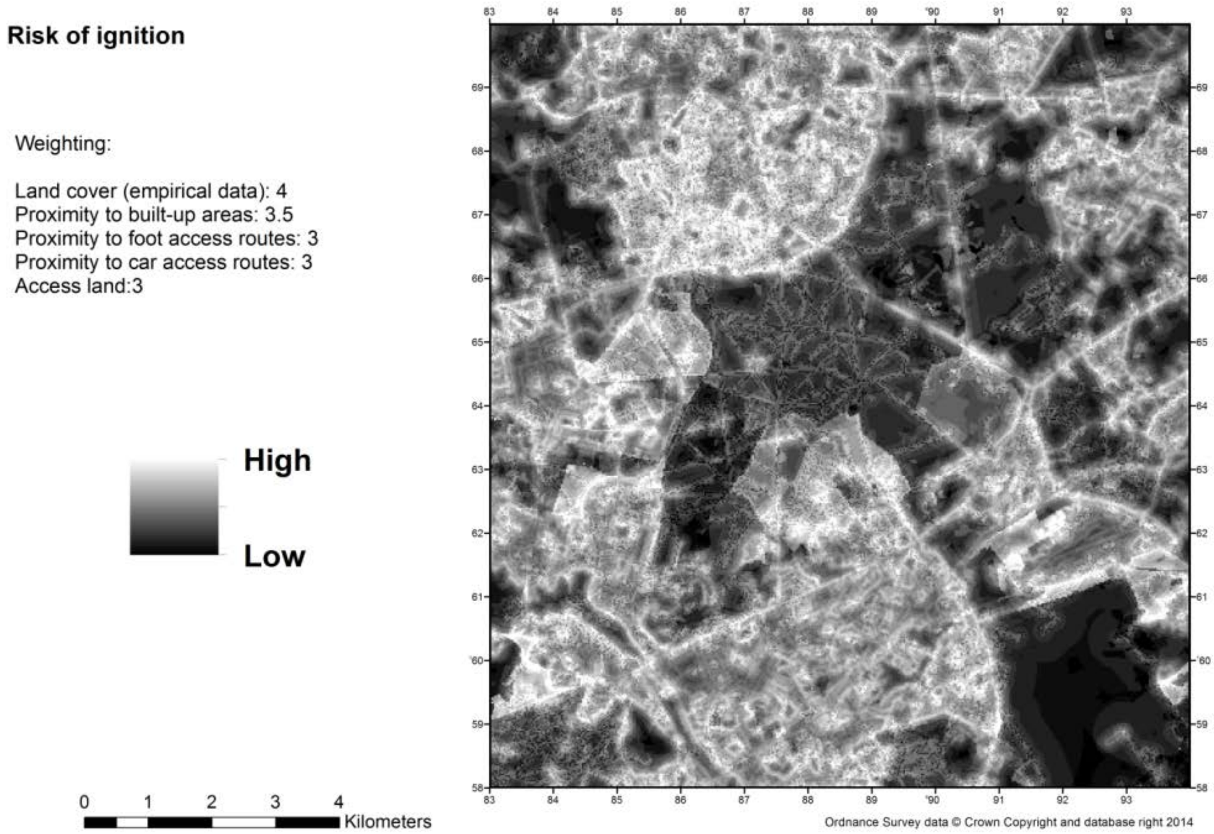
(a)


Risk of ignition
Weighting:
Land cover (expert judgement): 5
proximity to built-up areas: 3.5
Proximity to foot access routes: 3
Proximity to car access routes: 3
Access land: 3
Population density: 3
Infrastructure and installations: 1
High
Low
0 1 2 3 4 Kilometers
Ordnance Survey data © Crown Copyright and database right 2014

(b)


Risk of ignition
Equal weighting:
Land cover (expert judgement)
Proximity to built-up areas
Proximity to foot access routes
Proximity to car access routes
Access land
Population density
Infrastructure and installations
High
Low
0 1 2 3 4 Kilometers
Ordnance Survey data © Crown Copyright and database right 2014

(c)



(d)

Figure 30 (a)-(d): Output Risk of Ignition maps. See appendix 2 for scoring of individual components.

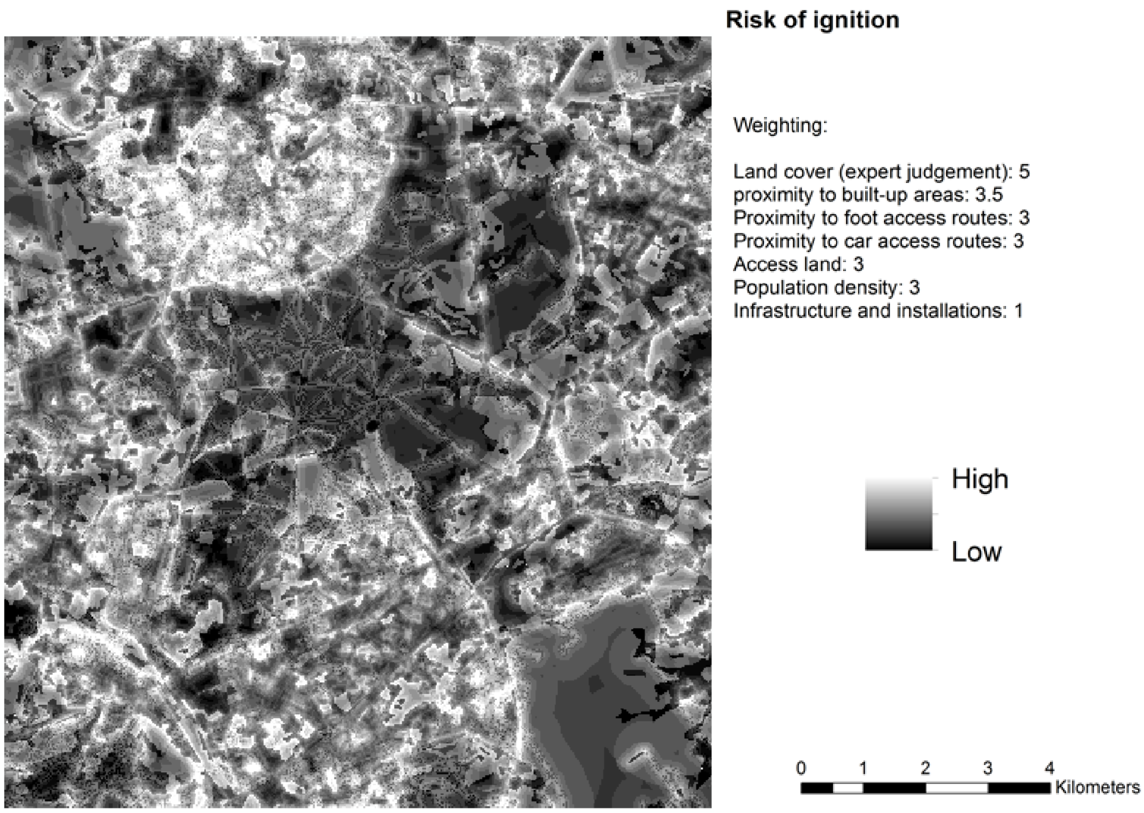


Figure 31: Final Risk of Ignition map (a slightly adapted version of Figure 30b)

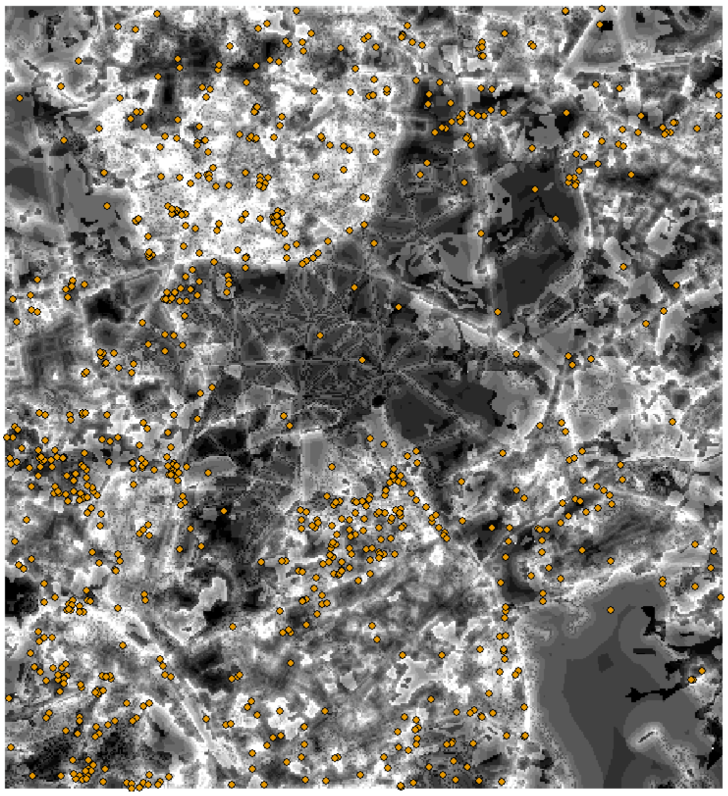


Figure 32: Final Risk of Ignition map – as Figure 31 (a slightly adapted version of Figure 30b) with the IRS points superimposed.

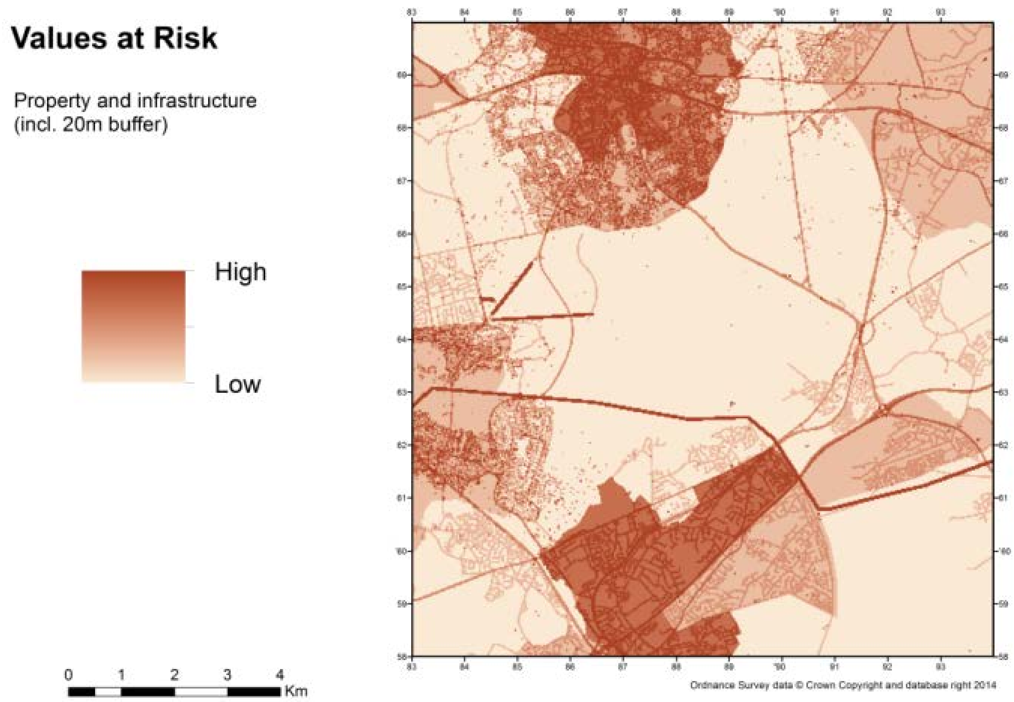
6.2 The final Values at Risk map

The steps involved in developing the final map of values at risk were more complex than for the final risk of ignition. They included:

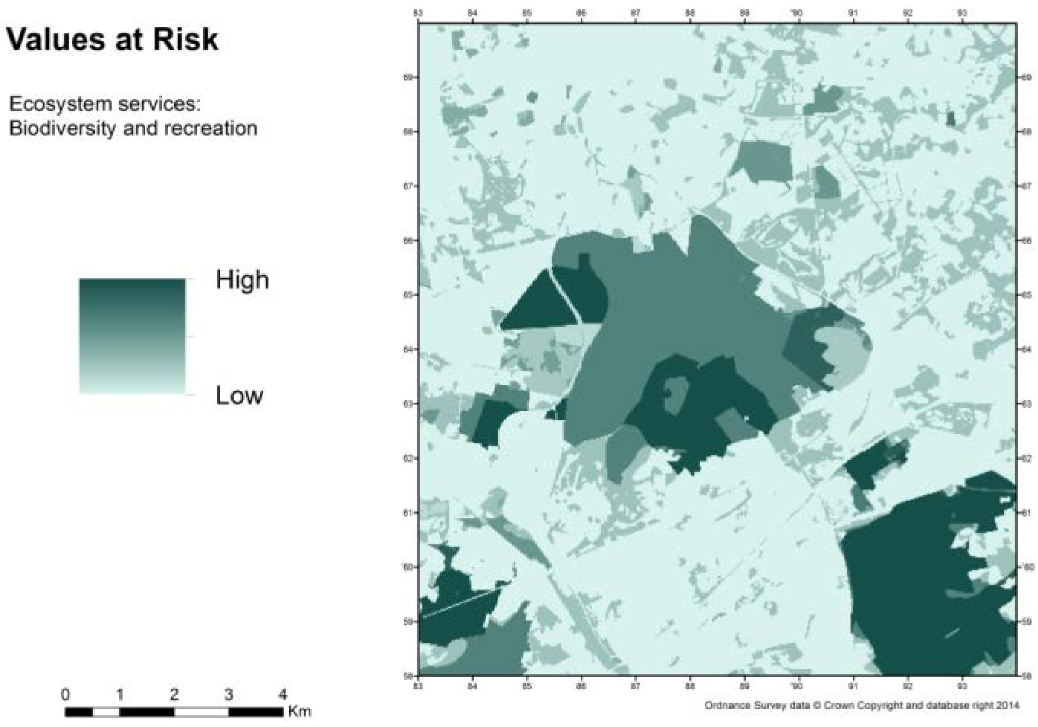
1) Assigning scores derived from the second workshop to the components (also see also Appendix 3). For the health and well-being sub-module, the values of each of the map components were divided into five classes based on standard deviation. The lowest vulnerability class was assigned a score of 1, and the highest a score of 5.
2) Converting point and line features into raster format, using the extent of the case study area and 25m cell. Where no features were present, the score of 0 was given.
3) Adding the layers within each component (e.g. property and infrastructure – transport, or cultural ecosystem services). In the case of rasters converted from point and line features, the addition resulted in the sum of the values in any given cell. For recreation and biodiversity under ecosystem services (rasters converted from polygon shapefiles), the highest value was used, following the logic that multiple overlapping designations do not result in a higher biodiversity or recreation value.
4) Normalisation of the rasters representing individual components for ecosystem services, property and infrastructure to a scale from 0 to 1.
5) Adding the ecosystem services components together, and separately adding the components within 'property and infrastructure' and finally repeating the process for 'health and well-being'. Whilst for the first two sub-modules, the components had equal weightings, for health and well-being the components were weighted according to the relative importance given to them by stakeholders during the second workshop and also reflecting the number of map layers (in order that each of the three sub-module summed to the same value). The vulnerability component was then normalised and added to normalised population density. See Appendix 3 for the exact formula. The resultant output for the three sub-modules are presented in Figure 33 (a) – (c). 'Property and infrastructure' are shown

in shades of brown, with dark brown being the highest concentrations of these values at risk (Figure 33a). ‘Ecosystem services’ are shown in green shades (Figure 33b), and ‘Health and well-being’ in lilac to blue shades, with blue being the highest concentration (Figure 33c).

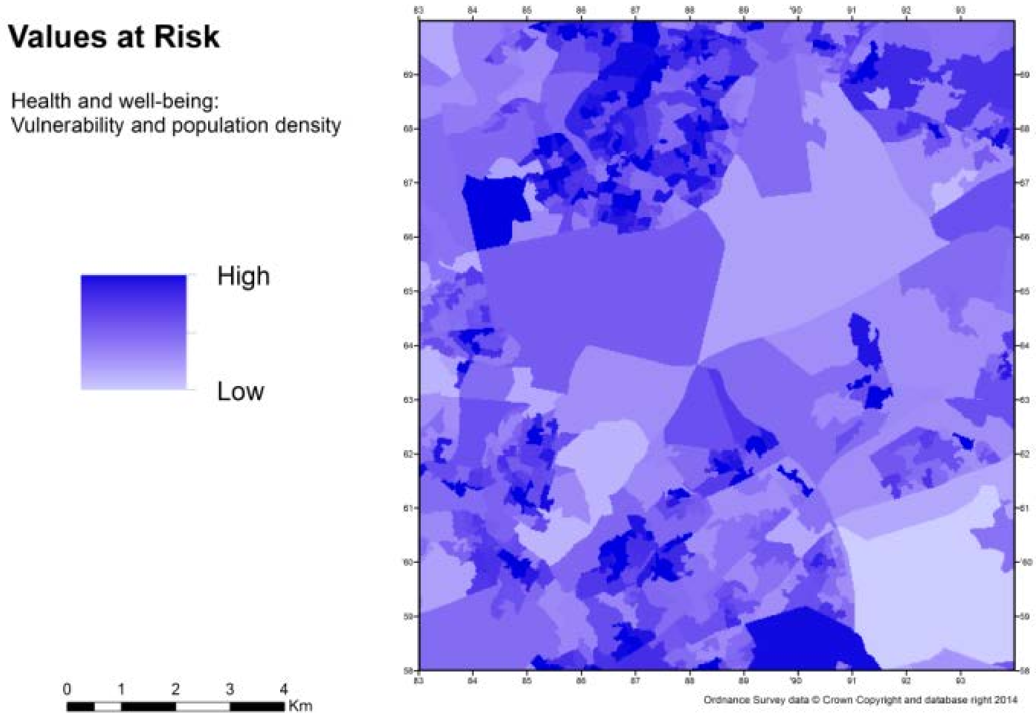
6) The three final output maps for the sub-modules – ‘ecosystem services’, ‘property and infrastructure’ and ‘human health and well-being’ – were added together using equal weights (Figure 34a) and weights reflecting the prioritisation of assets by FRS in an event of a fire (Figure 34b).
7) Normalising the final Values at Risk maps (Figures 34a and 34b).



(a)



(b)



(c)

Figure 33: Output for the three sub-modules of Values at Risk: (a) Property and infrastructure, (b) Ecosystem services, (c) Health and well-being.

The Values at Risk maps were presented to the stakeholders during sector-based meetings in May after the workshops had been completed. Stakeholders preferred the version of the map with weights emphasising the importance of human health and well-being, rather than property and environment (Figure 34b) to the version where health and well-being, property and infrastructure and ecosystem services all had equal weightings (Figure 34a). An important suggestion was made to “clip”, or restrict, the human health and well-being sub-module to built-up areas. This avoids artificial units relating to people in areas of the map that are essentially unpopulated. (These artificial areas arise because we follow the outline of “census output areas” on which human health and well-being assessment are based. These census output areas are contiguous.) This suggestion was followed (Figure 35) and the final Values at Risk map is presented in Figure 36.

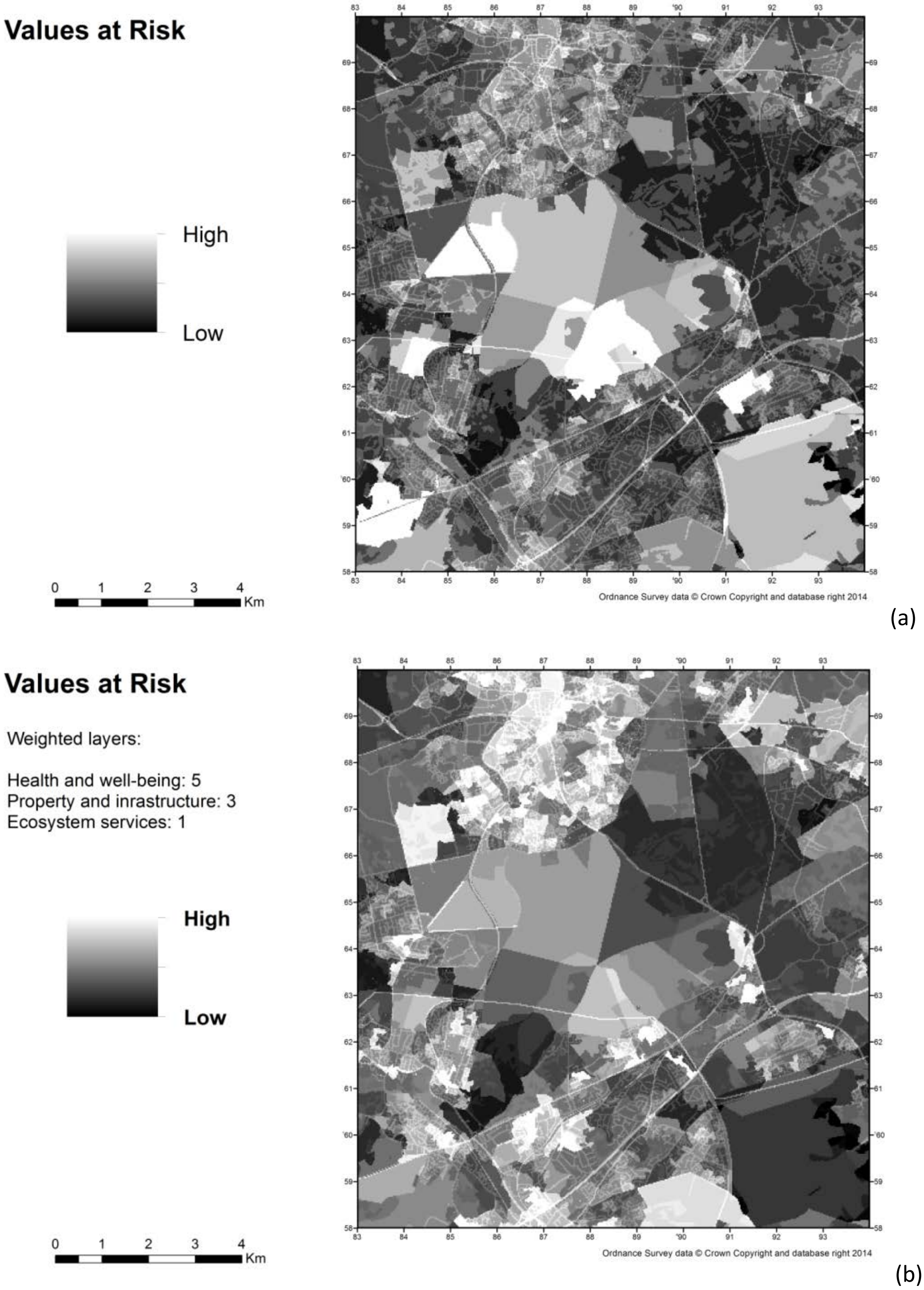


Figure 34: Combined Values at Risk maps, with sub-modules combined with different weightings: (a) Equal weights given to human health and well-being; property and infrastructure; and ecosystem services; (b) Values at risk weighted according to how values are prioritised by FRS in an event of a fire.

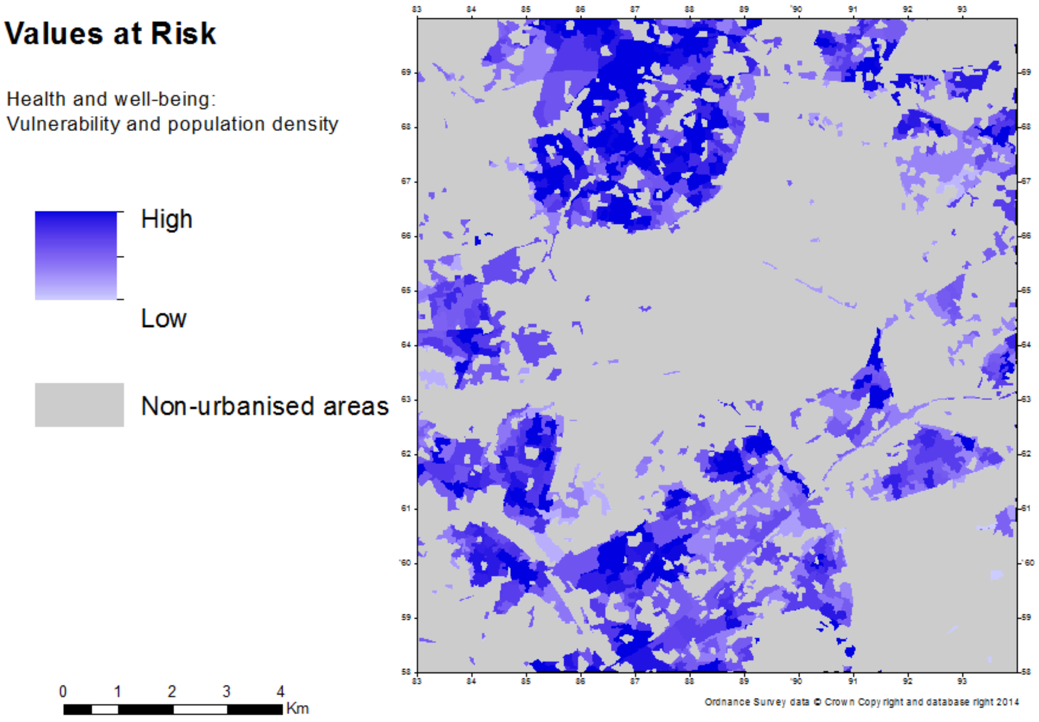


Figure 35: Values at Risk - health and well-being clipped to built-up areas.

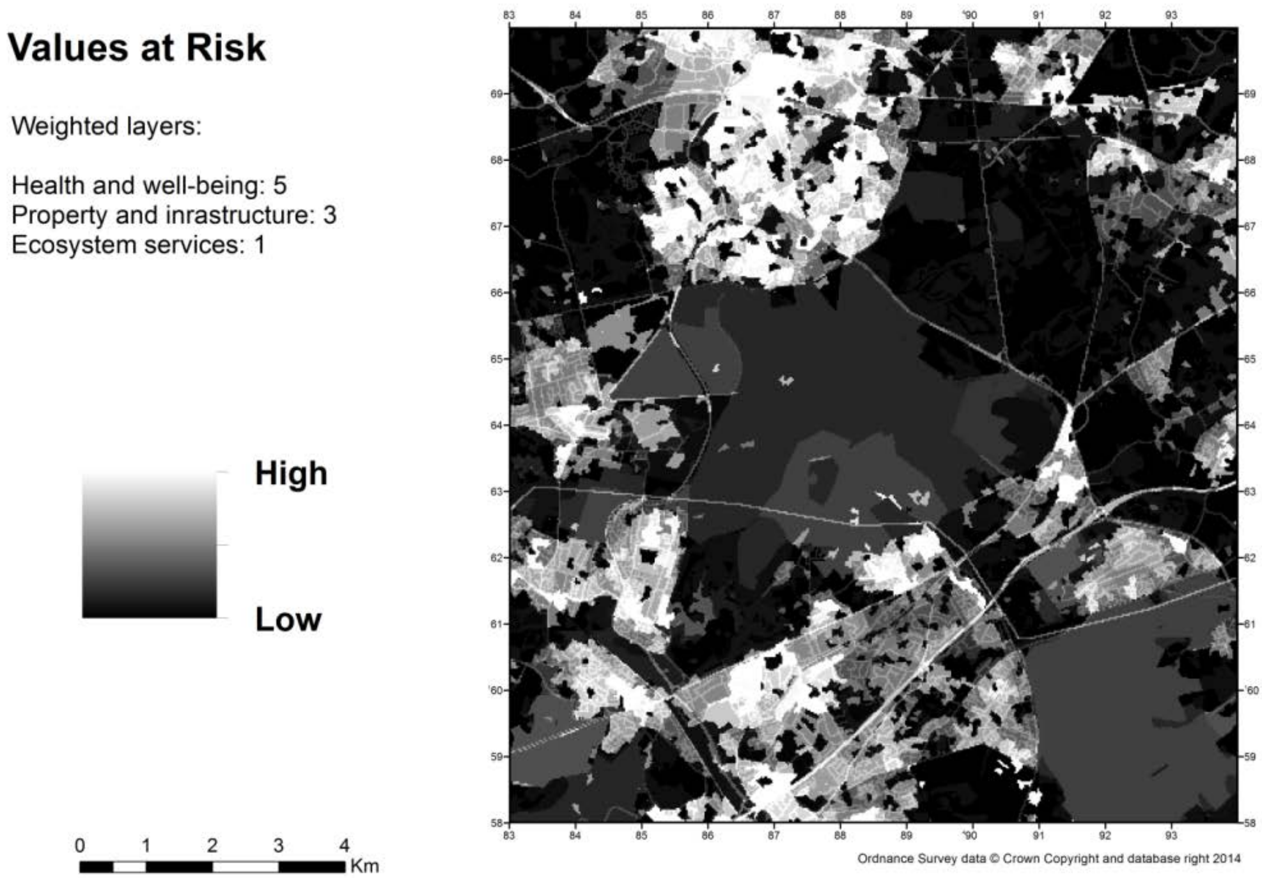


Figure 36: Final Values at Risk map, using clipped version of Heath and well being (Figure 34)

Issues and sources of uncertainty:

- The map presenting Property and infrastructure values at risk was constructed using an incomplete dataset. The utility-water assets are missing, and the utilities-energy dataset is patchy. Whilst Bracknell Forest provided data pertaining to the location of various assets within its jurisdiction, this data was not available for the remainder of the area, which may give the impression there are more values at risk in the north of the case study area than in the south (in particular in Figure 33a).
- Only a selection of ecosystem services are as yet included; incorporating regulating and provisioning services (respectively carbon stock and timber value) would change the map and increase the values in forestry areas.
- The original data is in the form of points, polygons and lines, which poses a difficulty in combining them. The importance of some assets can be downplayed when they are represented as points, because they may not be clearly visible on the map (e.g. Broadmoor Hospital). If the data is represented as symbols, the importance of some assets may overestimated (e.g. electricity substations; mobile communication masts).
- We tried to address the issue by surrounding the point and linear features with a 20m buffer to give them more prominence. However, this does not resolve the problem of poor visibility of some features at risk from fire spread. The use of a buffer also poses difficulties in the rasterisation process. When points are converted to raster, the number of such assets in a cell is recorded, allowing not only the presence of an asset but also their concentration to be represented. On the other hand, if buffers are used, only the presence or absence of value is recorded in the rasterisation process. This results in a loss of important information.
- The information about human health and well-being aspects was restricted to the extent of the built-up areas. A similar process could be applied to the density of VAT-based units. However, there is uncertainty as to whether the land belonging to these businesses actually stretches into the open space (as would be the case of forestry-based units), so was not done here.

Recommendations:

- In order to improve the assessment of values at risk, the missing data should be obtained through collaboration with local stakeholders and through engagement with entities such as energy and water companies. Again, carbon and timber stock assessments should be carried out to provide a better representation of ecosystem services. Other ecosystem services also need to be added.
- Ideally, the data should be provided as polygons rather than points or linear features. For example, Land Registry land parcels could be used to obtain the outlines of hospital or school grounds. However, such a process is likely to be extremely time-consuming.
- If data is only available as points and lines, a systematic method for developing buffers around these features should be used. For example, the width of the buffer could reflect the score that has been assigned to a feature based on the perception of its importance by the stakeholders. If such approach is taken, the values with the score of 5 might have a 5-times wider buffer than those with a score of 1.

7. Potential applications of WTA outputs

The recommendations for the application of WTA outputs listed below have been made by the stakeholders who were consulted in the series of sector-based or individual meetings in May 2014. It is important to note that these outputs were seen as a tool for facilitating discussion among local stakeholders - a generic “starter for ten” allowing local stakeholders to add their own knowledge. These stakeholders emphasised that it is impossible to have a prescriptive top-down approach, and that the WTA needs to leave room for local knowledge to be added so that the threat analysis is applicable to local conditions.

Risk of Ignition map:

- The map can support the inclusion and position of wildfires on Community Risk Registers, so similar RoI maps would be useful to Local Resilience Forums (section 1.3).
- It can support the FRS' statutory IRMP (DCLG, 2008) (section 1.3). An IRMP is an assessment of all risks to life and injury to the community, resulting in a long-term plan to make the FRS more responsive to locally identified needs. An IRMP is prepared by every Fire Authority in the country.
- The information provided is relevant to development control. Similarly to flood risk maps, WTA could be used by the local authority Planning and development control departments. However, in contrast to the risk of flooding, there is no national legislative framework to drive action on fire risk management. Thus, any action will depend on the willingness of the planners to go beyond the scope of the regulations.
- The RoI map shows the places where the presence of rangers or patrolling by Fire/Police service could be seen as a useful preventative measure.
- Awareness raising: it could be used to inform the local land owners about the risks present on their land (and, in combination with values at risk map, how it may affect adjacent areas), and where the landscape should be made more fire-resilient.
- A particular case of raising awareness is on FC land, where this information can be used to guide the forest management regime and be incorporated in contingency plans to meet the European Environmental Liability Directive (section 1.3).
- It could be used to inform the local community about the risk of wildfires.

Values at risk map:

- The property and infrastructure map is very useful for tactical, strategic planning of fire suppression for land owners (FC, MoD and Crown Estates, etc), as it shows clearly where assets are concentrated and risk reduction work in adjacent forest is needed.
- The values at risk maps of would be useful for an FRS commander in the case of an incident to decide where to deploy resources, and for informing IRMPs.

Potential application issues:

- There is a need for a firm justification for using information as a proxy for values at risk. For example, the use of mobile and temporary housing as a proxy for vulnerable housing is not correct, as some wooden permanent houses present in the area would not be classified as vulnerable.
- To local Emergency Planners, the values at risk maps do not represent a great value, since the local planners' knowledge exceeds the more generic information provided. FRS officers, however, felt that the values at risk maps were useful.
- The current lack of regulations at the national level pertaining to wildfire prevention and management reduces the likelihood of practical applications.

8. Recommendations for further work

Specific recommendations have been made to address sources of uncertainty in earlier sections. More general priorities for future work include:

1. *Development of the hazard module*: This is clearly essential to complete the WTA assessment. This requires a fuel layer with appropriate parameters for UK vegetation, a digital terrain model (DEM) and fire climate data. A fuel layer could be developed from recent FCE product which combines the NFI map with LCM2007 and OS MasterMap data. It could be refined for local scale work using FCE's sub-compartment data. DEMS are available at suitable spatial resolutions. Fire climate data, however, is not available at the fine 25m cell size used in this project. However, KCL's new probabilistic (e.g. top 10 and 20% values) UK maps of fire weather sub-indices at 2km (section 2.2.8), would be suitable for a regional or national scale WTA hazard module.

   For the local scale 25m scale, an alternative approach to building a hazard module would be to use multiple ('ensemble') runs of a fire behaviour model like Prometheus (Alberta Government, 2012; FireGrowthModel.ca, no date; Tymstra *et al.,* 2010). Multiple runs from an ignition point, repeated for a series of likely ignition points interpreted from the RoI map, would produce new layers showing probable fire intensity and rate of spread. Wind speeds and directions for the model would be obtained by studying weather conditions for past fires and using the top, say 10 or 20% of values in Prometheus.

2. *Mathematical modelling of RoI*: Stakeholder weighting used with multi-criteria evaluation is subjective and weights vary between stakeholder groups. A more objective method should be tried. Fire density can be predicted using multiple regression with predictor variables (map layers), although important layers which use categories (e.g. land cover) cannot be incorporated. Logistic regression is widely used because it allows categorical variables like land use to be included, but only predicts whether or not a fire (or high/low risk) will occur at each location (Martínez *et al*., 2009; Vilar del Hoyo *et al.*, 2011). Other alternatives are artificial neural networks, or decision trees which use a combination of mathematical modelling and expert knowledge (Amatulli *et al*., 2006).

   The spatial accuracy of the IRS point may limit the use of mathematical models at the 25m scale used in this project, and it may be more appropriate with a coarser cell size. More accurate RoI models will be possible if the geo-reference recorded in IRS can be standardised to an estimated point of ignition.

3. *Role of population characteristics*: Further work on the relationship between population characteristics and fire occurrence for the RoI module (e.g. material deprivation, crime levels). This may be best assessed at a regional or national level where there is a greater range of socio-economic conditions.

4. *Human vulnerability:* More research is required to understand human vulnerability to wildfires for the UK content, particularly factors which make people more vulnerable to smoke and other indirect impacts of fires (Finlay *et al*., 2012). Work in the USA and Australia on the wider social impacts of fires would be a useful starting point; see for instance Jakes *et al.* (2012), Newman *et al.* (2013), Steinberg (2011) and research reported in the International Association of Wildland Fire (IAWF) biennial conferences on Human Dimensions of Wildland Fire.

5. *Further ecosystem services* should be added to the values at risk module, for instance, timber, carbon and water, as indicated in Figure 25. Links with FR's Land Use and Ecosystems Services group and the Valuing Nature Network would be useful here. As discussed in section 1.5.1, burn severity recorded in the field or by remote sensing immediately after the fire (Chafer, 2013; Cocke *et al*., 2005) would help link fireline intensity from a hazard module to actual short-term impacts on ecosystem services.

6. *Quantifying losses*: Overlaying the actual and simulated perimeters of the Crowthorne Wood 2011 fire on the VaR maps will allow actual and potential areas affected to be quantified for each VaR. A buffer zone can be specified around the fire perimeter to estimate VaR indirectly affected. This requires that fire perimeters are routinely recorded for other areas where WTA is implemented.

7. *Updating baseline:* The baseline used in this study was immediately pre-2011 Crowthorne fire, so that the fire perimeter could be used to quantify losses and simulations of fire spread could be obtained. The layers should be updated for current use. Comparing WTA for the two dates could show the positive effect of the fire itself in potentially reducing fuel load and RoI values. The values at risk would also change, in particular if timber and carbon stock were included. 'What if' future scenarios could also then be modelled, such as changing scores to simulate the effect on wildfire threat of planting fire-resistant species, or of restricting public access.
8. *WTA currency:* Land use and values at risk change over time, so an operational procedure needs to be developed to update the maps every 5-10 years.
9. *Seasonality*: Stakeholders were asked to assume springtime conditions, but a different RoI model could be developed for summer fires. This would require using only IRS summer fires to assess the risk of ignition in different land cover types.
10. *Transferability* of the WTA approach needs to be tested in other typical types of UK environments where wildfires occur, notably a moorland-urban interface.
11. *Developing an interactive GIS tool* would allow users to switch layers on and off and assign different scores and weights in a 'live' process (section 5.1). It would be the ideal support for the WTA process, especially if it allowed the addition of users' own data layers (using information that is confidential or locally-specific). An example of such online interface (albeit on a different subject) is *Ecocities* (Cavan and Kingston, 2002), developed at Manchester University.
12. *Testing at coarser scales*: The data collation effort at the current 25m cell size is considerable. Such a fine scale tool is not needed at a regional and national level. WTA requires testing at coarser cell sizes up to the 2km grid cell size of KCL's fire climate severity data. A nested, multi-scale approach would be appropriate, i.e. developing WTA tools, with a coarser scale, strategic WTA used to identify national wildfire hotspots, at which a more intensive local WTA (as in this study) would be carried out (see below, Multi-scale WTA tools).

Multi-scale WTA tools?

A nested approach may be the most appropriate; *i.e.* developing a national or regional scale WTA to identify wildfire hotspots, where a more intensive local finer scale WTA (as in this project) would be recommended.

A coarser cell size of 2km would allow the Fire Severity sub-indices recently developed by KCL to be incorporated. The 2km Fine Fuel Moisture Code data could be incorporated into a regional or national RoI module to covert risk of ignition into the more meaningful probability of *sustained* ignition (Figure 1). The other Fire Severity sub-indices could be used with a digital terrain model and a fuel map to create a national 'worst-case' wildfire hazard map. Worst case here means using assumptions of, say, the top 10% of wind speed and prevailing wind direction derived from studying past fires.

Work would be required to adapt the WTA method to this coarser scale; for instance, issues such as width of buffer zones (Romero-Calcerrada *et al*., 2010). At 2km resolution, a mathematical modelling technique such as logistic regression used with IRS data is likely to be a more appropriate way of combining layers than stakeholder weighting.

A national scale WTA could provide national indicators for the Adaptation Sub-Committee on Climate Change to use in the second CCRA and National Adaptation Plan; for instance, the total number of vulnerable people, number of businesses or the length of railways in wildfire-prone areas.

For VaR, a 2km scale may be less meaningful, and collating data for each of the tree sub-modules would be time consuming. One alternative is to develop just the risk of ignition and hazard modules a 2km national scale. These could then be combined to identify critical areas, or 'hotspots', where a more detailed WTA is required, which would include the full range of values at risk.

Another approach would be to work with other groups who have developed maps of national scale infrastructure and community resilience for other hazards such as flooding (RESNET, CREW, ITRC Infrastructure Transitions Research Consortium). These existing maps could then be combined with a national risk of ignition map developed from IRS to identify hotspots where local scale or regional scale WTA is required. The minimum requirement here would be a fire hazard module developed using ensemble runs of fire behaviour models, but ideally a finer grained WTA for RoI and VaR too.

Applications of such multi scale WTA tools include:

- Identifying FC's Public Forest Estate or privately owned woodland requiring local scale WTA;
- Targeting statutory nature conservation areas at risk for Natural England;
- Choosing communities for CFOA's planned introduction of the *Firewise Communities* program (Steinberg, 2011)
- Assisting roll-out of the National Risk Register by identifying Local Resilience Forums where wildfire risk should be reviewed for their Community Risk Register.

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10. Appendices

Appendix 1: List of workshop participants

Name	Organisation	Role	Presence at 1st workshop	Presence at 2nd workshop
Dr James Morison	Forest Research	Forest Carbon and Greenhouse Gas Balances Programme Group Manager	Y	Y
Rob Gazzard	Forest Services	Adviser, Technical Guidance. Chair of SE England Wildfire Group	Y	Y
Prof Andy Moffatt	Forest Research	Honorary Research Fellow	Y	Y
Stan Abbott	Forest Services	Environment and Planning Manager	N	Y
Agnieszka Wojtas-Barber	Forestry Commission	GIS Officer		Y
Patrick Stephens	Forestry Commission England	Operations manager SE of England	Y	Y
Alan Clark	Surrey Fire and Rescue Service	Area Commander West	Y	Y
Dr Thomas Smith	King's College London	Lecturer in Physical and Environmental Geography	Y	Y
Louise Osborn	Bracknell Forest Council	Emergency Planning manager	Y	Y
Chris Atkins	Bracknell Forest Council	GIS and Gazetteer Manager	Y	N
Ricky Taylor	EM Highway Services Limited	Environmental Manager	Y	Y
Des Sussex	Natural England	Land Management and Conservation Lead Adviser	Y	N
Terrence Beaumont	Heathland Conservation Society	Chairman	Y	Y
John Deakin	The Crown Estate	Chief Forester	Y	N
George Peet	MoD	South England Regional Head Forester	Y	Y
Mark De Jong	King's College London	PhD student and NERC PURE KTA	N	Y
Nick Oxborough	Royal Berkshire FRS	Group Manager (Performance Review)	N	Y

Appendix 2: Risk of ignition: scores and weights used in the final map

Component	Weight	Classes	Score
Land cover	**5**	Bare ground/rock; Urban/building; Quarry; Open water	1
		Broadleaved woodland; Mixed woodland (mainly broadleaved); Mixed woodland (predominantly coniferous) Low density woodland; Assumed woodland; Forest road or track	2
		Coniferous woodland; Felled woodland Ground prepared for new planting	3
		Young trees; Shrubland; Agricultural land; Powerline	4
		Grass; Heather; Heather grassland Other vegetation (gorse, heather, bracken, rhododendron)	5
Proximity to built-up areas	**3.5**	1st quantile (20% of IRS points) - 25 m distance	5
		2nd quantile (40% of IRS points) -49m distance	4
		3rd quantile (60% of IRS points) - 103m distance	3
		4th quantile (80% of IRS points) - 160m distance	2
		5th quantile (98%+ IRS points) - 1172m distance	1
Proximity to foot access routes	**3**	1st quantile (20% of points) - 15m distance	5
		2nd quantile (40% of IRS points) - 35m distance	4
		3rd quantile (60% of IRS points) - 76m distance	3
		4th quantile (80% of IRS points) - 143m distance	2
		5th quantile (98%+ IRS points) - 472m distance	1
Proximity to car access routes	**3**	1st quantile (20% of points) - 10m distance	5
		2nd quantile (40% of IRS points) - 40m distance	4
		3rd quantile (60% of IRS points) - 91m distance	3
		4th quantile (80% of IRS points) - 230m distance	2
		5th quantile (98%+ IRS points) - 1372m distance	1
Publically accessible land	**3**	MoD land - restricted access	-1
		MoD land - danger area	-2
Population density	**3**	< -1.5 Standard deviation (SD)	5
		-1.5 - -0.5 SD	4
		-0.5 – 0.5 SD	3
		0.5 – 1.5 SD	2
		> 1.5 SD	1
Infrastructure and installations	**1**	20m buffer around railways (after WTA)	3
		MoD fire range area	3
		20m buffer powerlines (after WTA)	2
		20m buffer - motorways	1

The components were added together and the resultant raster normalised following the formula (x – min) / (max – min).

Appendix 3: Values at risk: scoring, weighting, mapping

Health and well-being (weight : 5)

Component	Weight*	Layer	Score (value of SD)**				
			<-1.5	-1.5 - -0.5	-0.5 – 0.5	0.5 – 1.5	>1.5
Health	**5 / 2**	% people whose daily activities are limited by a long term illness	1	2	3	4	5
		% people describing their health as bad or very bad	1	2	3	4	5
Age	**4 / 2**	% people 75 years old and older	1	2	3	4	5
		% children 4 years old and younger	1	2	3	4	5
Evacuation issues	**3 / 4**	% lone parents	1	2	3	4	5
		% people not born in the UK and with less than 1 year residence	1	2	3	4	5
		% pensioners living on their own	1	2	3	4	5
		% people living in communal establishments	1	2	3	4	5
Vulnerable dwellings	**2 / 1**	% mobile or temporary dwellings	1	2	3	4	5
Income	**1 / 3**	Average income	1	2	3	4	5
		% people who are long term unemployed or who never worked	1	2	3	4	5
		% households rented from social or private landlords	1	2	3	4	5

*The denominator in weight here represents the contribution of the indicator to the layer. If there are two indicators in the layer, their score is 0.5; if there are four, it is 0.25. This system of scoring intends to weigh all layers within the health and well-being sub-module as equal.
** The scores for all layers are based on division into five classes based on standard deviation (SD) values

Property and infrastructure (weight: 3)

Component	Weight	Layer	Score
Property and infrastructure: Transport	**1**	Motorways (Strategic Road Network)	5
		A roads	4
		Railways	4
		Roads with bus routes	3
		Other roads	2
		Bridges	1
Property and infrastructure: Utilities – energy	**1**	Electricity substations	5
		Overhead electricity lines	4
		Petrol stations	3
		Electricity towers/pylons	2
		Gas pipelines	1
Property and infrastructure: Utilities – water	**0 – no data**	Reservoirs	5
		Water pumping stations	4
		Sewage treatment works	3
		Pipelines	2

Property and infrastructure: Utilties - communication	**1**	Radio transmitters	3
		Phone exchanges	3
		Mobile communications masts	3
		Sign gantries	1
Property and infrastructure: Emergency services	**1**	Fire stations	4
		Police stations	3
		Ambulance stations	2
		Designated rest centres	1
Health and social services	**1**	Hospitals	5
		Prisons / secure mental hospitlas	4
		Schools	3
		Care homes	3
		GP surgeries	2
		Community centres	1
Other property	**1**	Businesses (VAT-registered units)	3
		Civic buildings	2
		Listed buildings	2
		Local Land & Property Gazetteer data	2

Processing: For each layer, scores were assigned to features and converted to raster. Layers within components were added together and normalised to 0-1 scale following the formula (x – min) / (max – min). The exception is the transport component, where the A-Roads and bus routes overlap with other roads. To avoid double counting the scores, the maximum value was selected from these three layers. The resultant layer was normalised added to the other normalised property and infrastructure layers. The resultant layer was normalised.

Ecosystem services (weight: 1)

Component	Weight	Layer	Score
Ecosystem services: Supporting - biodiversity	**1**	Special Areas of Conservation	5
		Special Protection Areas	5
		Sites of Special Scientific Interest	4
		Ancient Woodlands	3
		Local Nature Reserves	2
		Priority Habitat Inventory	2
		Traditional Orchards	2
		Local Wildlife Sites	1
Ecosystem services: Cultural - recreation	**1**	Registered Common Land	3
		Country parks	3
		Open Country	2
		Areas accessible under the CROW Act	2
		Parks and gardens	1

Processing: For each layer, scores were assigned to features and converted to raster. As the different layers of nature conservation / recreation overlap spatially, the maximum value was selected (following the assumption that multiple designations do not increase the biodiversity/recreation value of a given area). The resulting rasters were normalised to 0-1 scale following the formula: (x – min) / (max – min); added together, and normalised again.

Mapping values at risk:

The final map was developed by adding together 5*(total of health and well-being) + 3* (total of property and infrastructure) + 1* (total of ecosystem services)

Appendix 4: Data catalogue: data sources used in developing the Risk of Ignition and Values at Risk layers

Dataset	Source	Source: other details	Date	Spatial accuracy / spatial unit	Open data?	Copyright/referencing
Bridges	Bracknell Forest Council			Unknown	No	Based upon Bracknell Forest Council data. Contains Ordnance Survey data © Crown copyright and database right 2014
Bus routes	Bracknell Forest Council			Unknown	No	Based upon Bracknell Forest Council data. Contains Ordnance Survey data © Crown copyright and database right 2014
Civic buildings	Bracknell Forest Council			Unknown	No	Based upon Bracknell Forest Council data. Contains Ordnance Survey data © Crown copyright and database right 2014
Community centres	Bracknell Forest Council			Unknown	No	Based upon Bracknell Forest Council data. Contains Ordnance Survey data © Crown copyright and database right 2014
Designated rest centres	Bracknell Forest Council			Unknown	No	Based upon Bracknell Forest Council data. Contains Ordnance Survey data © Crown copyright and database right 2014
Local authority land and property gazetteer	Bracknell Forest Council			Unknown	No	Based upon Bracknell Forest Council data. Contains Ordnance Survey data © Crown copyright and database right 2014
Local wildlife sites	Bracknell Forest Council			Unknown	No	Based upon Bracknell Forest Council data. Contains Ordnance Survey data © Crown copyright and database right 2014
Parks and gardens	Bracknell Forest Council			Unknown	No	Based upon Bracknell Forest Council data. Contains Ordnance Survey data © Crown copyright and database right 2014
Sign gantries	Bracknell Forest Council			Unknown	No	Based upon Bracknell Forest Council data. Contains Ordnance Survey data © Crown copyright and database right 2014
Vulnerable locations	Bracknell Forest Council			Unknown	No	Based upon Bracknell Forest Council data. Contains Ordnance Survey data © Crown copyright and database right 2014
Ambulance services	Care quality commission	http://www.cqc.org.uk/	2014; updated weekly	Postcode centroid	Yes	Based upon Care Quality Commission data
Care homes	Care quality commission	http://www.cqc.org.uk/	2014; updated	Postcode centroid	Yes	Based upon Care Quality Commission data

			weekly			
Hospitals	Care quality commission	http://www.cqc.org.uk/	2014; updated weekly	Postcode centroid	Yes	Based upon Care Quality Commission data
Land Cover Map 2007	Centre for Ecology and Hydrology	Downloaded from Edina Digimap	2011	Raster data. 25x25 m cell.	No	Based upon LCM2007 © NERC (CEH) 2011. Contains Ordnance Survey data © Crown Copyright 2007. © Edina Digimap *(third party licensors)*
BT phone exchanges	Cross-reference of http://maps.thinkbroadband.com/ and http://www.samknows.com/		2013	Postcode centroid	Yes	Contains Royal Mail data © Royal Mail copyright and database right 2014
Schools	Department of Education	http://www.education.gov.uk/edubase/public/quickSearchResult.xhtml?myListCount=0	2014; updated weekly	Postcode centroid	Yes	Contains Royal Mail data © Royal Mail copyright and database right 2014; Contains National Statistics data © Crown copyright and database right 2014
Listed Buildings	English Heritage	http://www.english-heritage.org.uk/professional/protection/process/spatial-data/	?	Unknown: geocoding consisted of both address matching and manual data capture	Yes	Contains, or is based upon, English Heritage's National Heritage List for England data © English Heritage.
IRS points	Fire and Rescue Service		2013	Unknown	No	?
Gas pipelines	Forestry Commission England			Unknown		Based upon Forestry Commission England data. Contains Ordnance Survey data © Crown copyright and database right 2014
National Forest Inventory	Forestry Commission England	http://www.forestry.gov.uk/forestry/INFD-8EYJWF	2011		Yes	Based upon Forestry Commission England data. Contains Ordnance Survey data © Crown copyright and database right 2014
Overhead powerlines	Forestry Commission England			Unknown		Based upon Forestry Commission England data. Contains Ordnance Survey data © Crown copyright and database right 2014
Fire stations	FRS	Surrey: http://www.surreycc.gov.uk/people-and-community/surrey-fire-and-rescue/contact-surrey-fire-and-rescue/surrey-fire-and-rescue-locations-and-station-action-plans; Berkshire: http://www.rbfrs.co.uk/fire_stations.asp; Hampshire: http://www.hantsfire.gov.uk/aboutsite/contact/yourlocalstation.htm	?	Postcode centroid	Yes	Contains Royal Mail data © Royal Mail copyright and database right 2014; Contains National Statistics data © Crown copyright and database right 2014
GPs	Health and social care information centre		Oct-13	Postcode centroid	Yes	Contains Royal Mail data © Royal Mail copyright and database right 2014; Contains National Statistics data © Crown copyright and database right 2014
Radio transmitters	http://www.ukfree.tv/ and local knowledge		?	Grid reference	Yes	

Railways	OS MasterMap	Topography Layer	2013	1m	No	Ordnance Survey data © Crown copyright and database right 2014
Roads	OS MasterMap	Integrated Transport Network	2013	1m	No	Ordnance Survey data © Crown copyright and database right 2014
Tracks and paths	OS MasterMap	Topography Layer	2013	1m	No	Ordnance Survey data © Crown copyright and database right 2014
Extent of the MoD land	MoD			?		Contains Ordnance Survey data © Crown copyright and database right 2014
Line (overhead electricity line)	National Grid	http://www2.nationalgrid.com/uk/services/land-and-development/planning-authority/shape-files/	?	?	Yes	
Ancient Woodlands	Natural England	http://www.gis.naturalengland.org.uk/pubs/gis/GIS_register.asp	2013	Unknown. Vector data	Yes	© Natural England copyright. Contains Ordnance Survey data © Crown copyright and database right 2013
Country Parks	Natural England	http://www.gis.naturalengland.org.uk/pubs/gis/GIS_register.asp	2010	Unknown. Vector data	Yes	© Natural England copyright. Contains Ordnance Survey data © Crown copyright and database right 2013
Countryside and Rights of Way (CROW) Access Layer	Natural England	http://www.gis.naturalengland.org.uk/pubs/gis/GIS_register.asp	2006	Unknown. Vector data	Yes	© Natural England copyright. Contains Ordnance Survey data © Crown copyright and database right 2013
CROW section 15 land	Natural England	http://www.gis.naturalengland.org.uk/pubs/gis/GIS_register.asp	2010	Unknown. Vector data	Yes	© Natural England copyright. Contains Ordnance Survey data © Crown copyright and database right 2013
CROW Section 16 land	Natural England	http://www.gis.naturalengland.org.uk/pubs/gis/GIS_register.asp	2009	Unknown. Vector data	Yes	© Natural England copyright. Contains Ordnance Survey data © Crown copyright and database right 2013
Local nature Reserves	Natural England	http://www.gis.naturalengland.org.uk/pubs/gis/GIS_register.asp	2012	The actual boundaries have been interpreted by GIU onto the August 2002 cut of OS MasterMap	Yes	© Natural England copyright. Contains Ordnance Survey data © Crown copyright and database right 2013
Open Country	Natural England	http://www.gis.naturalengland.org.uk/pubs/gis/GIS_register.asp	2009	Unknown. Vector data	Yes	© Natural England copyright. Contains Ordnance Survey data © Crown copyright and database right 2013
Priority habitat inventory	Natural England	http://www.gis.naturalengland.org.uk/pubs/gis/GIS_register.asp	2013	10 to 100m	Yes	© Natural England copyright. Contains Ordnance Survey data © Crown copyright and database right 2013
Registered Common Land	Natural England	http://www.gis.naturalengland.org.uk/pubs/gis/GIS_register.asp	2005	Unknown. Vector data	Yes	© Natural England copyright. Contains Ordnance Survey data © Crown copyright and database right 2013
Special Area of Conservation	Natural England	http://www.gis.naturalengland.org.uk/pubs/gis/GIS_register.asp	2012	OS MasterMap – produced and supplied by Ordnance Survey from data at 1:1250, 1:2500 and 1:10000 surveying and mapping	Yes	© Natural England copyright. Contains Ordnance Survey data © Crown copyright and database right 2013

				standards - is used as the primary source.		
Special Protection Area	Natural England	http://www.gis.naturalengland.org.uk/pubs/gis/GIS_register.asp	2012	OS MasterMap – produced and supplied by Ordnance Survey from data at 1:1250, 1:2500 and 1:10000 surveying and mapping standards - is used as the primary source.	Yes	© Natural England copyright. Contains Ordnance Survey data © Crown copyright and database right 2013
SSSIs	Natural England	http://www.gis.naturalengland.org.uk/pubs/gis/GIS_register.asp	2012	OS MasterMap – produced and supplied by Ordnance Survey from data at 1:1250, 1:2500 and 1:10000 surveying and mapping standards - is used as the primary source.	Yes	© Natural England copyright. Contains Ordnance Survey data © Crown copyright and database right 2013
Traditional orchards	Natural England	http://www.gis.naturalengland.org.uk/pubs/gis/GIS_register.asp	2011	Unknown. Vector data	Yes	© Natural England copyright. Contains Ordnance Survey data © Crown copyright and database right 2013
Communication masts	Ofcom	http://stakeholders.ofcom.org.uk/sitefinder/sitefinder-dataset/	2012	1m (10 digit grid reference)	Yes	
% children <= 4 years old	ONS	Census 2011, KS102	2011	Output area	Yes	Office for National Statistics, 2011 Census: Aggregate data (England and Wales) [computer file]. UK Data Service Census Support. This information is licensed under the terms of the Open Government Licence [http://www.nationalarchives.gov.uk/doc/open-government-licence/version/2].
% households rented from social/private landlords	ONS	Census 2011, KS402	2011	Output area	Yes	Office for National Statistics, 2011 Census: Aggregate data (England and Wales) [computer file]. UK Data Service Census Support. This information is licensed under the terms of the Open Government Licence [http://www.nationalarchives.gov.uk/doc/open-government-licence/version/2].
% lone parent households	ONS	Census 2011, KS107	2011	Output area	Yes	Office for National Statistics, 2011 Census: Aggregate data (England and Wales) [computer file]. UK Data Service Census Support. This information is licensed under the terms of the Open Government Licence [http://www.nationalarchives.gov.uk/doc/open-government-licence/version/2].
% lone pensioner households	ONS	Census 2011, QS113	2011	Output area	Yes	Office for National Statistics, 2011 Census: Aggregate data (England and Wales) [computer file]. UK Data Service Census Support. This information is licensed under the terms of the Open Government Licence [http://www.nationalarchives.gov.uk/doc/open-

						government-licence/version/2].
% mobile and temporary households	ONS	Census 2011, QS402	2011	Output area	Yes	Office for National Statistics, 2011 Census: Aggregate data (England and Wales) [computer file]. UK Data Service Census Support. This information is licensed under the terms of the Open Government Licence [http://www.nationalarchives.gov.uk/doc/open-government-licence/version/2].
% people > 75 years old	ONS	Census 2011, KS102	2011	Output area	Yes	Office for National Statistics, 2011 Census: Aggregate data (England and Wales) [computer file]. UK Data Service Census Support. This information is licensed under the terms of the Open Government Licence [http://www.nationalarchives.gov.uk/doc/open-government-licence/version/2].
% people living in communal establishments	ONS	Census 2011, KS405	2011	Output area	Yes	Office for National Statistics, 2011 Census: Aggregate data (England and Wales) [computer file]. UK Data Service Census Support. This information is licensed under the terms of the Open Government Licence [http://www.nationalarchives.gov.uk/doc/open-government-licence/version/2].
% people who describe their health as bad	ONS	Census 2011, KS301	2011	Output area	Yes	Office for National Statistics, 2011 Census: Aggregate data (England and Wales) [computer file]. UK Data Service Census Support. This information is licensed under the terms of the Open Government Licence [http://www.nationalarchives.gov.uk/doc/open-government-licence/version/2].
% people with <1 yr residency coming from outside UK	ONS	Census 2011, QS801	2011	Output area	Yes	Office for National Statistics, 2011 Census: Aggregate data (England and Wales) [computer file]. UK Data Service Census Support. This information is licensed under the terms of the Open Government Licence [http://www.nationalarchives.gov.uk/doc/open-government-licence/version/2].
% people with long term limiting illness	ONS	Census 2011, KS301	2011	Output area	Yes	Office for National Statistics, 2011 Census: Aggregate data (England and Wales) [computer file]. UK Data Service Census Support. This information is licensed under the terms of the Open Government Licence [http://www.nationalarchives.gov.uk/doc/open-government-licence/version/2].
Average weekly household net income estimate	ONS	Average Weekly Household Net Income Estimate	2008	Output area	Yes	Office for National Statistics, 2011 Census: Aggregate data (England and Wales) [computer file]. UK Data Service Census Support. This information is licensed under the terms of the Open Government Licence [http://www.nationalarchives.gov.uk/doc/open-government-licence/version/2].

Density of VAT-registered units	ONS	Local Units by Broad Industry Group: Urban/Rural, 2011	2011	MSOA	Yes	Office for National Statistics, Local Units by Broad Industry Group: Urban/Rural, 2011.
Long term unemployment/never worked	ONS	Census 2011, KS611	2011	Output area	Yes	Office for National Statistics, 2011 Census: Aggregate data (England and Wales) [computer file]. UK Data Service Census Support. This information is licensed under the terms of the Open Government Licence [http://www.nationalarchives.gov.uk/doc/open-government-licence/version/2].
Postcode centroids	ONS open data	https://www.ordnancesurvey.co.uk/opendatadownload/products.html	2014	Postcode centroid	Yes	Contains Royal Mail data © Royal Mail copyright and database right 2014; Contains National Statistics data © Crown copyright and database right 2014
LA boundaries	Ordnance Survey	Downloaded from Edina Digimap	2011	Local authority	No(?)	Ordnance Survey data © Crown copyright and database right [year]
LSOA boundaries	Ordnance Survey		2011	LSOA	Yes	Office for National Statistics, 2011 Census: Digitised Boundary Data (England and Wales) [computer file]. UK Data Service Census Support. Downloaded from:http://edina.ac.uk/census
MSOA boundaries	Ordnance Survey		2011	MSOA	Yes	Office for National Statistics, 2011 Census: Digitised Boundary Data (England and Wales) [computer file]. UK Data Service Census Support. Downloaded from:http://edina.ac.uk/census
OA boundaries	Ordnance Survey		2011	OA	Yes	Office for National Statistics, 2011 Census: Digitised Boundary Data (England and Wales) [computer file]. UK Data Service Census Support. Downloaded from:http://edina.ac.uk/census
OS Background data	Ordnance Survey	Edina Digimap		1:50000	No	Ordnance Survey data © Crown copyright and database right [year]
Police stations	Police headquarters websites	http://www.thamesvalley.police.uk/yournh/yournh-find-station/yournh-nh-liststats.htm; http://www.surrey.police.uk/contact-us/local-police-station-finder/surrey-heath#sthash.qA4GXQd2.dpuf	current	Postcode centroid	Yes	Contains Royal Mail data © Royal Mail copyright and database right 2014; Contains National Statistics data © Crown copyright and database right 2014