The Best Strategy for Mitigating Moorland Wildfire Risk

A Report to Moors for the Future

Jonathan Aylen[1], Gina Cavan[2] and Kevin Albertson[3]

jonathan.aylen@manchester.ac.uk
gina.cavan@manchester.ac.uk
k.albertson@mmu.ac.uk

1. Jonathan Aylen, Manchester Institute for Innovation Research, Manchester Business School, The University of Manchester, Manchester M13 9PL, corresponding author;
2. Gina Cavan, Geography, School of Environment and Development, The University of Manchester, Manchester M13 9PL
3. Dr Kevin Albertson, Department of Economics, Manchester Metropolitan University, Manchester M15 6BG

Final report, Moors for the Future small grant A79419
revised September 2007

Abstract

Climate changes are likely to bring more frequent wildfires. Fires are costly to fight, damage the eco-system, harm water catchments, cause erosion scars and disrupt transport. Intense fires may cause peat to ignite. Peat is a huge carbon store. Reducing the risk of fire and deployment of fire fighting resources are key issues.

Fire risk varies markedly by time of year, time of week and time of day. Fires occur at the end of the day, so there is limited time to fight them before darkness sets in. Fire outbreaks are influenced by vegetation, moorland management, and proximity to roads and footpaths. Wildfires are sporadic, often in remote locations and require specialised equipment.

This research aims to identify the best option in economic terms given the uncertainty surrounding outbreaks of moorland wildfires. "Zero tolerance" is expensive but an efficient way to tackle fires that do occur. In practice there is some optimum level of fires. A distinction needs to be drawn between normal risk and the remote chance of catastrophe, which requires special contingency planning.

Fires have "careers" and it is more cost-effective to catch them early before they spread laterally. For this reason, fire watching is particularly worthwhile. The cost of fighting a fire by conventional means is considerable. Recent fires cost between £8,500 and £132,000 to control in terms of ground based resources. Estimates of £1 million are quoted for fires that run out of control and take some weeks to extinguish. Dousing from a helicopter is an extremely cost effective solution and is nearly always cheaper than surface based crews, but less reliable due to factors such as weather and machine availability. Equipment that brings a more rapid response, such as All-Terrain Vehicles, are likely to be cost effective *even if seldom used*.

The report recommends a combination of fire fighting resources, with more emphasis on helicopter use and risk planning with attention to planning for catastrophe as well as regular fire events.

Contents

1. Introduction

2. The Problem of Moorland Wildfires
   - Analysing fire risk
   - The occurrence of fires
   - The timing of fires during the day
   - The career of a wildfire
   - Severity of fires
   - Summary: The incidence and spread of fires and their implications for fire fighting

3. What is the best approach to reducing wildfire risk in economic terms ?
   - A socially cost-effective solution
   - An optimum level of fires
   - "zero tolerance"
   - A socially optimum level
   - Do nothing
   - Behaviour towards risk
   - Catastrophic risk

4. Fighting Fires – the stylised facts
   - Technical alternatives for reducing fire risk
   - Technical alternatives for fighting fires
   - Coping with the consequences

5. Cost, Reliability and Effectiveness
   - Costing the alternatives
   - Reliability of different approaches
   - Effectiveness of different approaches
   - Base cases

6. Summary, Conclusions and Recommendations

7. Further Research Questions

8. References

9. Acknowledgements

Figures

Figure 1: The timing of grass, heath and moorland fires in Greater Manchester
Figure 2: The spread of wildfires
Figure 3: The spread rate of a fire increases over time up to a limit
Figure 4: The trade-off between reliability and effectiveness fighting moorland fires

Tables

Table 1: Information from Fire Services' Incident Reports for a sample of moorland fires

-

1. Introduction

This report is written for Moors for the Future. The research here develops earlier work for a project on "Climate Change and the Visitor Economy in England's Northwest" (CCVE) funded by DEFRA and the NW Regional Development Agency, and advised by the UK Climate Impacts Programme (McEvoy *et al.*, 2006). The CCVE work involved estimation of probability models to assess the effect of climate change on moorland wild fires as part of a wider study on the impact of weather and long run climate change on the visitor economy of the North-West. Using daily data for the Peak District National Park, a statistical probability model was specified and estimated showing the impact of climatic conditions and visitor use on the risk of wildfire. The significance of holiday and weekend effects showed increased public access to the moors increased the risk of wildfires. If UK tourism as a whole benefits from clement weather, climate change may mean more visitors on the moors, as well as a drier, more flammable environment.

Here we identify the best strategy for mitigating this moorland wildfire risk. This research was supported by a small project grant from Moors for the Future. The grant has been used to fund interviews with those experienced in preventing and tackling moorland wildfires. There is considerable expertise and tacit knowledge among fire service personnel, rangers, gamekeepers, land owners and pilots about tackling wildfires.

The grant has enabled us to achieve three objectives:

1) To extend the collection of data on wildfires in the Peak District National Park so that we have 31 years of daily evidence on fire incidents, their location and the associated weather conditions. We have begun to analyse fire reports associated with recent incidents so that we can relate the circumstances of wildfire outbreaks to the resources required to fight the fires. Evidence is limited, but we have insights into the commitment of personnel and equipment needed to fight wildfires.

2) To develop a framework for analysing the best way to manage fire risk from society's point of view. The research aims to identify the best options in economic terms given the uncertainty surrounding the outbreak of wildfires, and the varying effectiveness and reliability of the resources available.

3) To carry out a schedule of interviews to identify approaches used to tackle wildfires, the resources involved and the best policy measures that might be adopted to help manage the problem. These interviews were carried out with fire authorities around the Peak District National Park, rangers and land owners with experience of fighting fires, a helicopter company and a water company.

The resulting research provides a better understanding of the risks of wildfires and gives an insight into the importance of tackling fires as early as possible. The precautionary principle also stresses the importance of planning for a catastrophic fire year. On the other hand, it is clear that assessment of the cost of resources devoted to fire fighting is in its infancy.

This research continues, considering alternative models that might be used to forecast the timing and severity of wildfires in the Peak District. A clearer understanding of the size and duration of moorland wildfires will enable us to assess resources needed to fight fires when they do occur. There is a particular need to understand the career of individual wild fires. We make recommendations for further research at the end of this report which focus on:

- the need for better data on the severity of fires which can be tied in to incident reports;
- better understanding of "extreme" fire years;
- systematic collection of existing tacit knowledge about fire fighting techniques and making existing documentation more widely available;
- the need to understand the "career" of individual wildfires;
- the cost of alternative approaches to fire fighting.

-

2. The problem of moorland wildfires

Warmer, drier summers brought by climate change increase the risk of frequent wildfires on the moorland of the Peak District of northern England. Fires are costly to fight, damage the eco-system, harm water catchments, cause erosion scars and disrupt transport. Fires release carbon dioxide to the atmosphere. Intense fires may cause peat to ignite below ground (called "ground fires"). The impact of wildfire varies with vegetation and soil conditions. Peat covers much of the north and east of the Peak District and is a huge carbon store. Deployment of fire fighting resources is therefore a key issue.

The probability of moorland wild fire breaking out has four distinct features: Firstly, the chance of a fire *varies widely* from day to day and from year to year. More fires are reported at weekends and bank holidays, reflecting the impact of recreation activity as a cause of fires. Secondly, the timing of fires varies systematically throughout the day. Thirdly, the probability of a fire breaking out rises *non-linearly* in response to determining factors such as drought or temperature. Fourthly, the odds of a fire happening varies *spatially* from place to place throughout the peak district.

Analysing fire risk

Earlier research using statistical models assessed the chance of fires at different times of the year, days of the week and under various weather conditions (McMorrow *et al.*, 2006). These models were estimated using daily data between 1st February 1978 to 1st August 2004 and validated against daily evidence for the second half of 1976 and the first half of 1977, including the severe fire events of July and August 1976.

Results show that current and past rainfall damps fire risk. The likelihood of fire increases with maximum temperature. Fire risk also decreases with minimum temperature since rising night-time temperatures signal the onset of spring: Green vegetation of spring is moist and less fire prone than withered, brown vegetation of winter. Dry spells, hot spells or recent fire activity also signal extra fire hazard. Certain days are fire prone due to visitors – especially Saturdays and Sundays - and some months of the year are more risky reflecting the changing flammability of moorland vegetation. For example, bank holidays are twice as risky as an equivalent Monday that is not a bank holiday.

The initial fire risk model was estimated using Probit analysis on daily data across 27 years. This model assessed the probability of a fire breaking out on any given day. These results have since been confirmed using an alternative statistical technique, Poisson regression, which treats wild fires as "events" that turn up on a given day. There are very slight differences between the results from the two techniques, but essentially the key findings are highly robust across techniques with Probit analysis giving more accurate forecasts.

The central finding is that the danger of fire rises *non-linearly* with key risk factors. For example, the chance of one or more wildfires in the Peak on a Spring Bank Holiday is only 3% at 8^{o}C. This rises slightly to a predicted chance of around 7% at the average temperature for the day of 14.9^{o}C. But, a hot spell at 25^{o}C increases the chance of a fire dramatically to 26%. Note that temperature drops with altitude, so in principle higher grounds should be less vulnerable.

The occurrence of fires

Wildfires are sporadic and unevenly distributed events. In a sample of 375 moorland wildfires in the Peak District National Park Fire Rangers' Log across a period of 31 years, over a quarter of all fires took place during just four individual months: the very hot, dry summer of July and August 1976, and the dry spring of March and April 2003. Approaching two-thirds of fires took place in just eight out of 31 years. Taking two extremes, there were no recorded fires at all in 1979, yet there were at least 80 fires in the second half of 1976. In a typical year there are less than ten fires – the modal number is 5 per year. In the nature of random events, no year is typical. But, 2005 comes close: So, in 2005, there were just four fires – Hope Forest on a Sunday in July; two fires in early September at Hen Cloud on a Sunday and Nether Hey the following Tuesday; plus a fire on a Sunday in early October west of Rising Clough.

April and May and July and August are the worst months for wild fires – with an 8% chance of a fire in each month, compared with no recorded wild fires in December. Saturdays and Sundays are far more fire-prone due to the presence of visitors. For some reason fires are seldom reported on a Friday: the risk on Friday is only a third of that on a Saturday and barely a quarter of the risk of a fire breaking out on Sunday.

Spatially, there are two important influences on the risk of wildfire outbreaks: flammability and ignition sources (McMorrow and Lindley, 2006). Flammability, or vulnerability to ignition, is a function of weather conditions at the time and fuel loading. In turn, fuel loading is related to habitat type and moorland management. Weather conditions at the time of a fire are important in determining the effect of a fire, particularly wind speed and direction.

Turning to habitat, older heather stands have a high amount of woody matter and are vulnerable to fire as they have an increased fuel loading. So, vulnerability depends on the level of management. Bare peat interspersed with grass and shrub patches is particularly vulnerable to wild fire. In contrast, wetter habitats such as cotton grass are far less likely to be the site of wildfire outbreaks. Additionally, heather and grasses are considered to be "one-hour fuels" as they have a very short drying time due to their small particle sizes.

Ignition sources are a function of accessibility and attractiveness of habitat to visitors. Since people start the majority of fires, outbreaks of wildfires tend to occur near to roads and major footpaths, though these fires are also more likely to be reported. Car parks are not a risk factor. Increases in access areas, and increasing popularity of rural areas will result in an increase in fire risk.

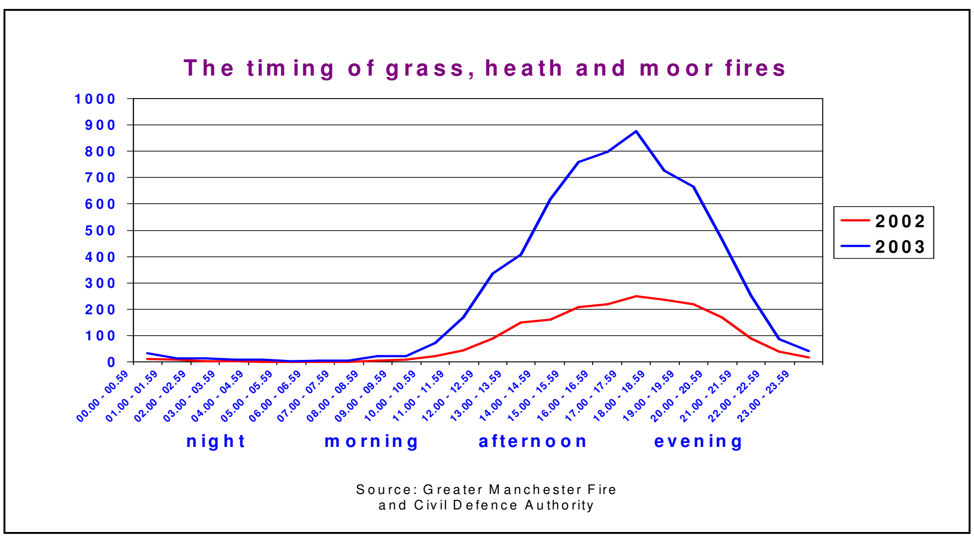
The timing of fires during the day

Fires tend to be reported in the late afternoon when the heat of the day has built up. A study of grass, heath and moorland fires in Greater Manchester shows the peak time for such fires is between 5 and 6 o'clock in the afternoon (Figure 1). Almost no fires are reported before 11 in the morning. In practice, reports of wildfires begin to flow in to fire stations from 3 o'clock in the afternoon and peak between 5.30 and 6.30 in the evening. A fire may well ignite and smoulder during the morning and lunchtime, but may not have developed sufficiently to be noticed before the late afternoon.

There are three related reasons why fires develop in the afternoon: heat, wind and moisture. Heat builds up during the day as part of the usual diurnal cycle. Our statistical analysis shows the chance of wildfire rises disproportionately with temperature. Any fire is more likely to develop and spread in breezier conditions. Wind speed is related to the heat of the day. Ambient winds vary throughout the day: Afternoons are windier and display more gusts than mornings or night time. Stronger afternoon winds feed and spread fire. Finally, moisture in the air, vegetation and soil tends to diminish with the drying conditions of the afternoon heat and breeze. All three factors, heat, wind and dryness, conspire to make wildfires more likely in the late afternoon.

The fact that fires are typically reported in the late afternoon has major practical implications for fire fighting. Wildfires are initially fought in the brief evening time period between tea-time and darkness when fire crews are pulled off the moors for health and safety reasons. There is only a short initial window for tackling a fire before it goes dark. Fire crews are then stood down before returning at first-light the next day, or later. So, if a fire is not doused in the first three or four hours, it has a chance to take hold over night. Admittedly the rate of spread of a fire is lower at night than during the day. Nevertheless, there is a clear threshold in fighting wildfires caused by the reporting time of a typical wildfire.

Figure 1: The timing of grass, heath and moorland fires in Greater Manchester



-

The career of a wildfire
Wildfires develop and spread over time, growing in severity. Fires have distinct behaviour patterns, or life spans. We coin the term 'career' to describe the evolution of a fire from ignition through to being extinguished and "damped down" to prevent re-ignition. We know of no other term to describe the life of a fire.

The career of a fire will depend upon temperature, wind speed, moisture, the available fuel load, the vegetation type, the topography of the fire area, the time of year and the time of day – to name but eight influential factors. So there are no hard and fast rules about how and why a fire develops in a particular way. However, attempts have been made worldwide to model the spread of fires and these have clear implications for the resources required to fight a fire. In particular, these models suggest it is far more cost-effective to catch a fire early than to wait for it to spread.

It is useful to distinguish between different parts of a fire: The head fire, flanking fires and the backing fire (Dold *et al.*, 2006). These correspond naturally to different parts of a fire circle, or fire ellipse (figure 2). The head fire is driven by the prevailing wind and usually travels fastest. The flanking fires burn laterally, across the wind and therefore make slower progress (unless there are still conditions). The backing fire (or "back fire") is burning back into the wind and is likely to make slowest progress of all as it is literally being blown back on itself. (In practice of course, the fire edge is likely to be far more ragged, see GMFRS, 2006, figure 50).

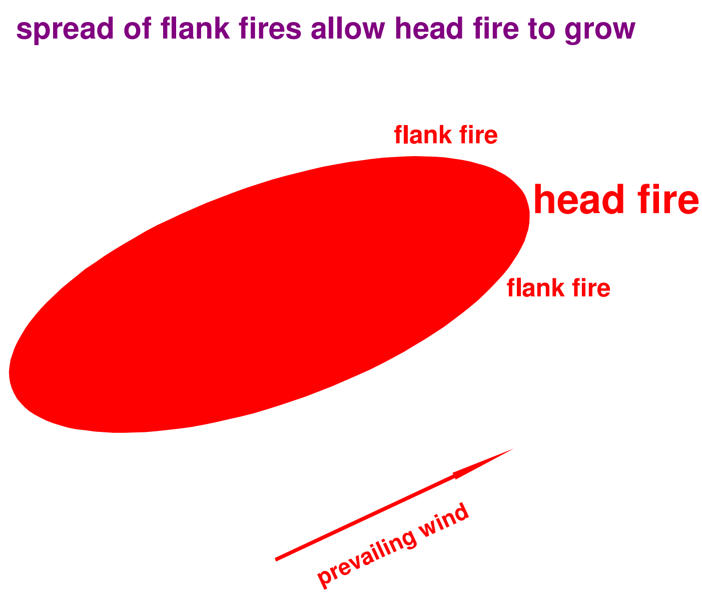


Figure 2: The spread of a wildfire

The advance of the head fire is likely to be supported by embers blown forward by the prevailing wind in advance of the fire front, causing "spot fires". The head fire is not directly propelled by the prevailing wind as the wind loses volume as it spreads across the fire scar behind the head. However, the growing intensity of the head fire sucks in air from all directions as hot fire gases rise upwards from the fire site. Head fires are likely to spread from the south-west towards the north-east in the Peak district, reflecting the prevailing winds in the area. This distinct pattern is likely to be modified by local topography.

The speed of advance is affected by topography. A narrow valley has a chimney effect, propagating fire along its length with the valley sides acting as fire breaks. These are known as "chutes". A fire on a slope is likely to be asymmetric as wind will flow uphill towards low pressure air at the top of the hill. This updraft will feed the fire at the top of the slope while tail-winding the fire on the lower side of the slope. The warmth of the fire pre-heats combustible material on the slope above. Hence fires can spread uphill very quickly.

-

The crucial point about wildfires is that the spread of a head fire increases with time as the flank fires burn further apart. So a fire caught early has little chance to spread. When the width of a fire is low, the speed of advance is also low. However, as the sides spread out the head fire can accelerate giving rise to a much bigger problem. There is a limit to the potential spread rate and the acceleration of the head fire drops off as the fire gets bigger. But, the fall off in the spread rate is scant consolation: By that time the fire is already a major problem.

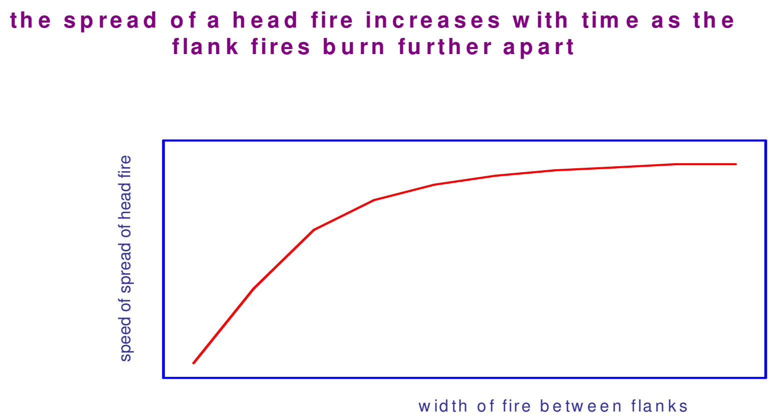


Figure 3 The spread rate of a fire increases over time up to a limit

It is therefore important to tackle a wildfire promptly. The size of the fire perimeter that has to be tackled grows disproportionately with time, as does the area of damage, until the potential spread rate reaches a limit. But, by then, you already have a big problem.

Little is known about the progress of fires at night. During the night, denser air slows the flow of oxygen to a fire. Winds die away near the surface of the ground. Night time cooling reduces available heat. If the surface of land surrounding the fire cools sufficiently, water vapour will condense as dew on surface vegetation which will check the progress of a fire. The fire is literally damped-down as night time temperatures and pressures move towards the dew point. Daytime valley breezes flow uphill during the day, but may reverse at night, altering the shape of a fire on a slope as wind now feeds the downside of the fire and checks progress on the upside. On one fire studied, at the Roaches in 2006, the area of the fire doubled overnight between 2110 hours and 0430 hours the next day from the area of one football pitch to two – a slower rate of progress than if it had continued unchecked during the day for an equivalent seven hours.

Severity of fires

Severity is difficult to define. Area burnt is limited measure. Depth of burn also matters on peat. Moreover, a light controlled burn across heather may be desirable as a way of renewing the eco-system. However it is difficult to control the intensity of a fire and depth of burn, especially at certain times of year.

The impact of wildfires varies according to vegetation and soil conditions. At one extreme, a simple burn-through of dead heather and bracken in winter across moist soil may have few consequences. Indeed, it may be desirable to promote new growth and clear the fuel load of dead material. Paradoxically, controlled burning to reduce the fuel load may reduce subsequent fire damage due to wildfires. At the other extreme a fire setting in to underlying peat (essentially a carbon fuel) during a dry spell may have disastrous ecological effects. One future approach to measuring severity of a fire may be a measure of area burnt weighted by soil moisture content.

Summary: The incidence and spread of fires and their implications for fire fighting

Fire risk varies markedly by time of year, time of week, time of day, weather conditions, vegetation and moorland management and proximity to roads and footpaths. At one extreme, a patch of eroded peat next to a major footpath on a hot spring bank holiday afternoon following a dry spell is a fire outbreak waiting to happen. Yet an adjacent patch of boggy cotton grass is no risk at all during a damp, cold February. Moorland wildfires are a temporary, intermittent but recurrent problem. These findings are important for fire fighting as incidents tend to cluster together in time. This bunching means resources can be stretched either through long deployment on a severe fire, or repeated deployment on a sequence of fires. The concentration of fires can cause acute pressure on resources as local fire services are unable to cope with a large number of simultaneous incidents.

Fire spread accelerates because the head fire is able to burn more vigorously as the width of a fire increases. For this reason it is crucial to catch a fire early as it gets progressively more difficult to tackle with time.

-

3. What is the best approach to reducing wildfire risk in economic terms ?

A socially cost-effective solution

The overall question is: What is the best alternative from society's point of view for managing wildfire risk in the Peak District National Park at each time of year and each location? This research aimed to identify the best option in economic terms, given the uncertainty surrounding outbreaks of wild fires. The aim is to take a dispassionate view about the most socially cost effective way of reducing wildfire risk, regardless of who gains and who bears the losses.

We do not concern ourselves with the question of who pays for fire fighting. We confine ourselves to the policy issue of what is the most cost effective outcome from society's point-of-view. In economic terms we are concerned with minimising the marginal social opportunity cost of fire fighting. In simple terms, we are trying to find the best way to reduce the impact of the next fire.

In principle, we might argue that society should keep spending on fire prevention and fire control until the benefit of deploying the extra resources just matches the extra cost of deployment. In practice, it is hard to establish what the benefits and costs of fire prevention and fire fighting might be. The benefits of reduced fire incidence are hard to establish as it is difficult to infer what fire damage might have been caused otherwise. It is also difficult to put monetary values on, say, a square kilometre of moorland remaining un-burnt other than in terms of the potential cost of restoration. As we show, assessment of the costs of fire prevention and fire fighting is in its infancy. Instead, the best that can be done is to assess the least cost way of achieving a given reduction in fire incidence. Even the question of the most cost-effective approach is not straightforward.

Of course, there is no one answer: The best outcome is a combination of policy measures varying over time and from place to place across the peaks. Some locations have easy road access and are close to convenient water supplies. In contrast, areas of eroded peat close to major footpaths on, say, Kinder or Bleaklow are hard to reach with conventional equipment yet are at high risk at certain times, such as March, April and July and August. The best response varies throughout the year: There is little point in having extra fire crews or helicopters on standby during low risk times of the year.

Finally, the best solution to fighting fires is evidently constrained by budgets.

An optimum level of fires
The first problem to be resolved, is what level of fires is desirable? This is a policy issue best judged by stakeholders including conservationists, land-owners, user groups and the wider society. In the jargon of economics, it determines the objective function to be pursued by those responsible for managing fire risk in the peak. In simple terms, it answers the question: What should be done about wildfires?

Zero tolerance
One approach to fire management is a "zero tolerance" policy. This argues that all wildfires are potentially damaging to the environment and wildlife. So every effort should be taken to reduce the risk of a fire breaking out and any fires that do occur should be tackled straight away. This target is direct, easy to understand and intuitively appealing. The essence of a zero-tolerance policy is fire watching coupled with a rapid response, usually by helicopter.

Some organisations and land owners come close to a zero-tolerance policy in terms of fire fighting. United Utilities move towards automatic call-out of a helicopter in the event of a fire on their land during exceptional weather events. They also maintain their own Scot trak all terrain vehicle, fire fogging kits, portable dams and fire fighting equipment for personnel involved. The National Trust have a policy of calling out a helicopter straight away as soon as a fire is reported on NT land. The Trust have an insurance policy to cover helicopter call out fees. They support this with provision of a temporary pond at times of high fire risk. The pond holds 54,000 litres of water and is designed to receive a helicopter dip bucket. It is air portable, weighing around 100 kg and is kept in a lift bag to help rapid deployment if it is not already on station. In addition, the National Trust maintains an all terrain vehicle and "soft traks" which convey specialised fire fighting equipment such as portable dams and fire fogging pumps to remote fire sites. So, these two organisations have invested heavily in rapid response to wildfires on their property.

There are difficulties with zero tolerance as a principle. Undue emphasis on fire risk detracts from other aspects of the Peak District. Moor closure at time of high risk means a loss of recreation pleasures. Pre-location of fire fighting equipment can be visually intrusive and divert resources from other worthwhile tasks such as education or conservation. Secondly, obviating all fires is expensive in so far as it requires a high level of fire watching and stand-by crews. On the other hand, as we have argued, it is very efficient indeed to catch fires early in their career.

-

A Socially Optimum Level of Fires
The peak district is a managed environment. Fire has played a role in shaping this environment. Afterall, it is widely used as a management technique by gamekeepers in the winter to remove old heather. But, there may also be some optimum level of wildfire in the spring and summer. From society's point of view it may not be desirable to fight all fires straight away, whatever the circumstances. Some fires are limited in scope, only spread slowly over time and do not threaten to destroy underlying peat. They can be tackled in a planned and measured way, typically on the next day. At the other extreme, some fires in peat do continue burning beneath the surface for weeks. One answer is to establish some form of risk assessment which gives individual fires a priority rating in terms of the urgency and resources they should command. This is, in effect, the approach adopted by each Incident Commander when the Fire Brigades are deployed in the Peak area. However, this begs the question, how should those responsible assess the risk of each individual fire once it is reported ? In practice, the assessment is likely to include a wide range of factors such as fire crew safety, available resources, hours of daylight, the weather, threats to roads, power lines or property, areas of special scientific interest, potential fire breaks, smoke hazards and local topography.

Do Nothing
"Do nothing" is an evident option. Inaction may not find much favour among lobby groups promoting the interests of the Peak District and may run counter to obligations imposed by the relevant national park legislation on the Peak District National Park authority.

Behaviour towards risk

There is no single view which can be taken on risk: Behaviour towards risk depends upon the priorities or objectives of the many organisations concerned. There may be *no* significant risk associated with fires in some locations at some times of year (as is the case with controlled burning in winter or wildfires burning across frozen soil, an event that has happened once in a 27 year sample of wild fires).

Risk means different things to different people (loss of income to grouse moor owners; water pollution to water catchment owners; loss of amenity to National Trust; threat to wildlife to RSPB etc.) There is also a specific concern about release of CO_2 to the atmosphere from burning peat which is of wider significance given the role of carbon dioxide as a green house gas potentially contributing to global warming.

Catastrophic Risk
We can distinguish between "normal" risk and catastrophe. Normal risk is the type of risk we can handle in terms of normal probability distributions, or in conventional actuarial terms. Recent experience suggests fires occur almost every year - 30 out of the past 31 for example. Severe fire years typically occur in about 6% of years – say 6 times in 100 years. So, just two hot years – 1976 and 2003 – account for a third of all the fires in our sample. It is striking that there were at least 80 fires in the summer of 1976, over 20% of all fires in the past three decades.

Traditional approaches to risk management focus on what is normal and ignore extreme events. For example, our Probit model assumes fire risk is normally distributed, following a Gaussian distribution – the familiar bell-curve of probability where there is only a very small chance of a really bad fire year occurring. This is sometimes called *mild* randomness. In our work we have assumed the bell shaped curve underlying our analysis has "thin tails". That is to say grave events - such as 1976 - are rare, but not sufficiently likely to merit much concern compared with the familiar year-to-year pattern of manageable fires. As it happens, our Probit model was calibrated by excluding the data for the extreme year of 1976. Yet the model back-predicted the daily fire events of that dry summer reassuringly well. This is evidence that wild-fires can be handled using the normal probability framework. Inevitably, this judgement is based on limited data that is available and takes no account of underlying shifts in climate that may occur.

Catastrophic risk is an extreme event that seldom occurs. Fortunately, we have no opportunity to observe the likelihood of these dire events occurring. Here we are concerned with the awesome impact of remote event. This is the subject of disaster planning. By definition it is in the extreme tail of a probability distribution. (To put this in context, a 0.1% annual risk of a catastrophic sequence of fires would be a once in thousand year event.) It is questionable whether our three decades of fire observations is a sufficiently large window into the process of fire risk.

Extreme risk includes the total loss of all the peat in the face of hotter, drier summers due to widespread fires running out of control, or the effect of a disaster such as a plane crash with a heavy fuel load on deep peat during a dry summer.

The central difficulty is that some natural events – earthquakes, tidal waves, tropical storms – follow a different pattern, that of *wild* randomness. These events are not normally distributed, but follow a fractal process. As a result the extreme tails of the probability distribution are "fat". Severe events occur more often than the bell shaped distribution would predict (e.g. Katz *et al.*, 2005). There is some evidence that fires are more severe than they should be according to normal distributions (Moritz, 1997). So there is a risk of fires occurring which fall outside the natural variability of the ecosystem.

This discussion of extreme events is not just academic, as hotter and drier summers in the north-west of England brought by climate change increase the probability of a large jump in fire risk. As a result, a greater number of total fires may occur, but they may also be concentrated in just a few years, or indeed days. Events such as those of 1976 may be more common than our model supposes. Moritz (1997) examines the largest fires in Los Padres forest in the USA and finds that "Santa Ana" conditions characterised by hot, dry winds cause extreme fires which cross the transition from small to large events. Fire suppression techniques have little effect on these large conflagrations, though they have been successful in reducing the severity of smaller fires.

The risk of moorland fires is likely to increase with climate change as summer rainfall becomes more intermittent and less intense and temperatures rise. Osborn *et al.* (2002) show daily precipitation has already become more intense in winter and less intense in summer over the period 1961-2000. This enhanced seasonal cycle of increasing winter precipitation, heavier downpours and drier summers with fewer wet days and lighter rainfall may reflect changes in the mid-latitude westerly circulation (Mayes, 1996). This does not mean every summer will be drier: There have been episodes of intense summer rainfall during the 1960s (Osborn *et al.* 2000) and during 2007. But, on balance, the chance of a hot dry summer is greater now than it once was.

The policy implication is that we should assume that fire risk follows established patterns for day to day operational management, but plan for the possibility of catastrophe on the grounds that it may not be such a remote chance as it appears at first sight. Instead, extreme events should be regarded as an integral part of the ecosystem. In a fractal world, events such as wildfires can bunch into just a few days. Disaster planning is never urgent as there is little chance of the plans being put in to effect, but it is wise.

Our approach

One way to proceed is to make arbitrary assumptions in an under researched area - a "heuristic" or problem solving approach to the issues. It is a pragmatic and intuitive approach to making the problem tractable in ways which can be modified as more information becomes available.

Here we assume that risk rises with fire severity. As a crude first approximation we assume that fire severity increases non-linearly until a fire is tackled (figure 2). What really matters is the time a fire starts. In practice we can only observe the time at which a fire is reported. So we crudely assume there are two thresholds that matter:

- Time to first tackling the fire from reporting
- Time to a fire running "out-of-control" and threatening to become "severe"

This is a limited view: some fires burn themselves out or are doused by a change in the weather. Fresh, moderate fires can be attacked by fire beaters on the spot. (Rangers and wardens are often equipped with lightweight, portable fire beaters.) Even severe fires are ultimately brought under control.

However, this crude measure has the advantage that it captures the idea of risk becoming more severe with time. It also avoids ambiguous questions such as "what measures would reduce the risk of fire by *ten percent*". While this is precise, it is hard to grasp a reduction in risk of ten per cent.

The disadvantage is that it focuses upon management of fires that do occur, rather than focussing on reducing the risk of outbreaks occurring in the first place.

4. Fighting Fires – the stylised facts

This chapter considers the technical alternatives for reducing fire risk, fighting fires and coping with the consequences.

Various options are available for reducing risk of a fire breaking out. Among these, we have obtained systematic evidence on fire watching. Fire watching, managed burning and grip blocking are perhaps the most successful ways to reduce fire risk.

Reduce risk of fire breaking out:

1. Controlling access to the moors. There is no evidence moor closure works as the number of reported fires are not significantly different in statistical terms during closure periods. Closure may be counterproductive if it means fewer visitors around to spot fires when they do break out.

2. Education aimed at hikers and picnickers. This can include warning signs and ashtray pouches for cigarettes. It is not clear how effective this is. Reports from the Dorset heathland suggest it may halve the likelihood of fires. Other respondents suggest it may encourage arson by highlighting the potential for fires to occur.

3. Fire watching was maintained by the Peak District National Park Ranger Service during 2006.

4. Controlled burning in winter to reduce fuel load in subsequent summers. It has been shown that managed heather moorlands are less prone to wildfire outbreaks and are a lower risk vegetation type (McMorrow *et al.*, 2005). Burning to reduce the fuel load is therefore an effective management solution, widely used in the USA and Europe (e.g. Xanthopoulos, 2004). However, controlled burning is restricted to certain vegetation types. Controlled burning is also dangerous and managed burns may get out of control more frequently as climate change brings hotter and drier weather.

5. Fire breaks are seldom if ever practical. Fire breaks can be natural, man-made or both, and can be created by for example, ploughing or burning vegetation. A road can also provide a fire break. It is suggested that fire breaks should be 6m to 10m wide and at least 2.5 times the flame height to be effective in all conditions (Murgatroyd, 2002). However, interviewees noted that fire breaks had not been successful in the past, and fires have leapt across roads on many occasions. Natural breaks, such as rocks, cliff edges or dry stone walls can be more effective and a useful aid in tackling a fire.

6. Preventive wetting of dry vegetation. Experience in the Peak District suggests this option is not effective, since once the ground is dry, it takes a lot of water to re-wet. Vegetation near to a fire also dries again very quickly – typically within 15 minutes - due to the intense heat. Peat is particularly difficult to moisten as it does not absorb water very well, and requires water to be pumped inside it.

7. Grip blocking to maintain water levels in fire-prone peat. Saturated peat is less likely to burn. Small pools of water formed by grip blocking may be used for local fire fighting, though they tend to be silty and are likely to clog pumps.

Fire watching

Afternoon fire watches can prove very cost effective at high risk times of the year. A fire watcher located on the moors can spot and accurately report the location of fires to help rapid deployment of fire fighting resources, and tackle small fires on the spot. In economic terms, fire watching is cost effective because it reduces the resources needed to fight a fire when it does break out through earlier intervention.

The PDNP established a volunteer fire watch, funded in 2006 largely by Moors for the Future. It could be said this was highly successful as 2 fires were reported in 2006 by the fire watch. We make the rough and ready assumption that these fires were reduced from severe to minor as a result of early detection and precise location. Assuming the incidents were then tackled in one evening rather than across two days, the potential saving to the fire brigades may have been of the order of, say, £25,000 per incident quite apart from the avoidance of ecological damage. This costing is based on £10,000 say for a two appliance one day turn-out instead of £35,000 for a two day eight appliance turn-out. This implies fire watching saved society £50,000 of fire fighting resources in 2006.

-

Compared with the benefits, the costs of fire watching were relatively modest. The initial equipment provision, including shelters, binoculars and maps, cost around £6500. This equipment will last a number of years, and therefore, cost of volunteers will be the main cost in the future. Fire watchers are all volunteers trained in navigation, first aid, hill sense, approaching people, and other training related to the National Park. Fire fighting is included in the training, but only the awareness of dangers. Volunteer fire watchers are positioned in 11 locations which have between 180°- 360° vision, mostly at previous fire sites. Fire watch towers are not needed, since these locations are chosen for having a clear outlook. The fire watchers deployment is based on the Fire Severity Index level issued by the Met Office. When the index reaches 4 (serious risk) they are sent out (MOFSI, 2006) on the moors. The fire watch is only operational Monday to Friday, as part-time rangers patrol the moors at weekends. In 2006, the fire watch patrolled on 30 occasions over a 2-week period. The total cost for this was around £600. In truth, fire watching has multiple objectives as the watchers also provide information to the public.

It is difficult to predict far in advance when the fire watch may be needed. So staff availability for the fire watch is a problem since volunteers are needed during the warm summer period when staff may be on holiday. This has meant that all 11 fire watchers were not available on each occasion.

In practice, there is also an informal fire watch kept on the Moors by planes and helicopters transiting the area. There is no systematic evidence on fires reported to Air Traffic Control, but anecdotal evidence is compelling.

Technical Alternatives for Fighting Fires

All fires are different, but it is useful to capture the broad techniques used to fight fires when they do break out.

Static fire-fighting resources

Specific requirements are needed for fire fighting. Clean water is needed for the fire fighting equipment. Ideally, water should come from steep-sided ponds clear from obstruction and that are not silted up. Therefore, naturally occurring ponds appropriate for nature conservation are not ideal for use as water sources for fire fighting. Precautions need to be taken if extracting water from permanent ponds as many are on SSSI land and need to be compliant with English Nature requirements. There is also a problem with “permanent” ponds of ensuring a permanent water supply, as water is most likely to be needed in the spring/summer when ponds are most likely to dry up. This occurs frequently with the pond on Snake summit, which is in a useful location for fire fighting, but is often dry over the summer. However, the Snake summit pond can be topped up from a stream further along the road by a water tanker shuttle service (we return to this below).

Temporary ponds are a more reliable source of water. These are made of rubberised canvas. They have open-tops, and are a variety of sizes. Smaller open-top portable dams holding 3,000 litres cost around £600, and can be easily loaded onto soft-track vehicles for positioning. It is more effective to set up portable dams at a fire site when needed, rather than leave them in high fire risk locations on the moors, so that resources are not tied up. However, equipment is left at a fire site for a few days if it is still in a high state of alert.

The National Trust purchased a large temporary pond for fire fighting with members’ donations in 2006, The pond cost around £5,000 and is able to hold 54,000 litres of water. This temporary pond is stored in a lift bag so that it can be quickly taken to site. This large pond weighs around 100kg, including a safety impact mat to stop the pond material from piercing. The pond is filled by pumping water from nearby streams. It takes about an hour to erect the structure and, depending on the flow of water, takes about 40-45 minutes to fill. It takes time to drain the pond and move it again after use.

The main problem with these temporary ponds is vandalism. Signs can be used to inform the public about the purpose of the pond and discourage vandalism. If temporary ponds are set-up for just 3-4 weeks at a high risk time, vandalism is not usually a problem.

Mobile vehicles

All-terrain vehicles (ATV) are useful for carrying crew and equipment to remote fire locations far into the moor. Fire engines often cannot get close to a fire site. Conventional tenders are often no more than transport to reach a rendezvous point. ATV’s significantly reduce walking time for fire crews (by 40 minutes in the case of the Bleaklow fire). Additionally, ATV’s are useful for carrying heavy equipment, when helicopters are not always available. In some cases, landowners will not pay for helicopters to ferry equipment. These ATVs cost up to £30,000 each. Training in their use is provided free by Derbyshire Fire

-

Service. Within the FOG resources, ATVs are owned by Derbyshire Fire Service, Greater Manchester Fire Service, Peak District National Park, United Utilities and the National Trust.

One example of an all-terrain vehicle is the Pinzgauer L6P – light 6-wheel drive pump. This is classed as a military vehicle. GMC bought this specifically for moorland fires. It contains a small water tank, fogging system, and can carry 2 crew in the front and 6 in the back. This is a self contained unit based at Bolton North. Other vehicles regularly used for fire fighting around the Peak District include trailers and soft traks which are loaded with fire kits such as pumps, tanks, canvas buckets, hoses and foggers. The PDNP have 5 trailers which cost around £100,000, purchased with Government support following the introduction of the Countryside and Rights of Way Act.

Helicopters on standby for firefighting

Helicopters are valuable for investigating initial smoke reports and, if a fire is sighted, to assess the fire site. This is much quicker than walking to a remote site since it can often take up to 2 hours to walk to a fire. Fire officers can also be flown to the site of a fire for a rapid initial assessment.

Pennine Helicopters take around 15 minutes to respond to a fire call in the Peak District and to get to the fire site, depending on the location. Bleaklow Moor and Black Moor are close to their base and may only take 5 minutes to reach.

The need for helicopter support depends on a number of factors, including the vegetation type, time of the year, location, conditions, and the presence of any natural boundaries. Most fires can be dealt with typically within a couple of hours, especially if the helicopter is called out as soon as a fire is reported. A longer stay may be required to support ground operations, for example to carry equipment and ferry people.

An ideal water source is located between 1-5 minutes flight time away from the fire. However, if there is no local water source, a helicopter can still be used long with a longer turn-around, e.g. 5-15 minutes. The Peak District is amply supplied with reservoirs. Helicopters are able to use reservoirs if working with the Fire Service, and use water resources for free. The water authority may sometimes isolate a particular reservoir from the water supply if informed.

Ideal water sources for helicopter dipping buckets water are steep-sided ponds or reservoirs containing clean water on top of the Moors. Virtually the only natural pond is the roadside pond at the top of the Snake Pass where the Pennine Way crosses the A57 road (NGR SK 087 929) between Kinder and Bleaklow. This has the advantage of road access so that it can be readily topped up by a fire brigade shuttle from streams further down the A57.

The Pennines are well supplied with reservoirs as it is a major water catchment area. One central difficulty is that the reservoirs, by their nature, are typically in a river valley. Elevation matters. Helicopters do not climb well. They take time and power to gain height. So use of a reservoir for fire fighting is not the obvious solution it appears. There is a penalty in terms of a swift turn round or costs. The more easterly reservoirs in the Woodhead valley are skirted by electricity pylons which are an additional operational hazard.

Pennine Helicopters have two types of dipper buckets which can be hired to aid fire fighting:

- Bambi bucket - opens in the centre, providing an intense drop of water in one area. A Bambi bucket costs around £3,000.
- Kestral bucket – more control is possible with this bucket as it is able to control the flow of water. Regulating the flow of water out of the bucket is an important feature which helps to efficiently deploy water, especially with a slow turn around. A Kestral bucket also fragments water, converting the moisture to water vapour much faster. It is more expensive to deploy a Kestrel bucket because it is electro-magnetically controlled, and requires a compressed air supply to regulate the operation. A Kestral bucket costs around £9,000.

Using Pennine Helicopters as an example for costs, the minimum charge for call-out is £2,400. This covers 2 hours helicopter use and deployment of a ground crew. The fee is £850 per hour after this. If the fire operations continue into the next day, there is an initial set-up charge for the second day. The combination of low cost relative to alternatives and very rapid response make helicopter use an extremely cost effective solution, if it is available.

Contracts for a retainer or standby helicopter payments would, however, be unduly expensive. Also, a large number of crew would be needed, for example, 5 ground crew plus - taking duty hours into account - at least 5 pilots. For a true contract such as this, a reserve helicopter would also be required. The costs

-

involved in maintaining a genuine retained service mean that it is not a practical option. Discussion with stakeholders suggests a 'trust relationship' is better since a contract would be prohibitive and expensive.

So the essential feature of helicopters is that they are highly cost effective on a call-out basis if available, but expensive to deploy if guaranteed availability for fire fighting means this is their only use.

Technical Alternatives for Coping with the Consequences

Managing the consequences of a fire may be cheaper than tackling every incident as soon as it occurs. Restoration alternatives include reseeding and replanting vegetation. Fire-site restoration projects by Moors for the Future have been very successful in re-vegetating areas using nurse crops of heather and grass seeds to stabilise peat. Heather brash and geojute-textiles are applied to physically stabilise the peat and protect it against erosion.

However, post-fire restoration is not a simple option, as considerable resources are needed to restore and monitor restoration. For example, due to the remote locations of the fire sites, helicopters are often needed to deliver materials to site. It is also not a quick solution, as it will take up to 5 years for natural vegetation to establish.[1] In the meantime, fire scars are unsightly and eroding peat bearing heavy metals will be carried off along streams into water catchments.

Restoration costs vary substantially. Some areas regenerate naturally if left to themselves. According to United Utilities, severely damaged areas, such as eroded peat may require full treatment up to £10,000 per hectare, equivalent to £2.6 million a square mile. Seen in this light, fire fighting may be the more socially cost effective outcome.

[1] http://www.moorsforthefuture.org.uk/mftf/restoration/firesite.htm

5. Cost, Reliability and Effectiveness

Costing the alternatives

It is difficult to cost a fire incident: In principle, we need to know the additional cost imposed on the emergency services by the need to deploy, use and retrieve extra equipment from incidents. Typically, these extra costs include overtime for fire fighters and officers, transport to and from an incident, extra fuel for vehicles and pumps, extra food and beverages for crews, extra wear and tear and depreciation on appliances and the considerable resources required to clear-up after an incident.

These costs are not straightforward as equipment may be damaged during deployment or require extra maintenance following prolonged use. There are indirect costs of re-positioning back-up crews to provide station cover while local crews are deployed on a moorland fire incident. Specialised equipment such as water tankers and all-terrain vehicles may be needed for this type of fire. Police may have to attend, for instance to supervise traffic on adjacent roads. Fires often flare up again with additional call-outs which are logged as separate incidents. The opportunity cost of these fires is time the fire service would otherwise have spent on scheduled inspections, training, meetings and education activities which have to be postponed.

We have not discovered any systematic evidence on costs of deployment for moorland fires. We therefore analyse a sample of recent incidents (table 1). These have been costed on the basis of £1,000 per appliance per hour, which includes the cost of 4 firefighters (average number attending per appliance). Given this figure, recent incidents have ranged from £8,500 for a small fire close to an urban area at Stalybridge to a broad estimate of £132,000 for a fire in a remote location on Bleaklow Moor. These costs could be refined with further research, but the broad order of magnitude seems unlikely to change. One informed source suggests a resource cost nearer to £2,000 an hour should be used. An estimate of £1 million for a recent prolonged moorland fire outside the Peak District boundary also seems reasonable.

Seen in this light, helicopter call-out is a very cost effective solution – especially if rapid dousing from airborne buckets can prevent a fire developing into a major incident requiring substantial deployment of ground based resources. Early use of a helicopter does not mean a ground based response is not required. Personnel may be required to supervise the fire site, beat out peripheral fires, dig out any residual burning peat and make sure the fire does not flare-up again. But use of a helicopter can convert a major incident into a minor one, or stop a fire from developing into a major incident. For example, early deployment of a helicopter might well have saved £100,000 at well-managed incident such as the Roaches in Staffordshire. (A helicopter was not available at the time due to maintenance.)

This is not to say that helicopters should be relied upon exclusively because of the issue of availability. Rather, planning for wild fires should anticipate using a combination of resources for the most cost effective solution.

Reliability of Different Approaches

Reliability has a range of different dimensions:

1) *Call out reliability.*
Conventional ground based fire brigades may be reluctant to move over remote moors during darkness, unable to reach remote locations with suitable equipment, or may be committed elsewhere. By and large, conventional fire services seem to be highly reliable during daylight hours. Daylight operation is less of a constraint than it seems since fires damp-down and only spread slowly at night. Moorland fire fighting operations often commence in the late afternoon of one day, stand down at dusk and recommence at first light the next day.

   Helicopters may not be available due to other commitments, outages for regular maintenance, the problems of night time operation, difficult flying conditions such as fog, the need for positioning flights from distant airfields, the availability of specialised equipment such as buckets or convenient local water supplies. For example, a helicopter was not available for the fire at the Roaches starting on 25th July 2006 due to periodic maintenance. Notice too that fires cluster in time. There is often an issue of which fire should command the use of scarce helicopter resources when fires are burning simultaneously. One helicopter can only attend one fire at a time.

-

2) *Access*
Helicopters have clear access advantages being able to move swiftly to the most remote locations, subject only to constraints of weather and visibility. Conventional fire crews may face a long trek with equipment, unless supported by all-terrain vehicles. However, helicopter access is constrained by dense smoke and fog. Helicopter operations were restricted by fog on the second day of the Bleaklow fire, 20th July 2006. Helicopter operation may also make things worse if the downdraft from the rotor blades disturbs ash and spreads burning embers on to un-burnt areas or re-ignites a doused area.

3) Water availability
Both conventional fire crews and helicopters face problems of water supply. This is a real constraint, especially as natural ponds such as the small pond at the top of Snake Pass (NGR 087929) tend to dry in drought conditions when needed most. There are some reservoirs at high elevations (e.g. Chew Reservoir, or Black Moss reservoir on Saddleworth.) There is a case here for introducing hydrants or rising mains as an alternative to temporary, air portable ponds at high risk times and locations. Another, less visually attractive and therefore contentious alternative would be to dam local stream valleys, such as Wildboarclough at the northern edge of Bleaklow or the top end of the River Alport on Alport Moor.

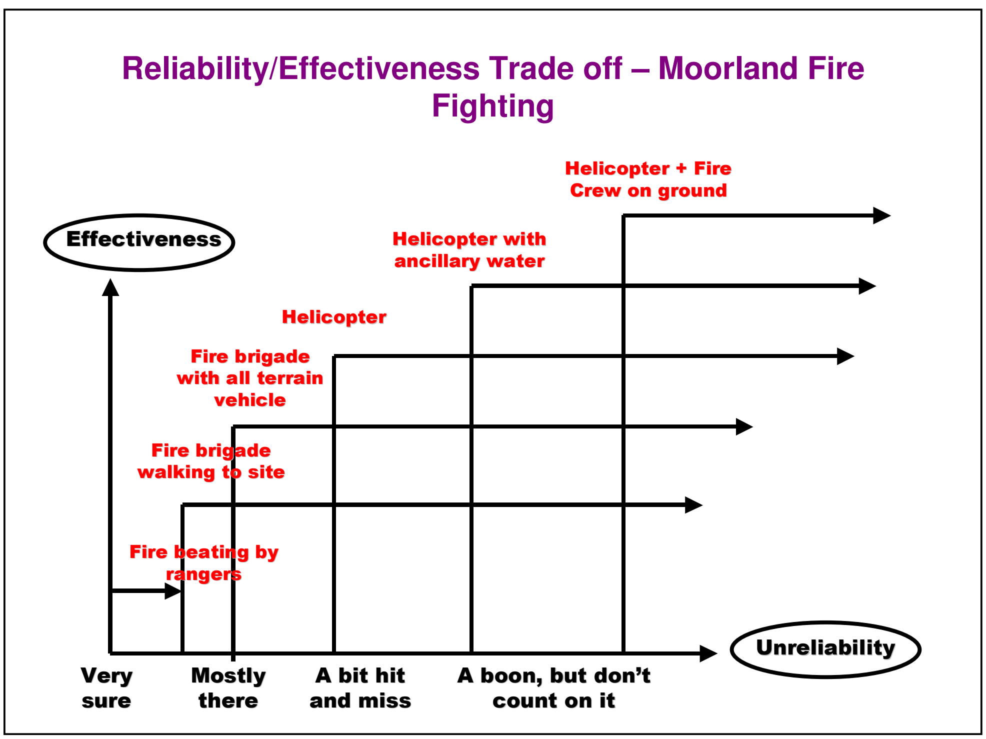
4) Staying on station
Fire fighters require considerable support while deployed in terms of drinking water, food and drink and toilet facilities but they can typically stay on station all day if they are provisioned.

Effectiveness of Different Approaches

Our narrow concern here is:
- how effective are the alternative approaches in terms of reduced time to first fighting fires?

and,
- reducing the chance of a fire running out of control by reaching an incident sooner ?

Figure 4: The trade-off between reliability and effectiveness fighting Moorland Fires



The diagram (figure 4) summarises the effectiveness-reliability trade-off. Essentially, fire watchers or rangers on the spot at a small fire are a very swift, efficient and cheap solution to tackling small fires in the early afternoon before they get out of hand and spread. Evidently, fire watching – "being there" – is a very reliable solution.

The difficulty with tackling a fire at first hand is that it may already be out of control in terms of portable fire beating equipment. So the next most reliable solution is to call out the fire brigade who are nearly always available on emergency stand-by. As we have seen, this is not a very cost effective option from society's point of view. There is also a problem of access to remote locations. By the time fire fighters reach a fire in the early evening there may be little daylight left to allow them to tackle the fire before returning to their appliances. So rangers in charge of fire watching should, preferably seek help from a helicopter first to establish whether it is available. However, helicopter availability is a bit "hit-and-miss".

The base case for fighting a larger fire is for conventional tenders and fire crews to turn out to the nearest roadside and walk off across the moor to tackle the blaze. But here we can begin to establish the benefits of investing in an all-terrain vehicle (ATV). If an investment of £30,000 in an ATV can save a minor incident from turning into a major incident on just one or two occasions, it will have paid for itself. If an ATV can deploy a crew and specialized equipment to a fire in, say, an hour instead of two hours it may readily reduce the potential costs of the incident from, say, two days costing £50,000 to, say, one turn-out costing £10,000. Because of the imperative of rapid deployment during the early stages of a fire, specialized equipment may well recover its costs in just one outing. In the same fashion, we can compare the "extra" or "marginal" cost of any additional equipment with the cost saved in terms of fire fighting. This analysis applies to portable ponds, hydrants, stand pipes, and – as we have seen - fire watching or other potentially cost-effective measures which enhance the speed/effectiveness of response.

Evidently, then the optimum solution needs to take account of the effectiveness-reliability-cost trade off. Notice in table 1 the huge amount of resources required to fight just one small fire the size of two football pitches in a less accessible location over a two day period. It follows that small scale, local measures that can avoid these types of major outlay and enhance the effectiveness and reliability of a rapid response are likely to show high returns on investment – even if very seldom used.

We have confined our analysis to the potential savings realized by rapid, reliable and low cost response to fires. These savings have been highlighted as the avoidance of major fire fighting operations. These figures of cost savings to the fire brigades ignore other costs associated with wild fires. These additional "social" costs include transport disruption, additional costs of land remediation, loss of income from land due to fire damage, and additional costs of water treatment due to particulate and heavy metal run off in catchment areas.

-

6. Summary, Conclusion and Recommendation

Climate change is likely to bring more frequent wildfires. Fires are costly to fight, damage the eco-system, harm water catchments, cause erosion scars and disrupt transport. Intense fires may cause peat to ignite. Peat is a huge carbon store. Reducing the risk of fires and early deployment of fire fighting resources are key issues.

Fire risk varies markedly by time of year, time of week and time of day. Fire outbreaks are influenced by vegetation and moorland management, weather conditions and proximity to roads and footpaths. Wildfires are sporadic, often in remote locations and require specialised equipment.

This research identifies the best option in economic terms given the uncertainty surrounding outbreaks of wildfires. Opinions may differ over the objectives of policy towards moorland wildfires. "Zero tolerance" is expensive, though it is efficient to catch fires early. In practice there is some optimum level of fires. A distinction needs to be drawn between normal risk and the remote chance of catastrophe, which may require special plans.

Fires have "careers" and it is far more cost-effective to catch them early before they have spread laterally. We recommend a combination of policy measures to mitigate the risk of moorland wild fires, determined by a trade-off between the costs, reliability and effectiveness of each solution. The level of investment will depend upon behaviour towards risk. Some organisations such as the National Trust and United Utilities have invested in their own specialised equipment to protect their moorland. The mix of resources deployed will vary with location and time of year.

The cost of fighting a fire by conventional means is considerable. Recent fires have cost between £8,500 and £132,000 to control in terms of ground based resources alone. Estimates of £1 million are quoted for fires that run out of control and take weeks to extinguish. Dousing from a helicopter is an extremely cost effective solution, but is less reliable due to factors such as weather and machine availability. Resources that can support a rapid, reliable and effective response to a wild fire - such as fire watching, access vehicles and emergency ponds - may show a very high return on investment in terms of fire brigade resources saved, *even if the dedicated personnel and equipment are seldom used.*

The report recommends a combination of fire fighting resources, with more emphasis on helicopter use, rapid deployment to remoter locations and risk planning. Attention should be paid to planning for catastrophe as well as regular fire events. The remote possibility of extreme fire events should receive more attention in view of likely climate trends and the impact of hotter, drier summers in particular.

-

7. Further Research Questions

1) There is a need to improve understanding of the severity of fires. Although the timing and location of fires is recorded, little is known about what determines their size and severity. There is limited data in Peak District Fire Records on *area* burnt, but this tells us nothing about *depth* of burn on peat. Area burnt is one proxy for severity of a fire. This data may be sufficient to carry out a Tobit analysis which models both the chance of a fire breaking out and the severity of a fire when it does occur. Results would allow a prediction of the level of resources required to tackle an incident, in addition to its likely timing. The data would be all the more valuable if it were tied in to specific Fire Service incident numbers so that evidence on resources deployed could be correlated with the nature and size of the fire in a systematic way.

2) Using comprehensive evidence on fires from another country, it may be possible to establish whether wildfires display "mild" or "wild" randomness. Observations need to be based on a very long time frame to capture infrequent, but important, extreme events. This arcane debate on the remote probability of an extreme fire year has implications for disaster planning in the face of climate change.

3) There is relatively little *explicit* knowledge about the reliability and effectiveness of alternative fire fighting techniques for handling wildfires. At the moment there is considerable *tacit* knowledge on the reliability and effectiveness of alternative fire fighting techniques among fire personnel, game keepers, wardens and helicopter pilots. The Fire Operations Group for the Peak District has been remarkably successful in sharing and enhancing this tacit knowledge since its inception in 1996. The Greater Manchester Fire and Rescue Service (2006) *Operational Guidance and Policy Document "Moorland, Mossland and Afforestation Firefighting"* is a manual of fire fighting practice for moorland wildfires that would be valuable for the rest of Britain. This knowledge could be systematically extended through interviews with experienced fire fighters from other areas, an analysis of Incident Reports, and by capturing the knowledge of land agents and gamekeepers.

4) There is a need to understand the "careers" of wildfires: how and when they start (as opposed to when they are reported), how they develop by day and by night, how they die down or are extinguished. This is a key issue as we need to understand how early intervention might prevent severe problems developing later. We could also gain an appreciation of fire management choices, such as the case for leaving fires at nightfall, versus maintaining a night time presence. Observation and instrumentation of controlled fires may help establish the likely career of wild fires.

5) There is little information of the cost of alternative fire fighting strategies, either the costs borne by fire authorities or the wider social and environmental costs. There is evidence on costs from a small sample of respondents, but we do not have systematic evidence on resources deployed at a large number of fires in terms of personnel, officers, equipment and fuel. There is a need to tie-in Peak District fire records with Fire Brigade reports so that resources devoted to tackling each fire can be established. There are also wider social costs associated with fires including transport disruption, additional costs of land remediation, loss of income from land due to fire damage or extra costs of water treatment due to particulate and heavy metal run off in catchment areas.

8. References

D. Boys and S. Trotter, *Increasing water supplies for fighting moorland fires in the Peak District*, Conference Proceedings – 10th February 2005, Moors for the Future Report No. 6, October 2005.

John Dold, Anna Zinoviev and Rodney Weber, "Nonlocal flow effects in bushfire spread rates", in *V International Conference on Forest Fire Research*, D.X. Viegas (ed.), 2006 available at: http://www.maths.manchester.ac.uk/~jwd/bushfire/Dold_06_NFEiBSR.pdf last downloaded 26 Jan 2007.

Greater Manchester Fire and Rescue Service, *Operational Guidance and Policy Document "Moorland, Mossland and Afforestation Firefighting",* Manchester: GMFRS, October 2006

Richard W. Katz, Grace S. Brush and Marc B. Parlange, "Statistics of extremes: modelling ecological disturbances", *Ecology*, vol.86, no.5, 2005, pp.1124-1134

D. McEvoy, J.F. Handley, G. Cavan, J. Aylen, S. Lindley, J. McMorrow and S. Glynn, *Climate Change and the Visitor Economy: the Challenges and Opportunities for England's Northwest*, Manchester: Sustainability Northwest and Oxford: UK Climate Impacts Programme, 2006

Julia McMorrow, Jonathan Aylen, Kevin Albertson, Gina Cavan, Sarah Lindley, John Handley and Richard Karooni, *Climate Change and the Visitor Economy, Technical Report 3: Moorland wild fires in the Peak District National Park*, Manchester: Centre for Urban and Regional Ecology, January 2006.

Julia McMorrow and Sarah Lindley, *Modelling the Spatial Risk of Moorland Wildfire*, Final report, Moors for the Future small grant, Geoinformatics Research Group, Geography, School of Environment and Development, the University of Manchester, December 2006

J. Mayes "Spatial and temporal fluctuations of monthly rainfall in the British Isles and variations in the mid-latitude westerly circulation", *International Journal of Climatology*, vol. 16, no.5, 1966, pp.585-596

Meteorological Office Fire Severity Index (MOFSI), last accessed 1st January 2006:
http://www.openaccess.gov.uk/lwwcm/resources/file/ebc7ac43784c72a/Index_Report_final_version3.0.doc

Max A. Moritz, "Analyzing extreme disturbance events: fire in Los Padres National Forest", *Ecological Applications*, vol.7, no.4, November 1997, pp.1252-1262

R. Murgatroyd, *Forest and Moorland Fire Suppression*, Forestry Commission Technical Note, September 2002.

T.J. Osborn, M. Hulme, P.D. Jones and T.A. Basnett, "Observed trends in the daily intensity of United Kingdom precipitation", *International Journal of Climatology*, vol.20, 2000, pp.347-364

T.J. Osborn and M. Hulme, "Evidence for trends in heavy rainfall events over the UK", *Philosophical Transactions: Mathematical, Physical and Engineering Sciences*, vol.360, no.1796, 2002, pp.1313-1325

G. Xanthopoulos, V. Varela, P. Fernandes, L. Ribeiro and F. Guarnieri, *EuroFireLab, Deliverable D-06-02, Decisions support systems and tools: a state of the art*, February 2004, EVR1-CT-2002-40028, at http://eufirelab.org

9. Acknowledgements

We are grateful to those who have generously responded to our requests for advice. They include:
Peter Arnfield, Derbyshire Fire Service
Dan Boys, Moors for the Future, Castleton
Professor John Dold, School of Mathematics, University of Manchester
Garry Goodwin, Staffordshire Fire and Rescue Service, Leek
Ian Hurst, Peak District National Park Authority, Bakewell
John Logsdon, Quantex Research, Manchester
Chris Ruddy, Pennine Helicopters, Saddleworth
Andy Shaw, National Trust, Edale
United Utilities, Warrington
Steve Yearsley, Greater Manchester Fire and Rescue Service

-

Table 1 Information from Fire Services' Incident Summary Reports for a Sample of Moorland Fires

Date	Location	Time to attendance	Helicopter response	Vegetation	Area burnt	Duration	Incident start	Incident end	Equipment	Total hours[2]	Cost[3]
13/09/03	Blackshaw Moor SK007591	15 mins	N/A	2 heather fires 30m2 and 100x50m	Small fire	2 days	21:05	00:28 14/09	20 ltrs foam compound, 4 main jets used		
15/04/04	Quarnford SK021365	7 mins	N/A	Grassland	150x100 metres	1 day	15:46	18:34			
04/06/06	Owler Bar SK293780	14 mins	N/A			1 day	13:55	21:25	4 appliances, 16 crew, 1 officer	15 hours	£15K
19/07/06	Bleaklow Moor SK124974	30 mins	18 minutes Day 2- Unable to fly due to fog Day 3 -in use at 13.34	Heather and peat	½ $mile^2$ Day 2 - 2sq miles, reducing to 1sq mile by 19:47	3 days	14:29	12:58	Helicopter- requested by UU, water bombing, beaters; 20 appliances, 80 crew & 6 officers	132 hours	£132K
23/07/06	Stalybridge	1 hour	N/A			3 days	15:21	19:22	2 appliances, 4 crew	8 ½ hours	£8.5K
25/07/06	The Roaches	11 mins	Helicopter out of commission, water relay system set up instead			3 days	19:19	12:42 27/06	140 firefighters, 3 officers, 30 fire appliances, 10 land rovers, 2 ATVs, 2 trailers		
26/07/06	Stalybridge		N/A	Heather and grassland		2 days	08:46	18:32 27/06	4 appliances, 10 crew & 1 officer		
30/07/06	Crowden SE063079	20 mins	N/A	Heather		2 days	15:49	17:06 31/07	8 appliances, 36 crew, 1 officer	37 ½ hours	£37.5K

[2] Calculated by adding together the attendance times of all appliances. Appliance counted each time it attended.
[3] Cost is based on the number of appliances only (i.e. using an appliance for 1 hour, including an average of 4 crew members costs £1000). Therefore it does not include additional costs of officers, or the cost of additional resource movements such as appliances on standby at other stations to cover those out on call. One interviewee also noted hidden costs of cancelled meetings and appointments.

-