MCEER
EARTHQUAKE ENGINEERING TO EXTREME EVENTS

A Summary of MCEER Reconnaissance Efforts

MCEER RESPONSE

Collection and Preliminary Analysis of Aerial and In-Field Building Damage Information in the Aftermath of the 2007 California Wildfires

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ImageCat Inc.

This field campaign, undertaken in the aftermath of the 2007 California Wildfires, was funded by the National Science Foundation through the SGER program and MCEER's Remote Sensing Institute (http://mceer.buffalo.edu/research/remote_sensing/default.asp). It presented the research team with a unique opportunity to collect perishable damage data on neighborhood and per-building levels, focusing on affected urban environments throughout Southern California. The type of surveying undertaken is particularly useful for post-disaster damage assessment and also creates a compelling baseline dataset for examining change and recovery in the future. Further, the data collected is useful for re-insurance loss estimation, as well as research on engineering and planning more resilient communities.

The 2007 U.S. wildfire season was noted as unusually strong and extensive by many indicators. By the end of the season, more than 85,500 fires across the country had burned over 9.3 million acres of land. In Southern California alone, from October 21-24, 23 separate fires consumed close to 520,000 acres of land, destroying around 3,000 structures (RMS, 2008). More than half a million people were evacuated throughout the region. The weather in the months preceding the fires was persistently hot and dry, leading to a large amount of ready fuel. Indeed the temperature in the region at the time of the fires was high, measuring between 92ºF and 97ºF inland (33ºC and 36ºC) with relative humidity levels between 10% and 15%. This coupled with unusually strong (hurricane force) Santa Ana winds created prolonged firestorm events, which swept into both historically high and low vulnerability areas. Many possible causes for the fires have been stated, from accidental and deliberate fire-starting, to power lines damaged by the high winds. During the whole fire season, an estimated $1.8 billion was spent on fighting wildfires and $2.5 billion in insured losses were recorded (RMS 2008).

The fire season raised many questions, not least about the mitigation strategies needed to minimize the vulnerability of established communities (including retrofitting of older properties), as well as creating discourse on creating new resilient communities, for instance the 'Shelter in Place' communities found in San Diego. Two of the main foci for discussion included the strictness of building regulations, and the trend of house building on Wildland Urban Interfaces (WUI). The fires are a recurrent phenomenon, and lessons are still being learned as to the best practices for urban planning, the strictness of building regulations, fire management techniques and the importance of good ecological management.

ImageCat responded to these events by deploying a number of aerial and ground-based surveys of the damage, using the VIEWS™ field data collection and visualization system. VIEWS™ was previously used in reconnaissance activities following the 2003 Bam, Iran earthquake (Adams et al., 2004a), Hurricane Charley and Hurricane Katrina (Adams et al., 2004b, Womble et al., 2006), the Niigata, Japan earthquake in October 2004 (Huyck et al., 2006), the Asian Tsunami of 2004 (Ghosh et al., 2005) and the 2008 tornado outbreak in Tennessee (McMillan et al., 2008). This event is the first wildfire where the VIEWS™ system has been utilized, collecting detailed *aerial* and *ground* survey data to identify and map the damage across a wide-ranging area.

Some of the terrain around the wildfires was noted by firefighters as high to extreme difficulty for access, due to the amount of vegetation and the steepness of the slopes. Therefore, for recording building and environmental damage, aerial reconnaissance is a very useful tool to collect accurate and spatially continuous data. Demonstrating the flexibility of VIEWS™ for multi-platform damage detection and to acquire detailed structural information, ground-truth data was also collected with a high-definition video camera deployed from a moving vehicle. The ground based deployment shows the type of buildings populating certain areas, the vegetation surrounding structures, the building materials that survived, and other aspects of hazard and vulnerability in much greater detail.

In terms of timeliness, to gain an accurate record of the event and assess the level of damage before recovery starts to occur, it is essential to collect perishable information *rapidly*. Through funding from MCEER, these deployments occured within 1 month of the fires. Through NSF SGER funding and subsequent research grants, the data collected will form part of a larger research thrust into the use of advanced technologies to support wildfire mitigation, planning and strategy.

Aims and Objectives

The data collection and preliminary research activities documented in this report aim:

To benchmark firestorm damage from the 2007 California wildfires, and to provisionally analyze the relationship between hazard and vulnerability factors and burn occurrence.

From this aim, three objectives for the post-wildfire reconnaissance mission were identified:

- Collect perishable wildfire damage information
- Explore new VIEWS™ system functionalities in the wildfire context
- Characterize wildfire damage using aerial imagery

In addition to this, three further objectives were identified for a preliminary analysis of the collected data. These serve to establish key directions for future research activities:

- Compare and contrast the characteristics of different fires within the 2007 California fire season
- Compare observed damage with Fire Hazard Severity Zone (FHSZ) maps
- Examine neighborhood-scale hazard and vulnerability factors that may have contributed to the variable areas of burn.

Data Collection

The goal of the field deployments in California was to collect perishable information regarding the damage characteristics of buildings and infrastructure, and the environment surrounding the damage areas. Two deployments were undertaken:

- Aerial reconnaissance of the area
- Ground survey team deployed in particularly hard hit areas of the fires

VIEWS™ Data Collection

To capture damage characteristics in the aftermath of a natural disaster, especially when considering *perishable* building damage, a quick response from scientists and engineers is required. The VIEWS™ system was used to address this need for quick and accurate data collection. VIEWS™ is a notebook-based system, which integrates GPS-registered digital video footage, digital photographs and observations with high-resolution satellite or aerial imagery collected before and after a disaster. Figure 1 shows the VIEWS™ system being deployed in the field. This is the first instance of using the VIEWS™ system and high-resolution satellite imagery for wildfire field reconnaissance. As such, it offered the survey team a unique opportunity to investigate the use of remote sensing for wildfire-related urban damage assessment. It also enabled the survey team to expand the multi-hazard data collection capabilities of the VIEWS™ system from earthquakes, hurricanes and tsunamis to wildfire.

The VIEWS™ system was adopted to streamline wildfire field data collection, and collect a perma-

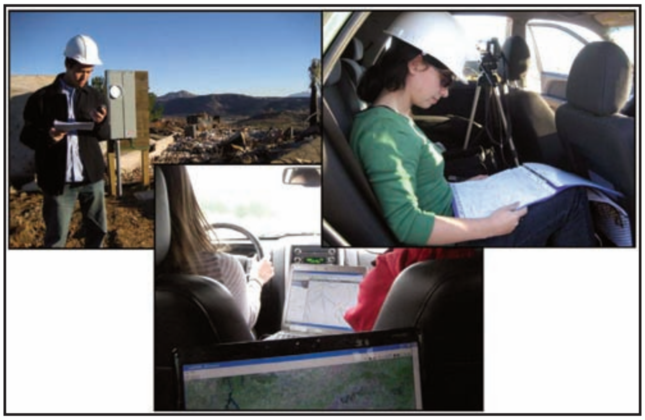

Figure 1. Deployment of the VIEWS™ system.

nent visual record of damage sustained on a per-building basis. It may be deployed from either aerial, moving vehicle or on foot perspectives, depending on access, in-field conditions, and the geographic scale of analysis. For the wildfires, VIEWS™ recorded the structural damage sustained by properties, and in interesting cases included more in-depth footage of building materials than has previously been recorded using this system. It focused on residential structures that were burned, but also included some industrial facilities. Two other important features captured included (1) the general surrounding environment - for instance, the type and density of vegetation cover affects the spread of wildfire; and (2) seemingly undamaged structures, to give a comparison and idea of the type of structures which typified the communities examined. It is envisioned that such perishable data on damage severity and extent could, in the case of future catastrophic events, be used by key decision makers, emergency response personnel, and researchers for planning response and wildfire mitigation policies.

Aerial Deployment

Extensive aerial deployment was conducted during October and November 2007. Aerial deployment was guided by the intersection of active fire areas (i.e., from MODIS active fire data) with maps of urban settlement, to focus the attention on habited areas. Initial reports of damage were also utilized. Table 1 shows initial reports on the size of the fires. The areas researched by aerial deployment generally fit with the most damaged areas according to this table. The main fires which were examined were the Witch (Creek), Poomacha, Rice and Harris fires in San Diego, the Grass Valley and Slide fires in San Bernardino, the Malibu Canyon fire in Los Angeles County, and the Santiago fire in Orange County. Figure 2 shows the geographical location of the fires examined by ImageCat aerial deployment.

Aerial reconnaissance proved to be the most effective means of capturing real-time *regional* damage information on these fires. Whereas satellite imagery is normally the preferred data sensor, the fact that many of the affected areas were obscured by dense smoke for days made it impossible for this imagery to be used to identify burned structures in a timely way. Aerial reconnaissance with GPS-based video technology was a more effective means of measuring the extent of damage caused by these fires. The data was interpreted and mapped to show areas of burn, and destroyed buildings were identified. This allowed a GIS and database of destroyed buildings to be created which was the basis of further analysis with multi-source datasets. Figure 3 shows an image from one area of deployment in San Diego, showing a partially destroyed neighborhood. These were mapped and combined with parcel data to show destroyed areas, as shown in Figure 4.

Table 1. Size and damage characteristics of the 2007 fires

Event	Size (acres)	Buildings Destroyed	Commercial Buildings Destroyed	Outbuildings Destroyed
Witch	197,990	1040	30	414
Harris	90,750	206		247
Poomacha	49,410	136		19
Slide	12,789	201		3
Grass Valley	1,247	174		2
Santiago	28,012	16		
Ranch	58,401	1		
Buckweed	38,356	21		
Malibu Canyon	4,565	6	2	
Magic	2,824			
Rice	9,000	206	2	40
Horno	21,084			
Nightsky	35			

Source: State Office of Emergency Services; county, state, federal fire agencies; county emergency officials

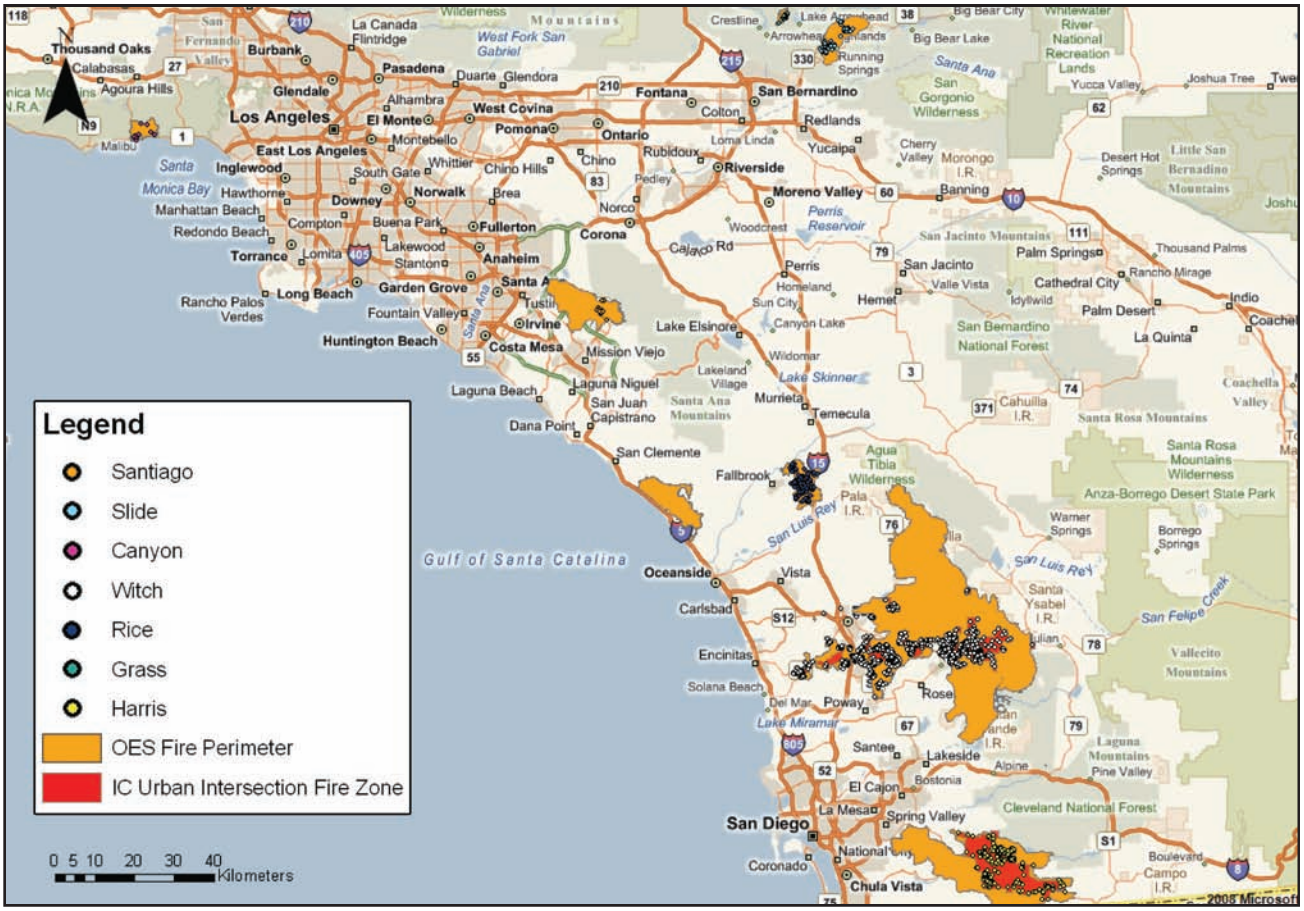

Figure 2. Locations of fires examined by ImageCat. Point symbols represent destroyed structures.

Figure 3. Example of aerial imagery, showing a partially destroyed neighborhood in San Diego.

Figure 4. A subset of the derived damage map, showing destroyed parcels.

The aerial imagery described here forms the basis of the preliminary Tier 2 analysis described in this report. In-depth Tier 3 research activities utilizing the ground-based VIEWS™ data described in the following section will be documented in a separate publication.

Ground Based Deployment

The ground based deployment was conducted from December 10-13, 2007. Study site selection for ground deployment was guided by a number of considerations. First, the six fires examined by aerial deployment were used as a first cut for study site selection, so as to link with this data.

Within these regions, the areas affected by the fires exhibited variability, both in terms of environment and building inventory. Another important factor to consider when selecting study sites is the broad type of vegetation and thus the burn characteristics. Table 2 shows the predominant type of vegetation found in the main fire events.

Table 2. Predominant types of vegetation encountered for various fires

Witch	Chaparral, grassland
Harris	Brush, grassland
Poomacha	Chaparral, grassland, brush, timber
Slide	Timber, grass understory, steep terrain
Grass Valley	Timber, grass understory, steep terrain
Santiago	Chaparral, grassland and brush
Ranch	Heavy chaparral and oak woodland
Rice	Chaparral, grassland and brush

Three main types of vegetation burn were identified; first the grass and chaparral fires of Witch, Harris, Poomacha, Santiago and Rice; second the timber and grass mix (on steep slopes) of the Slide and Grass Valley fires; and third the heavy chaparral and oak woodland of the Ranch fire. The Ranch fire did not result in many destroyed buildings, so this was not analyzed during this deployment.

Therefore, one field site example was chosen from a grass and chaparral environment and one from a timber and grass environment. The Witch Creek fire (encapsulating Rancho Bernardo, Poway and Ramona) in San Diego was recorded as the largest fire in terms of burned area, and the most destructive in terms of buildings destroyed, so this was chosen as the deployment region for grass and chaparral fires. Because of their close proximity, the Slide fire near Lake Arrowhead and the Grass Valley fire near Lake Gregory in San Bernardino were both used as timber and grass study sites. The final deployment schedule is shown in Table 3.

Table 3. Survey Schedule, showing the mode of deployment & characteristics of neighborhoods where video footage was collected

Date	Areas Covered	Mode of Deployment	Remarks
10.27.07	Witch (west side), Rice	Aerial	
10.28.07	Canyon, Buckweed	Aerial	
11.03.07	Witch (east side)	Aerial	
11.10.07	Harris fire	Aerial	
11.12.07	Santiago	Aerial	
11.20.07	Grass Valley	Aerial	
12.10.07	Slide fires	Walking, driving	Steep terrain, icy, surveyed on foot
12.11.07	Witch – Rancho Bernardo	Driving	Ranch type properties, driving tour
12.12.07	Witch – Rancho Bernardo	Driving	Ranch type properties, driving tour
12.13.07	Grass Valley	Driving	Steep terrain, however houses clearly visible from road

Witch Fire

General Observations

The approximate perimeter of the Witch fire is shown in Figure 5, as derived by the California Office of Emergency Services (OES). These perimeters marked the furthest extent of the burn; within this zone building damage was not seen to be consistently distributed when viewing the aerial photography. Therefore, ImageCat identified severely damaged areas within this wider boundary, which focused the analysis on the intersection of the burn with buildings.

The main source of fuel in the Witch fires was chaparral. This is a highly flammable mix of low, scrubby bushes and stunted trees. From visual inspection of the aerial VIEWS™ data, burn, and therefore

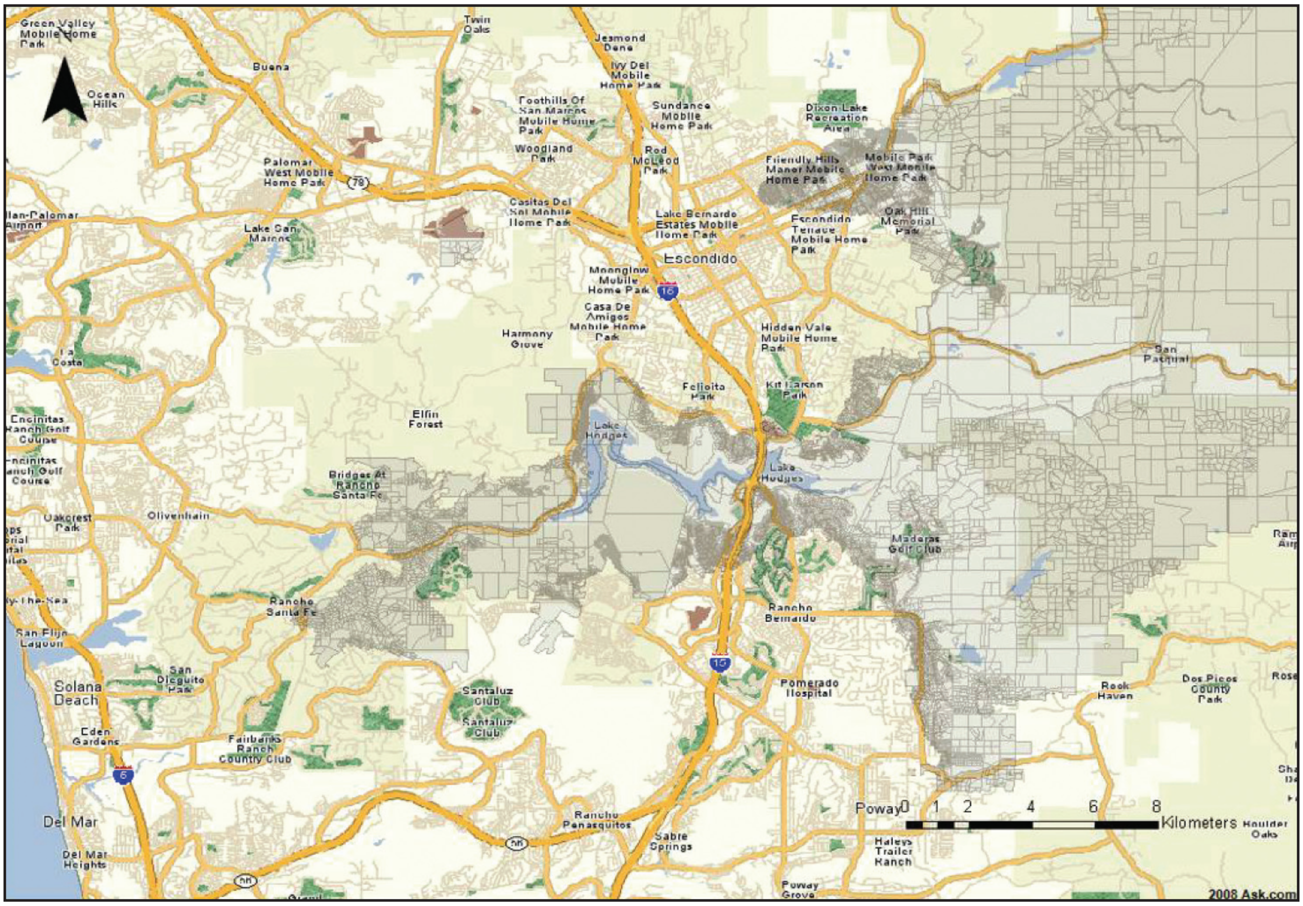

Figure 5. Witch Fire, showing approximate extent of the fire perimeter, cross referenced with parcel data.

damage in this area is very variable and patchy. For instance, Figure 6 shows the burned chaparral around one neighborhood. Buildings are seemingly destroyed at random. The factors determining whether a house in this type of environmental situation is subject to burn or not clearly depends on a number of factors, which may include: ember travel; the quality of house construction; vegetation clearance; and fire management techniques.

There are a couple of distinctive types of construction within the Witch fire area. The first type commonly encountered is shown in Figure 6, ranch type structures, where homes are separated by considerable distances, and are fairly large in size. The second type is the more densely populated areas of Rancho Bernardo, as shown in Figure 7. Again, a fairly random distribution of burned buildings was seen here.

The VIEWS™ footage in Figure 8 shows the difference that a well maintained clearance zone around a property can make. The irrigated lawns act as a barrier between the chaparral burn and the property

Figure 6. Chaparral burn in Poway, and the patchy nature of the damage to ranch style properties.

(i.e., the empty spaces of land are thought to be new construction areas, not destroyed parcels). A large part of fire protection activities involves vegetation clearance. Organizations such as Cal Fire disseminate regulations and information on vegetation clearance parameters around properties. For instance, the current defensible space clearance regulation is 100 feet around properties in California. A defensible

Figure 7. *The patchy nature of house destruction through Rancho Bernardo.*

Figure 8. *Good vegetation clearance practices helped to avoid house destruction.*

space perimeter around buildings and structures provides firefighters with a working environment that allows them to protect against encroaching wildfires, as well as minimize the chance that a structure on fire will spread to the surrounding wildland. More information can be found in Cal Fire (2008).

Damage Distribution – Witch Creek Fires

Once the VIEWS™ data was interpreted, maps of damage could be derived. Figure 9 shows the distribution of destroyed buildings for the Witch fire. The heaviest concentration of buildings was

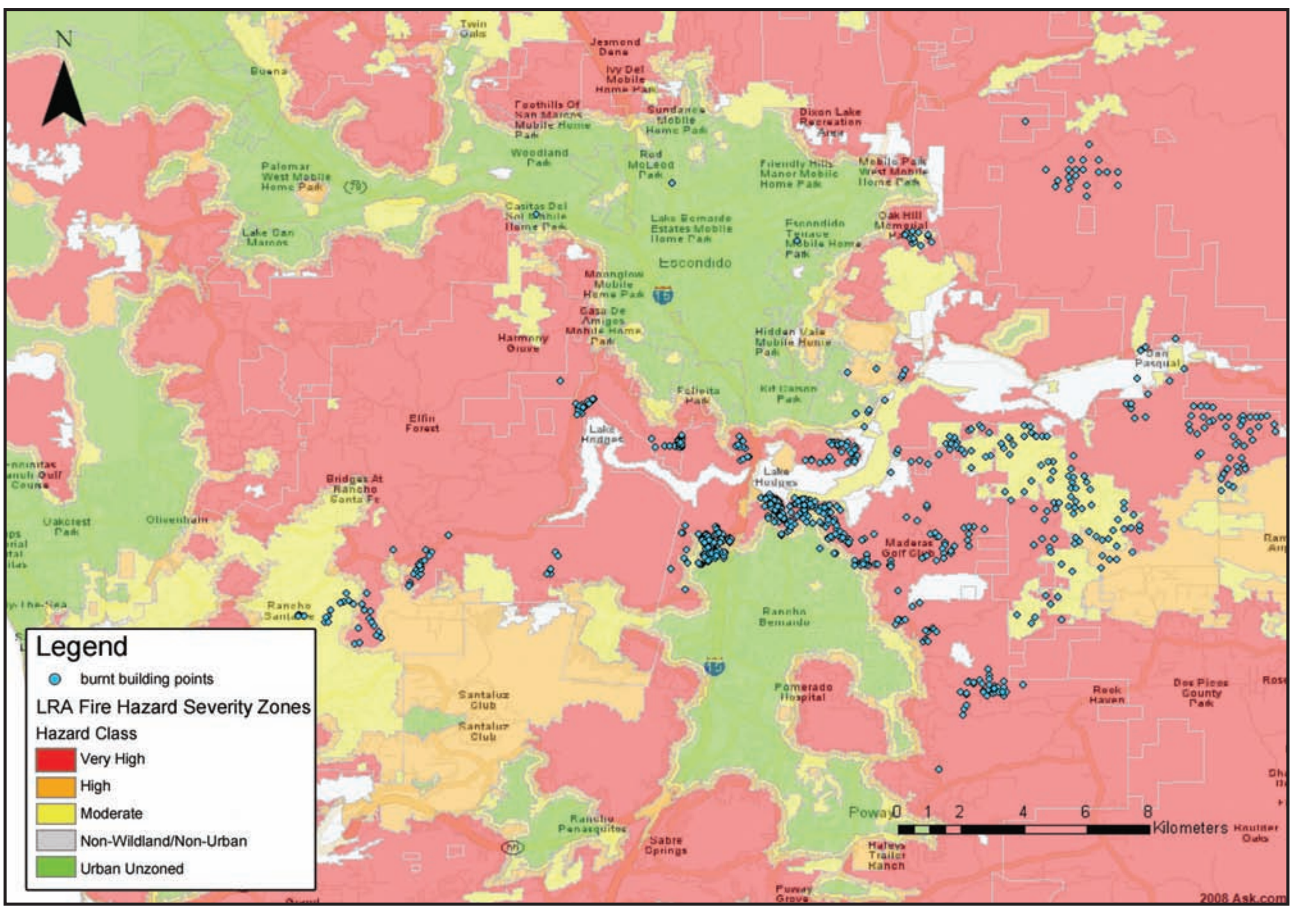

Figure 9. Witch Fire, showing locations of burned buildings, overlaid on LRA Fire Hazard Severity Zones.

destroyed between Lake Hodges and the Rancho Bernardo area, with a more scattered distribution to the east.

A first analysis examined the relationship between the amount of buildings destroyed and the Fire Hazard Severity Zone (FHSZ). This was undertaken for all fires. FHSZ maps are produced by the California Department of Forestry and Fire Protection (CDF) to map areas of significant fire hazards based on fuels, terrain, weather, and other relevant factors. These zones can be used as a basis for the application of various mitigation strategies to reduce risk associated with wildland fires. They can dictate building code regulation changes between zones. Thus the predictive power of these maps is very important.

The actual house burn was compared against these zones for each fire. The results are shown in Table 4. This suggests that for the most part, the zones proved to be fairly accurate, with generally the highest percentages of houses burning in very high hazard zones. The Witch fire is the only fire that had a notable amount (4%) of urban unzoned buildings outside 'high risk' areas. On further investigation, these buildings are spatially correlated; it seems that the fire spread fiercely into one particular area, as shown in Figure 10. Interestingly, the rate of burned buildings within the very high severity zone through which the fire passed is still quite low (as shown in Figure 11). This shows that in these types of chaparral fires, being well within the burn zone, and even in a high hazard risk area is not reason enough for a property to burn down.

Table 4. Building destruction FHSZ class breakdown for 2007 fire events

FHSZ class	Witch	Grass	Rice	Slide	Canyon	Harris	Santiago
Urban Unzoned	45	0	0	0	2	0	0
Non-Wildland Urban Interface	3	0	0	0	0	0	0
Very High Hazard	905	175	70	263	10	225	17
High Hazard	145	0	31	0	0	21	0
Medium hazard	147	0	77	0	0	1	0
Total	**1245**	**175**	**178**	**263**	**12**	**247**	**17**

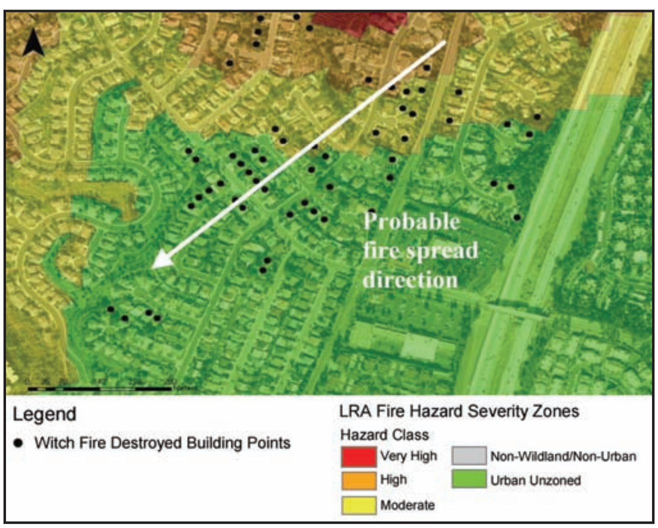

Figure 10. High density of destroyed houses with low hazard severity.

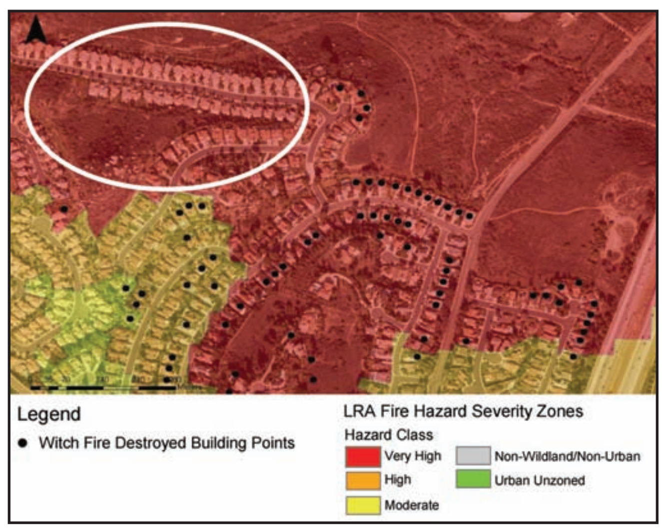

Figure 11. Low density of destroyed houses with high hazard severity.

Analysis – Witch Creek Fires

A preliminary set of analyses were undertaken to further examine correlations between potential hazard and vulnerability parameters and the destruction of buildings. The analysis was conducted at a *neighborhood* scale, corresponding with *Tier 2* of the *Tiered Reconnaissance Framework* (for details, see Adams et al., 2004a; also Womble et al., 2006). Although not employed for the present study, Tier 1 would offer a regional perspective, while Tier 3 would detail *per-building* characteristics.

A parcel set was obtained for the whole area of burn in San Diego. This was intersected with the burned buildings data layer, to create an output of: (1) 'destroyed' parcels, which contained destroyed buildings; and (2) 'non-destroyed parcels', which contained parcels where burn was encountered, however buildings were not destroyed.

In order to examine the environmental factors that contributed to the variable areas of burn (objective 6), NED data was used to derive geographical hazard parameters such as elevation, slope and aspect of parcels. Tax assessor data was also available in the form of a database containing per-building information on various useful vulnerability parameters such as age, building type and landuse.

Building stock

Figure 12 shows that the majority of building stock (around 53%) in San Diego is single family residential structures (either occupied or vacant). After this, timeshares, condominiums and mobile homes are very common. Considering the distribution of building stock among buildings that were destroyed, around 76% are single family residential. There is also a number of mobile homes (7%), and multiples of 2-4 units (3%). In terms of targeting information on fire mitigation, this distribution of building stock is important to know. As well as recording a high frequency of damage, residential properties are likely to be the most varied in terms of vegetation and build quality. As shown in Figure 8, it is important that good vegetation clearance practice and building regulations are followed, to hamper fire spreading through whole neighborhoods.

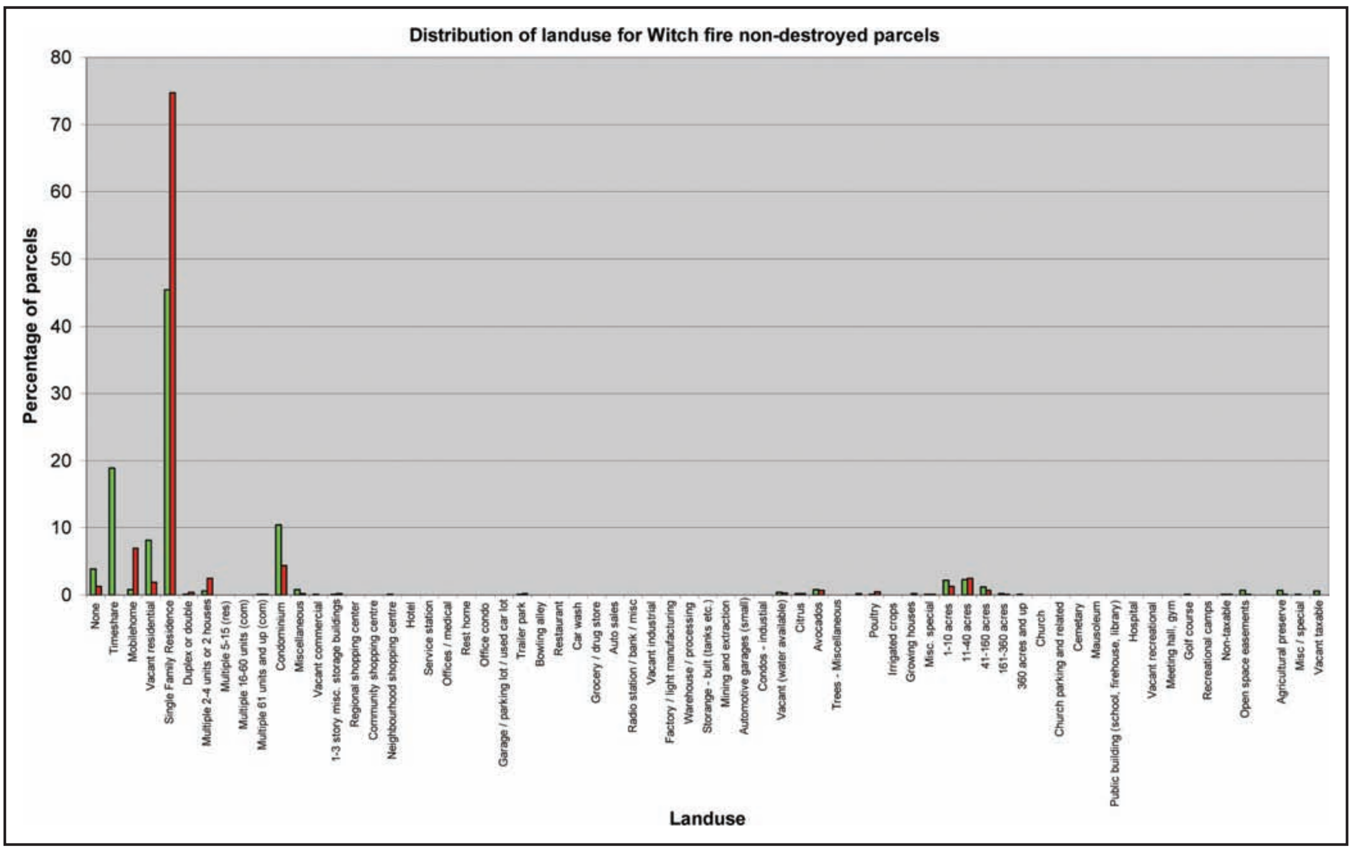

Figure 12. Percentage of parcels by land-use for non-destroyed (green) and destroyed (red) parcels.

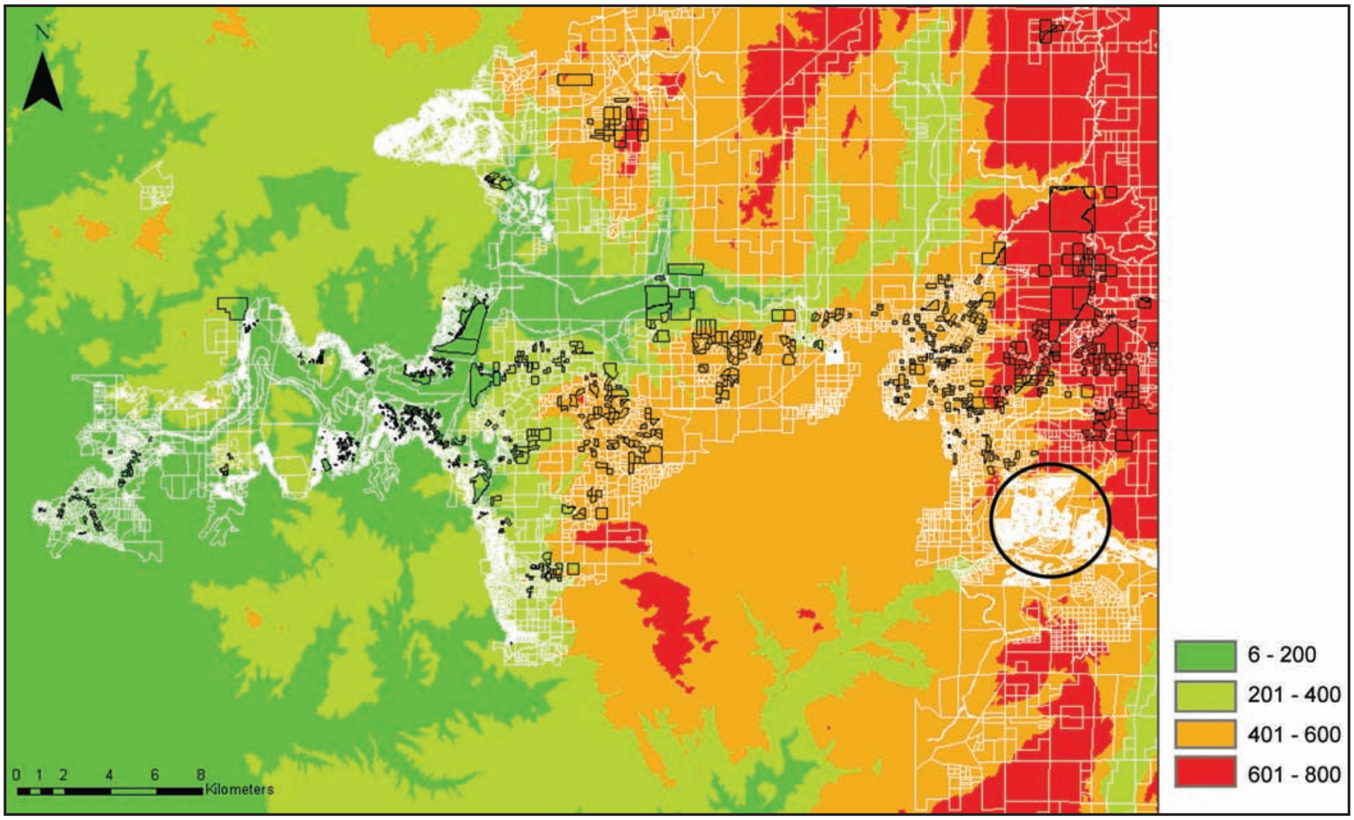

Figure 13. Distribution of elevation in San Diego, and overlain affected parcels (white) and destroyed parcels (black).

Tax assessor information was assessed to examine whether there was a correlation between age of building and probability of burn. The buildings were split into before and after 2003 builds, and the percentage of burn was calculated for each. It showed that housing age distribution was very similar in areas where houses did and did not burn down; 91% of houses destroyed and 92% of houses which survived were built before 2003.

Elevation

Considering Figure 13, the area affected by the Witch fire in San Diego displays a mixture of fairly low land in the West - up to 400m (all elevations are metres above sea level (asl)), rising to higher land in the East (600-800m). The fire generally spread from higher ground in the north east, downslope to lower land in the east, where it seemed to follow the line of the valley. Parcels through which the wildfire passed, but did not destroy the building, present two patterns: (1) high density, small area parcels, characterizing generally residential areas, tend to be concentrated around areas of low elevation, with one area in the east on medium elevation; and (2) larger parcels within agricultural land or wildland, are present over a mixture of elevations, but are most commonly found in higher elevation areas. The parcels where buildings were destroyed tend to be found over a range of elevations, and are found in a general strip, moving from the east to the west. Where the burn reaches high concentration residential areas, the destroyed parcels tend to be on the outskirts, namely the Wildland Urban Interface. A higher frequency of smaller parcels are found on lower elevations, while larger parcels are generally found at higher elevations.

Considering Figure 14, the distribution of parcel elevation for the whole area is shown graphically in relation to the distribution of elevation for parcels affected by the burn, but where no houses were destroyed, and distribution of elevation amongst parcels where houses did burn.

First when examining the elevation for the whole region, there is a range of elevation distributions. The largest proportion of parcels is found from 400-600m. The proportion of parcels decreases as elevation increases, but parcels are still found at 1600-1800m. The parcels affected by the fire tend to be in the lower elevated areas of the county (i.e., up to 1000m elevation).

There is an interesting pattern of response for burned structures, with a marked reduction in frequency at 400m and peak at 600m. Residential parcels of < 5 acres (Figure 15) where buildings were destroyed, are concentrated (65%) on low elevations of up to 200m, with just 37% on elevations of 200-400m. From Figure 16, the ranch areas are more focused on elevations of 600-800m. The ranch areas that contained the highest intensity fires (where buildings were destroyed) also tend to follow this distribution, with the highest proportion at 600m. Therefore considering the overall distribution of elevations in Figure 14, a dip is seen at the 400m elevation because although medium elevation parcels were affected by the burn, they were generally away from the line of greatest fire intensity; for instance, medium elevation residential parcels (circled in Figure 13) to the Southern extent of the fires fall within the burn zone, but the structures survived. This could potentially be due to good fire management, or rapid funneling of the fire down the valley from West to East.

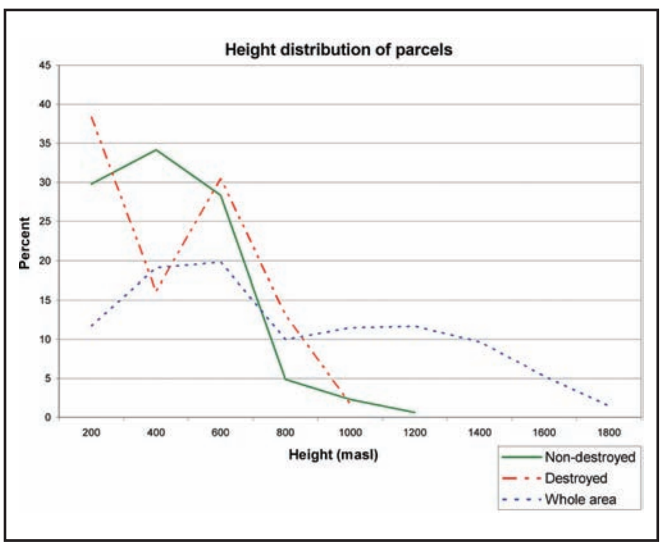

Figure 14. Distribution of elevation for the entire area (burned and non-burned) and affected parcels within the burn area containing destroyed and non-destroyed buildings.

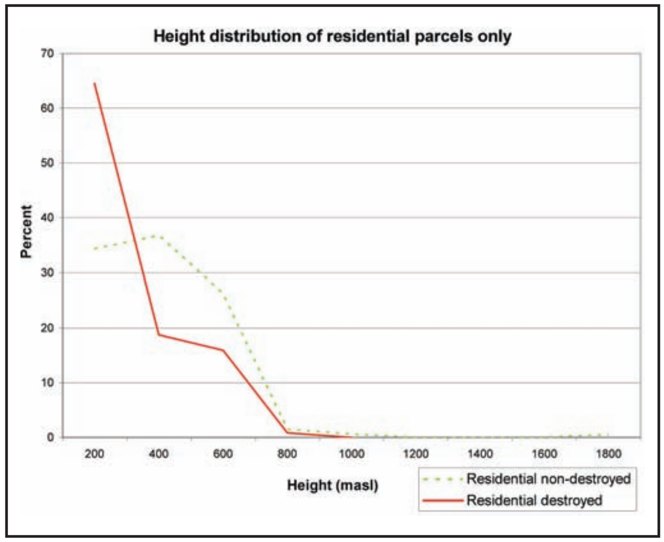

Figure 15. Distribution of elevation for burned and non-burned parcels of < 5 acres. This subset of smaller parcels is employed as a surrogate indicator for residential buildings.

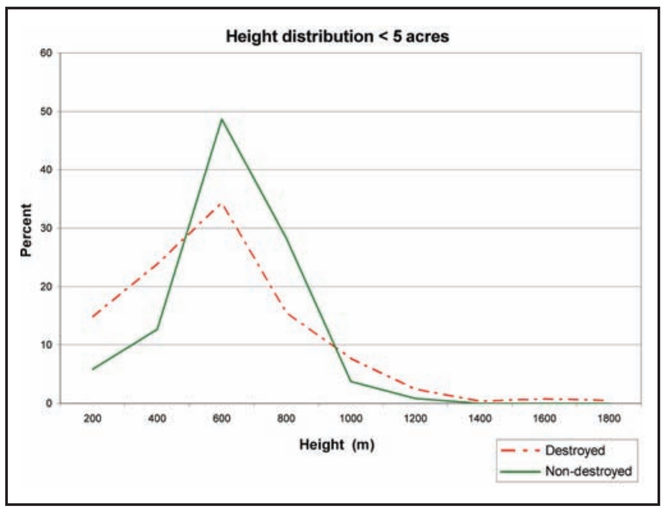

Figure 16. Distribution of elevation for burned and non-burned parcels of > 5 acres. This subset of larger parcels is employed as a surrogate indicator for ranch properties.

Aspect

In this area of San Diego, the distribution of aspect is generally quite even as shown in Figure 17 (whole area), with all degree ranges being populated (apart from a dip at 60-120 degrees). However, if we compare this to parcels affected by the burn (non-destroyed), they tend to show a tendency towards slopes facing a more south-westerly direction. Comparing affected parcels within the burn area (non-

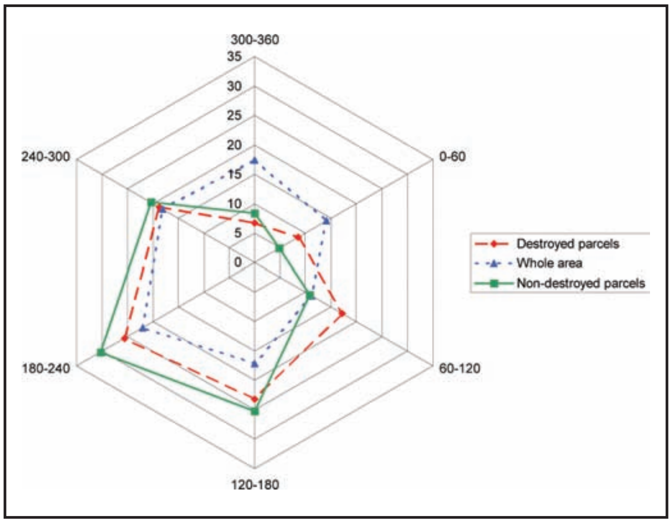

Figure 17. Distribution of aspect.

destroyed parcels) with parcels containing destroyed buildings (destroyed parcels), the parcels where buildings were burned had a more easterly component. This is examined further in Figure 18, where residential parcels were extracted as those below 5 acres in size, and the aspect of those which were destroyed and those which weren't were plotted. Residential structures facing a more easterly direction (either northeast or southeast) had a higher rate of burn than other aspects, and showed a markedly different distribution to the average.

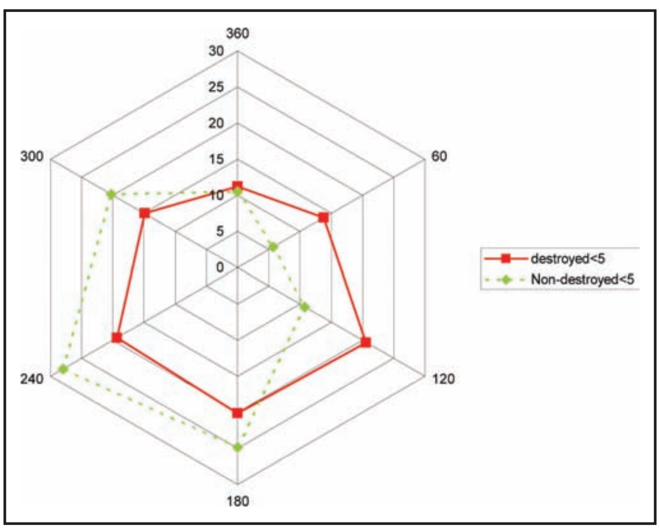

Figure 18. Distribution of aspect for residential parcels occupying < 5 acres.

Slope

The final parameter to be examined with NED data was slope. Considering Figure 19 covering the whole area, the largest percentage of slopes are flat or minor. Within the parcels affected by the burn where buildings were not destroyed, the majority of small parcels (i.e., parcels that are likely to contain residential structures) are found on relatively low slopes. Parcels containing destroyed buildings are concentrated around areas that juxtapose flat slopes with steep slopes. These usually correlate with the Wildland Urban Interface (WUI). As slopes get steeper, parcel sizes tend to increase, as less buildings are built there, and agriculture or wildland dominates.

Figure 20 shows the relationship graphically for the whole area. The proportion of slopes in each degree category is seen to decrease fairly linearly with increasing slope angle. When this global population is compared with the subset of affected parcels (destroyed and non-destroyed, Figure 21), a higher proportion of affected parcels are on relatively flat land, and minimal parcels burned on very steep land >25 degrees. Revisiting Figure 13, the fire appears to have spread downslope and into the valley where a number of residential communities lay. However, within the burn area, parcels where buildings were destroyed are more likely to be on steeper slopes of ~15 degrees.

When considering only residential parcels of < 5 acres in size where buildings burned, the majority of parcels are on 15-20 degree slopes. Fewer residential buildings were destroyed on slopes of 0-5 degrees, when compared to the general distribution of burned parcels, as although there are a lot of residential buildings built on very low slopes, these tend to be found in the center of residential communities. As the fire did not generally penetrate far into these areas, there are relatively few parcels in this category.

The most damage was caused where residential areas met steep slopes (see Figure 19); the perimeter of the residential communities were seen to be worst hit. This suggests that the Wildland Urban Interface has particularly high vulnerability. It also shows that steep slopes per se are not necessarily commensu-

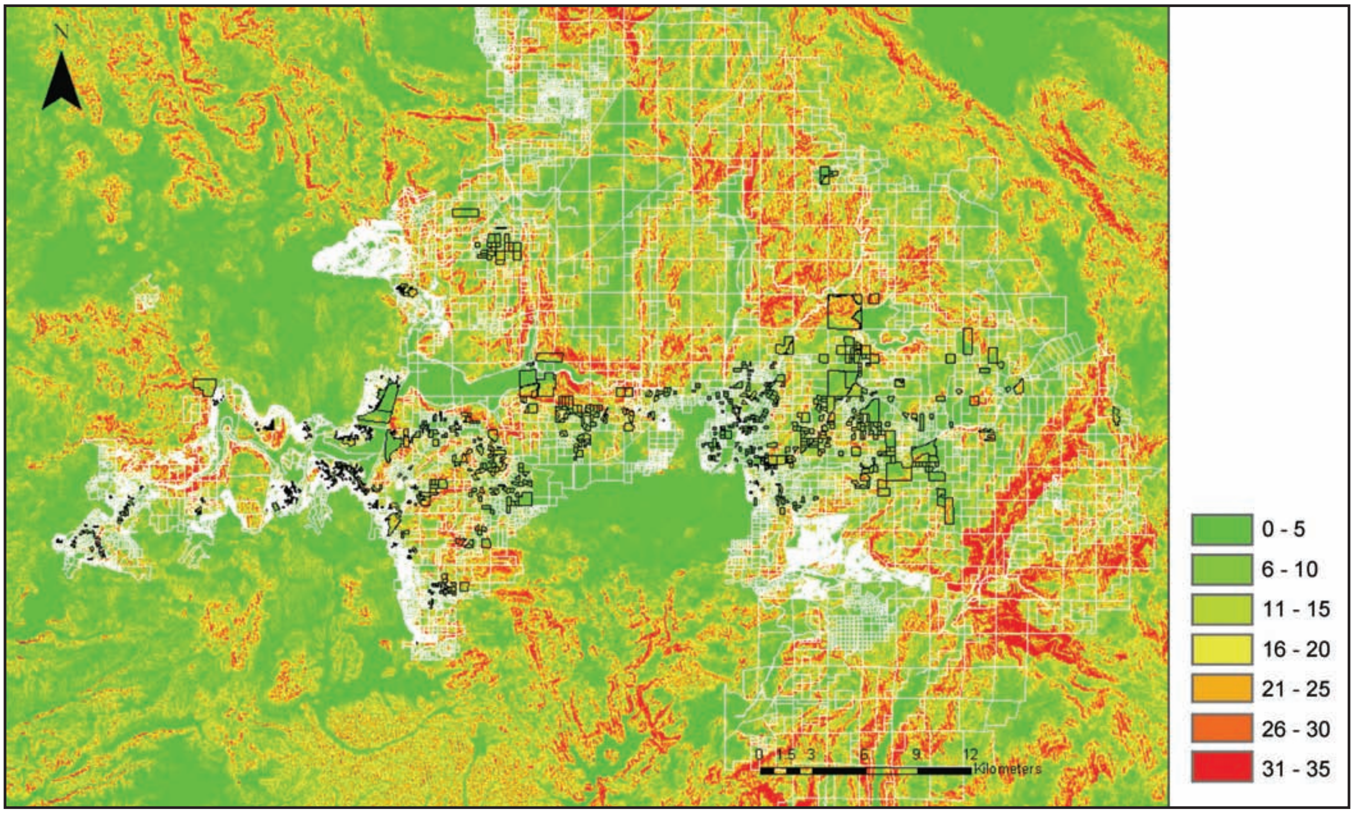

Figure 19. Distribution of slope in San Diego (degrees), overlaid with affected parcels (white) and destroyed parcels (black).

rate with devastation, as the fire in this case spread through relatively low sloped areas, and may be funneled down a valley by a ready source of fuel. However, houses on the perimeter of an urban area, especially if they are on steeper slopes where fuel is available, are at increased risk of burn.

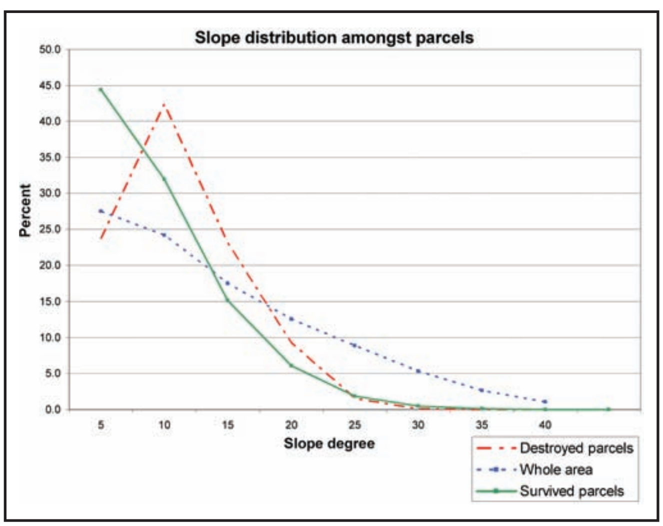

Figure 20. Distribution of slope for the Witch fire.

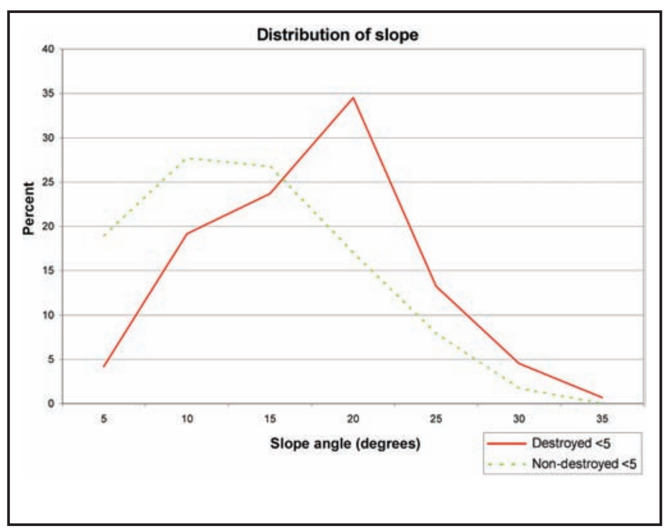

Figure 21. Distribution of slope for the Witch fire for parcels up to 5 acres.

Witch Fire Summary

The Witch fire burned between October 21-31, 2007. In this fire alone, 1,362 buildings were destroyed (derived by ImageCat), and 200,000 acres were burned (Inciweb, 2008). Preliminary analysis was undertaken into the distribution of burn, and destroyed structures throughout the fire, and the distribution of hazard and vulnerability factors such as elevation of parcel, aspect, slope angle and building age.

OES fire perimeters were used to determine the maximum extent of burn. VIEWS™ footage showed that within this area, burn intensity was variable, and building burn was at times sporadic. The fire was characterized by a grass and chaparral mix. The highest concentration of burned buildings tended to occur on the Wildland Urban Interface (WUI), where dense residential neighborhoods met open wildland. As the burn spread into an urban area, the occurrence of burned buildings became sporadic, suggesting direct fire contact was quickly replaced by ember travel ignition. Visual inspection of VIEWS™ data showed evidence of good vegetation clearance and well irrigated lawns saving houses from burn. Examining this spatial arrangement of burned structures in terms of density and relationship to fire front is an area of future work.

Most of the affected areas were classified as either high or very high fire hazard severity. However, some fire crept into an urban unzoned FHSZ area, where a relatively large cluster of buildings were burned. It is thought that unusually strong winds swept the fire deeper into these urban areas than would have been suspected.

In terms of relationships between burned areas and elevation of parcel, the analysis using NED data showed that the fire burned preferentially over higher ground, which may be a function of less development and increased vegetation cover. However, the vast majority of *building burn* was residential structures on *lower elevations*, as this is where they tended to be built. The fire was seen to sweep westward, downslope and into valley type areas, fanned by the southwesterly blowing winds. Destroyed buildings found in larger parcels (i.e., ranch type properties) were more likely to be found in higher elevations, further into the wildland in the west.

For aspect, the area affected by the fire had a larger natural distribution of parcels over south-southwesterly aspects. However, *burned buildings* tended to be distributed on more *easterly facing parcels*. This suggests that the fires blew in from the east and hit those aspects hardest.

A range of slopes were found in the area, and the burned area did not have particularly steep slopes compared with the general distribution. As seen, the chaparral fire blew into the valley, where parcels were relatively flat. However, properties which burned were more likely to be on steeper slopes than those which didn't burn. In this area, steeper slopes were more likely to be found on the outskirts of urban areas, leading to an area of Wildland Urban Interface where steeper slopes and dense houses meet.

Most buildings affected by the fire were residential single family dwellings or mobile homes. When age was considered as a possible determining factor for burn, no strong correlation was found at this tier 2 level. It is suggested a more forensic analysis is needed.

San Bernardino Fire

General Observations

The perimeter of the San Bernardino fire is shown in Figure 22, as derived by the California Office of Emergency Services (OES). This encompasses the Grass Valley and Slide fires. From viewing the aerial photography, burn within the perimeter boundary was seen to be patchy in intensity. ImageCat assessed the badly damaged areas within this area, and which focused the analysis on the intersection of burn with buildings.

Recalling Table 2, the fuels for the Slide and Grass Valley Fires were different from those that fed the Witch Fire. Rather than the chaparral and grassland that characterized the Witch fires, these fires occurred in the pine forests of the San Bernardino Mountains. Figure 23 shows how the difference in environment affected the type of burn experienced in the area. It shows a group of destroyed houses after the Grass Valley fire. It is possible to see the 'domino' effect of fires spreading through a community, from one home to the next. The homes in this area were in close proximity to trees, which empha-

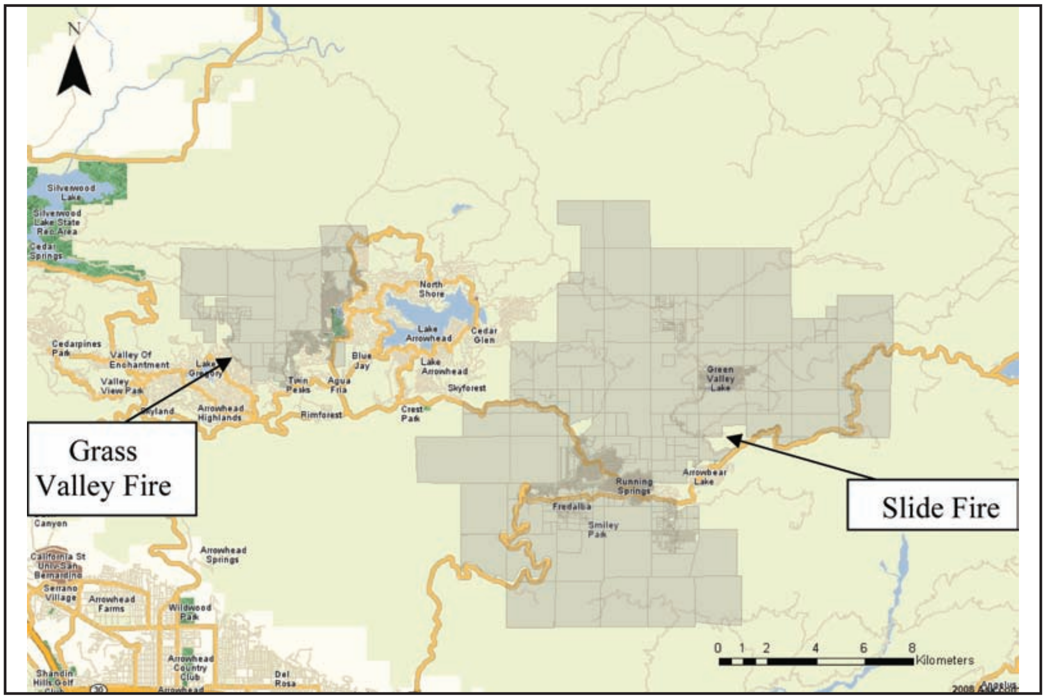

Figure 22. San Bernardino fire, showing rough extent of fire perimeter, cross referenced with parcel data.

Figure 23. Destruction of houses in the Grass Valley area.

sizes the importance of vegetation clearance around properties.

Homes affected by the Grass and Slide fires within the mountains are predominantly wood frame with clapboard siding. Roofs were either wood or asphalt shingle. The size of the homes in the affected areas ranged from small to moderate-sized cottages in the Slide area, to much larger homes in the Grass Valley fire area.

Damage Distribution – San Bernardino Fires

Figure 24 shows the distribution of destroyed buildings for the San Bernardino fires. The heaviest concentration of buildings that were destroyed was between Lake Hodges and the Rancho Bernardo area, with a more scattered distribution to the East.

A first analysis examined the relationship between the amount of buildings destroyed and the Fire Hazard Severity Zone (FHSZ). These zones can be used as a basis for the application of various mitigation strategies to reduce risk associated with wildland fires. They can dictate building code regulation changes between zones. Thus the predictive power of these maps is very important.

The actual house burn was compared against these zones for each fire. Table 4 shows the distribution of building destruction throughout the Grass Valley and Slide fires. All houses in the Grass Valley and Slide fires were within very high Fire Hazard Severity Zones. There is not as much variability between FHSZs as in the Witch fire area. This is predominantly due to the fact that the area under study contains large amounts of fuel in the form of trees, in close proximity to buildings.

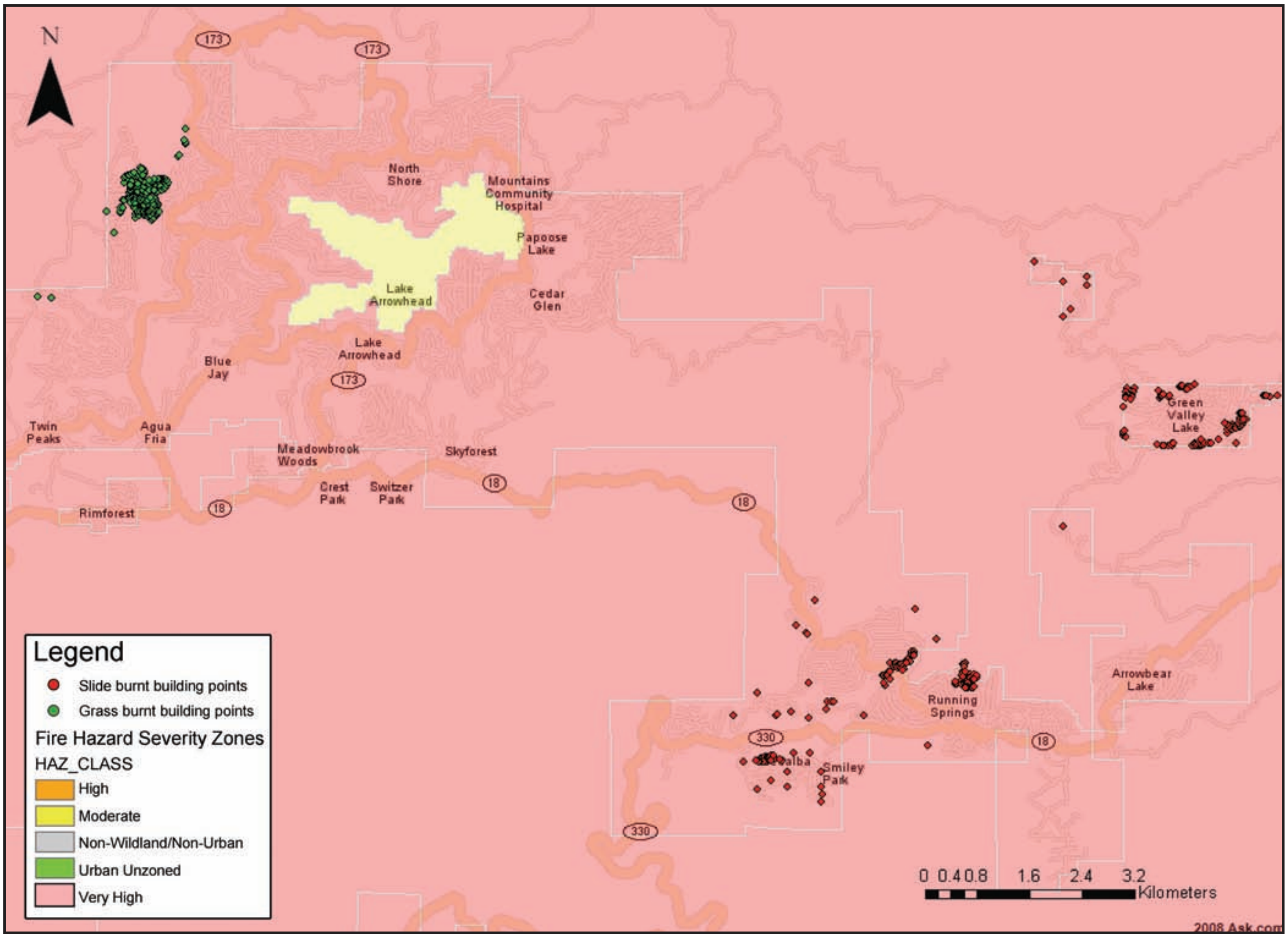

Figure 24. San Bernardino fires, showing locations of burned buildings, overlaid on LRA Fire Hazard Severity Zones.

Comparing Figure 24 with the parcel locations in Figure 22, clusters of burned buildings are all found within small communities. The parcels where buildings have been destroyed are generally small in size, as they belonged to neighborhoods where space is at a premium. There are many other parcels which burned. However, they are large in area, with only one or two structures on them.

Figures 25 and 26 show that the distribution of building burn within the Grass and Slide fires differs from that of the Witch fires. They are a lot more concentrated in their destruction, suggesting that the fire front passed through the whole neighborhood, with the 'domino' effect of houses setting the next one on fire. That stated, when ground VIEWS™ surveys were taken, even though the rate of building destruction looks high, there are still many homes in between burned buildings that were not touched by the fire.

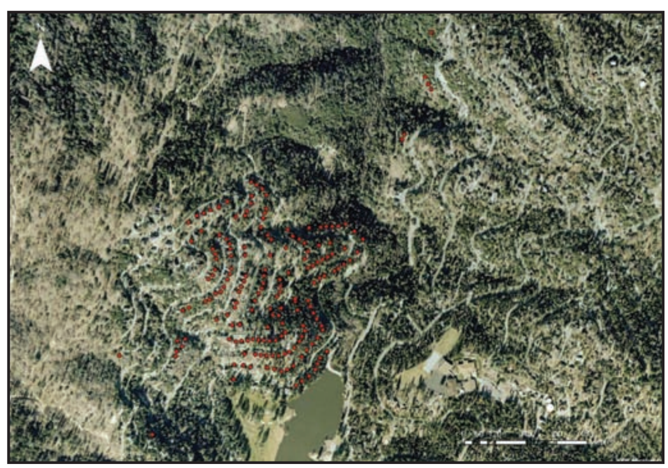

Figure 25. Distribution of burned buildings in Grass Valley Fire.

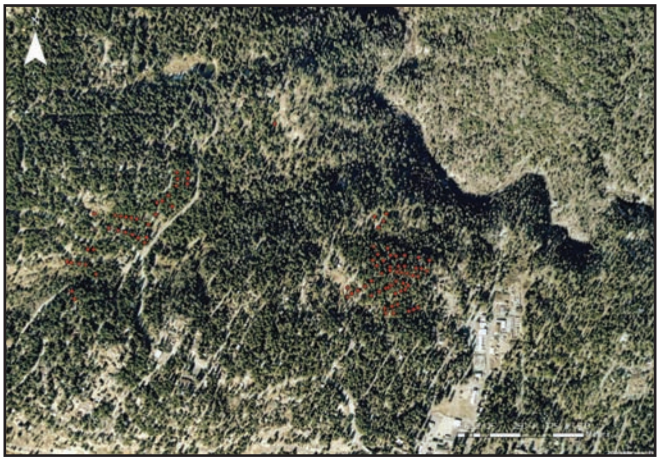

Figure 26. Distribution of burned buildings in Slide Fire.

Analysis – San Bernardino Fires

A preliminary set of analyses were undertaken to further examine correlations between geographical parameters and the destruction of buildings. A parcel set was obtained for the burn zones of the Grass Valley and Slide fires. This was intersected with the burned buildings data layer, to create an output of 'destroyed' parcels, which contained destroyed buildings, and 'non-destroyed parcels' which contained parcels where burn was encountered, however buildings were not destroyed.

NED data was used to derive geographical hazard parameters such as elevation, slope and aspect of parcels throughout the burn area identified above, and the wider region of San Bernardino. Tax assessor data was also available in the form of a database, which contained per-building information on vulnerability parameters such as age, building type and landuse. Unlike San Diego, San Bernardino had a very detailed tax assessor database. Using this data allowed a more detailed investigation of parameters such as building construction, and provided an independent validation of the NED slope angle distribution.

Building Stock

Detailed tax assessor data was available, which noted on a parcel level data such as slope position and angle, as well as structural elements including window frames, siding and roof characteristics, and age of building. Using this information allowed chi-squared tests to be carried out to examine the significance of certain factors in whether buildings were destroyed or not.

Housing type did not prove to be a significant factor when considering the survival or destruction of houses in this area. This is due to the fact that all recorded properties in the area were frame-type buildings (100%), with either mountain type (93%) or A-frame (6%) structures, leading to a chi-squared value of 0.6 (6df with all housing types considered). A lack of variety of structures meant a lack of a solid basis for testing differential burn. This was seen to be the same for roof type, with most houses composed of either composite shingle or shake.

It is known that building regulations changed in 2003 following previous severe firestorm damage. Therefore building age was separated into pre- and post-2003 construction, to see if there were any differences in destruction rates between the two groups. Chi-squared testing showed that there is a significant difference between rates. 6% of buildings built pre-2003 in affected parcels burned down, whereas only 3% of buildings post-2003 did. However, as no relationship was found in the results from San Diego, this requires further investigation.

Elevation

San Bernardino displays a range of parcel elevations throughout the area, and shows a greater mean elevation, and greater range than the San Diego area. In a firefighting context, the terrain was described as 'difficult' by the responders in this region (ENS 2007). Areas with a concentration of small parcels (suggesting residential properties) are clustered around medium to high areas of terrain, as shown in Figure 27.

Exploring the distribution of parcels with destroyed buildings further, the Grass and Slide fires exhibit different distributions of elevation. The Grass fires have a more concentrated grouping of burned structures, all at a comparably low elevation (Figure 28), whereas the Slide fires have damage spread over a wider area, covering a larger spread of parcel elevations (Figure 29) with higher average elevation. The fire burned around the periphery of concentrated residential parcels. The Grass Valley fire, seen in the top left cluster of Figure 27, has the single deepest incursion into a residential area.

Figure 30 shows the distribution in elevation in graphical form. Statistics from the whole area are shown in relation to the distribution of elevation for parcels affected by the burn, but where no houses

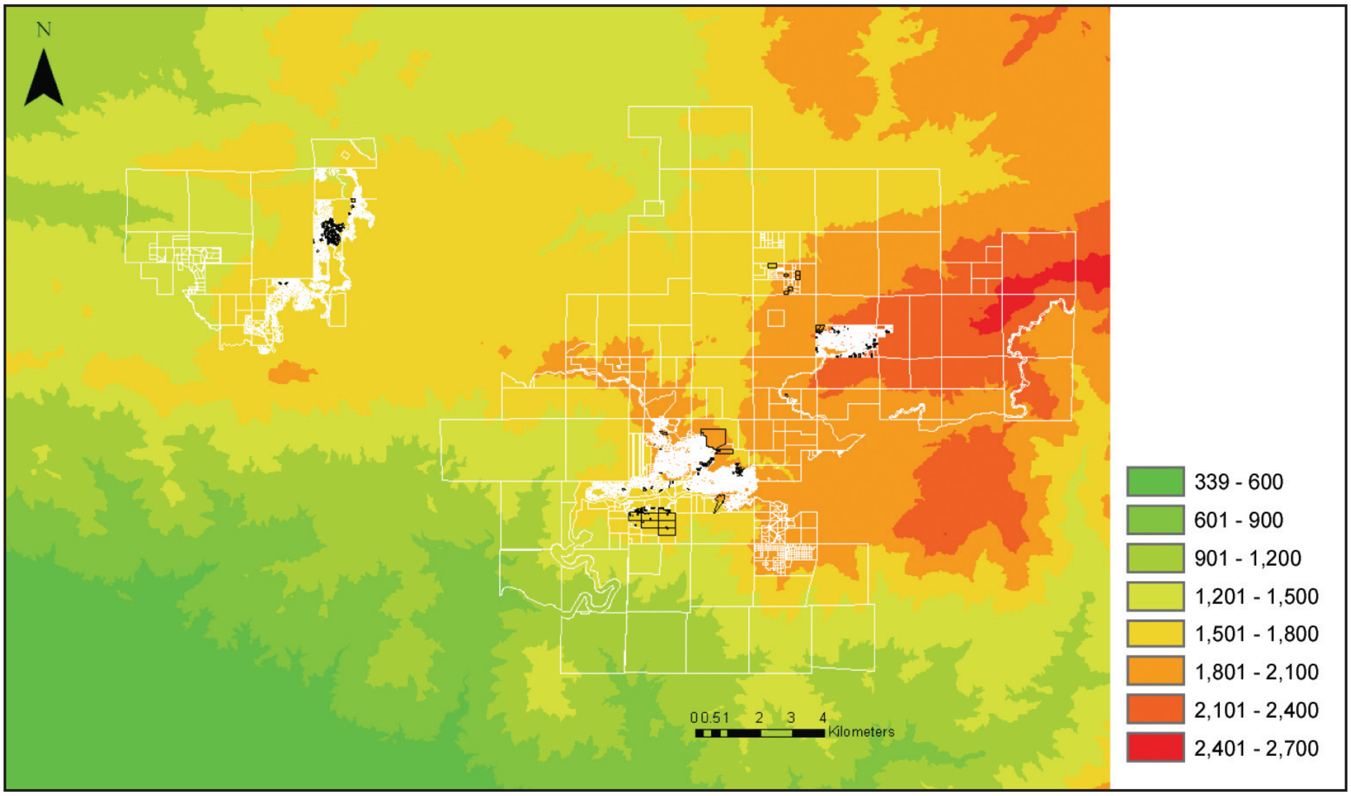

Figure 27. Distribution of elevation (m) in San Bernardino, and overlain affected parcels (white) and destroyed parcels (black).

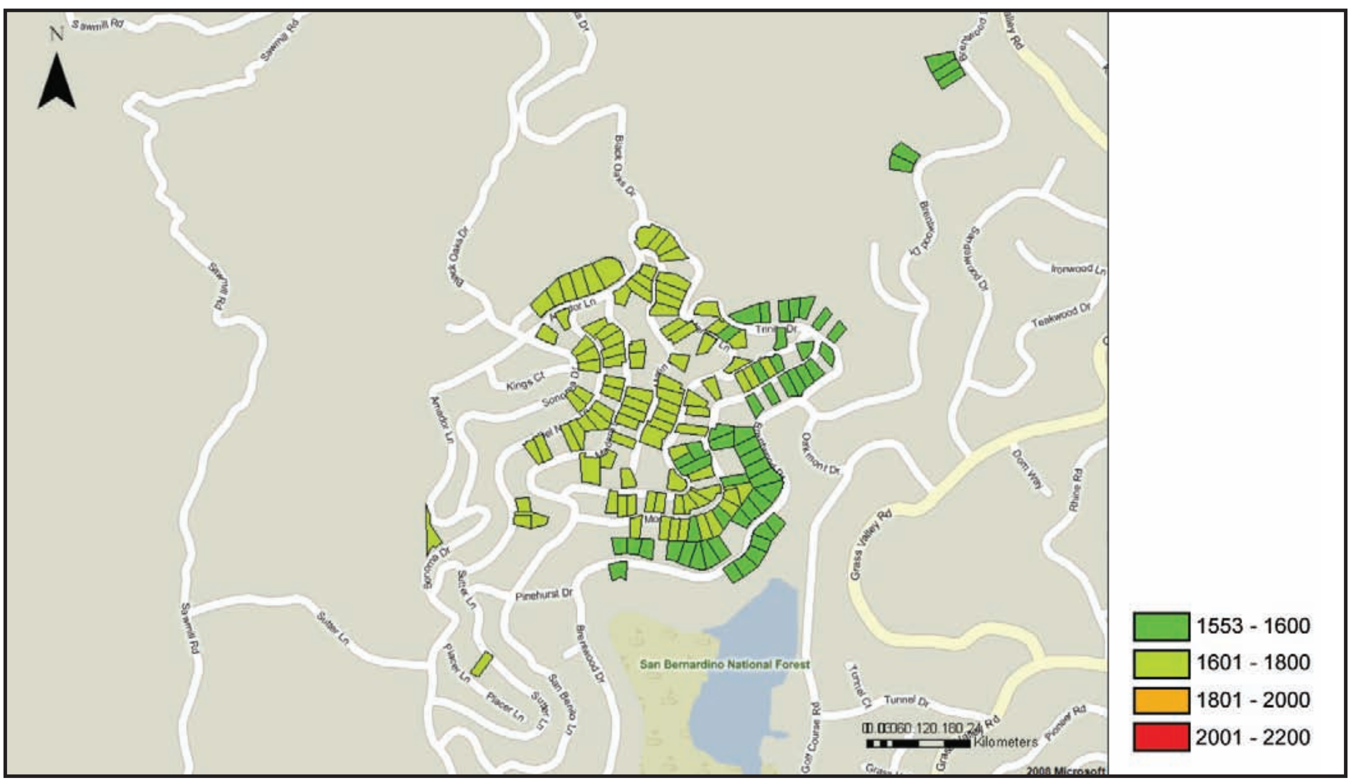

Figure 28. Close up of Grass Valley fire destroyed parcels, showing elevation distribution (m).

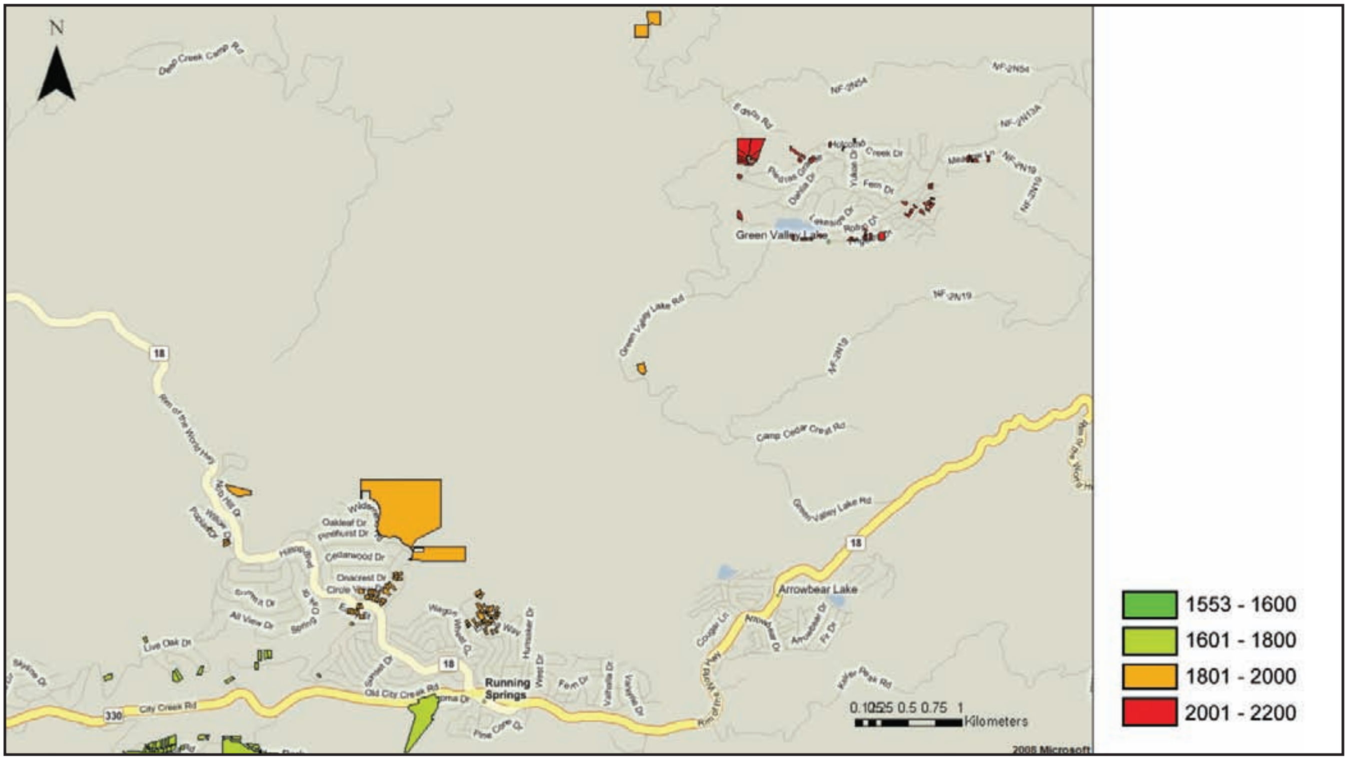

Figure 29. Close up of Slide fire destroyed parcels, showing elevation distribution.

were destroyed (this is marked as 'non-destroyed' parcels on the figure), and distribution of elevation amongst parcels where houses did burn (destroyed).

Considering this area of San Bernardino as a whole, elevation is distributed over a wide range, from 500m elevation to 2500m. The largest proportion of land is found at around 1500-1700m. Parcels affected by the burn but where the structure survived generally occurred at higher elevations of over 1500m. Comparing this to parcels where buildings were destroyed, the same general trend can be seen, although with a slight shift in frequency towards lower elevations of ~1700m. Two peaks within the distribution of destroyed building parcels can be seen. The first peak generally correlates to the elevation of parcels in the Grass Valley fire, whereas the second peak contains parcels from the Slide fire.

When isolating smaller parcels of up to 5 acres in size (Figure 31), generally concurrent with residential parcels, the majority of non-destroyed parcels are found at 1900m in elevation, with destroyed parcels having the largest distribution at a lower elevation of 1500m. This suggests that there is a slight tendency for houses on lower elevations to burn. This can be explained by re-examining Figure 27, where the residential concentrations are built on hilltops, with the perimeter of these concentrations falling into a lower elevation category. In summary, parcels exhibit a tendency to burn on higher elevated ground in comparison to the whole area, but there is a tendency within the burn zone

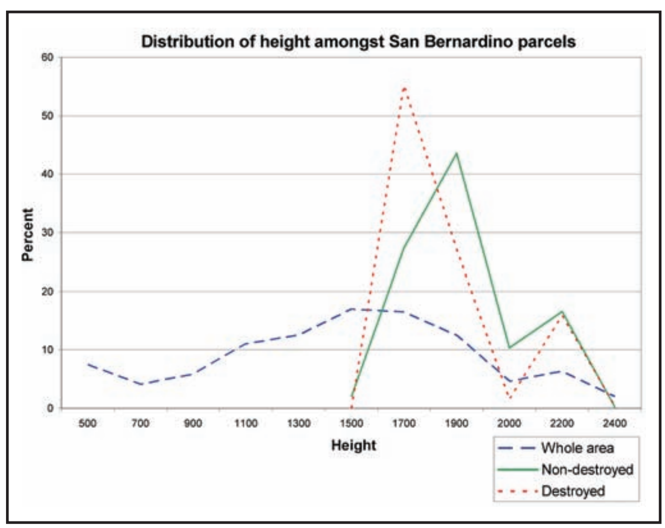

Figure 30. Distribution of elevation amongst San Bernardino parcels.

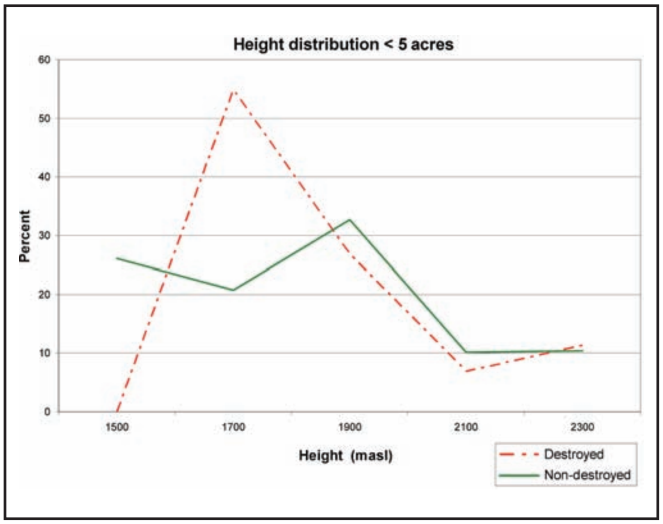

Figure 31. Distribution of elevation amongst San Bernardino parcels < 5 acres in size.

for structures to be destroyed on slightly lower than average elevations. This is likely a function of the distribution of urban planning with the burn only touching the perimeters of residential areas, rather than any preference for the fire to burn structures on lower parcels.

Aspect

Figure 32 shows the distribution of aspect throughout the San Bernardino area, along with the location of destroyed parcels, marked in black. From visual analysis, the majority of small parcels (suggesting residential properties) in the Grass Valley area are to be found on aspects of east facing slopes (either east, southeast or northeast), whereas the concentrated parcels in the Slide fire area are to be found on southern aspects (either southeast or southwest). The affected parcels, which are larger (and tend to suggest agriculture, ranch or wildland environments), span a mixture of aspects.

Further investigating the distribution of destroyed versus non-destroyed parcels, those areas where buildings were affected by the burn were magnified in Figures 33 and 34. Most of the buildings in the Grass Valley fire burned through one particular neighborhood, with considerable tendency towards aspects of 1-180 degrees (i.e., north, northeast and southeast). The buildings destroyed during the Slide fire are more disparate and varied in aspect.

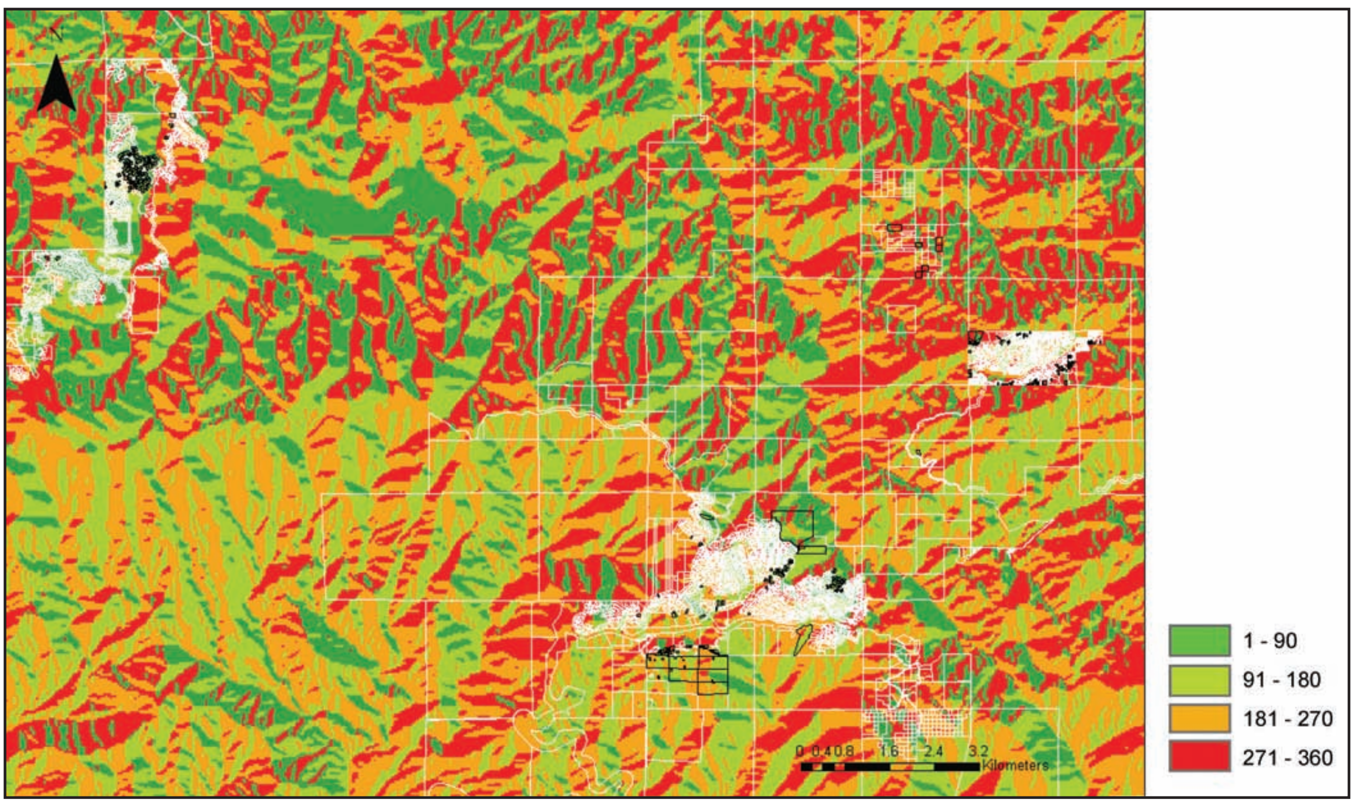

Figure 32. Distribution of aspect (degrees) in San Bernardino, and overlain affected parcels (white) and destroyed parcels (black).

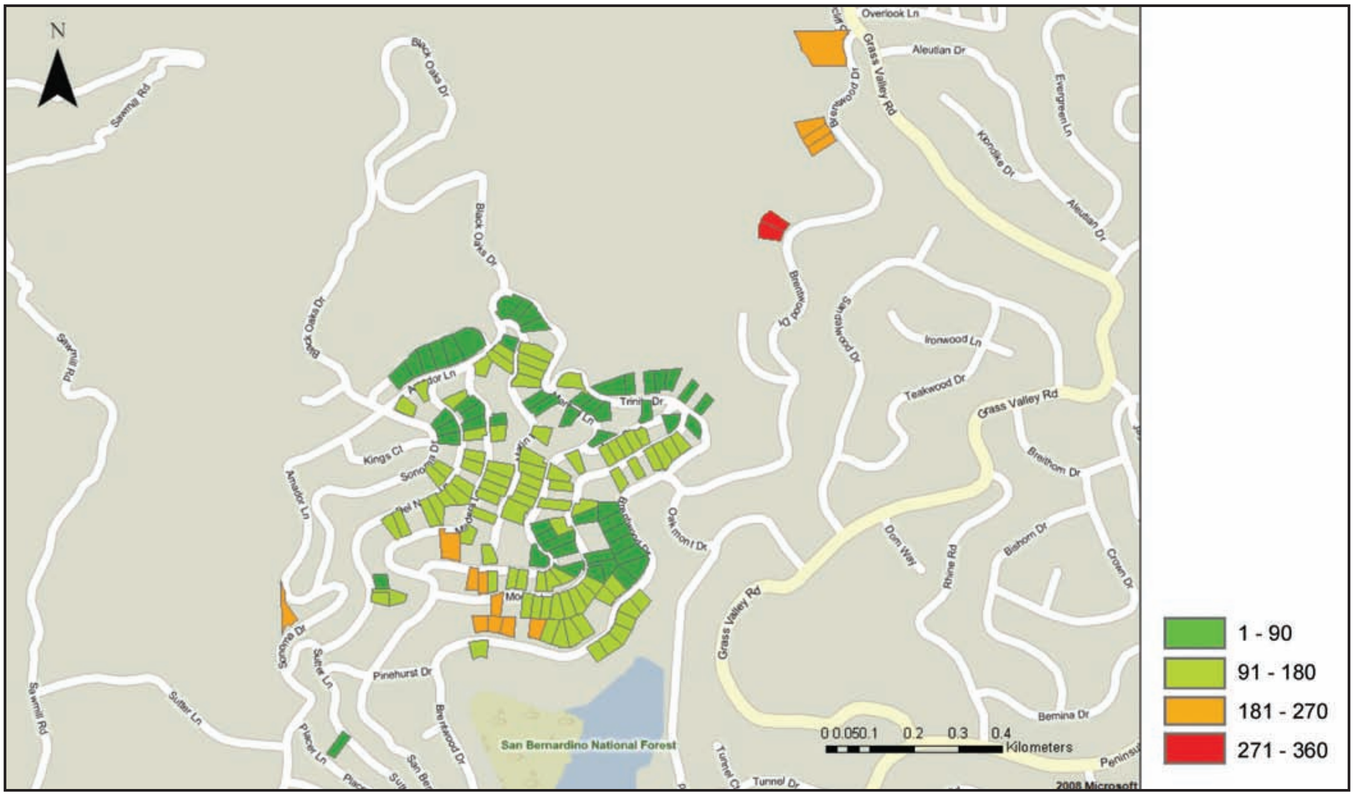

Figure 33. Close up of Grass Valley fire destroyed parcels, showing aspect distribution (degrees).

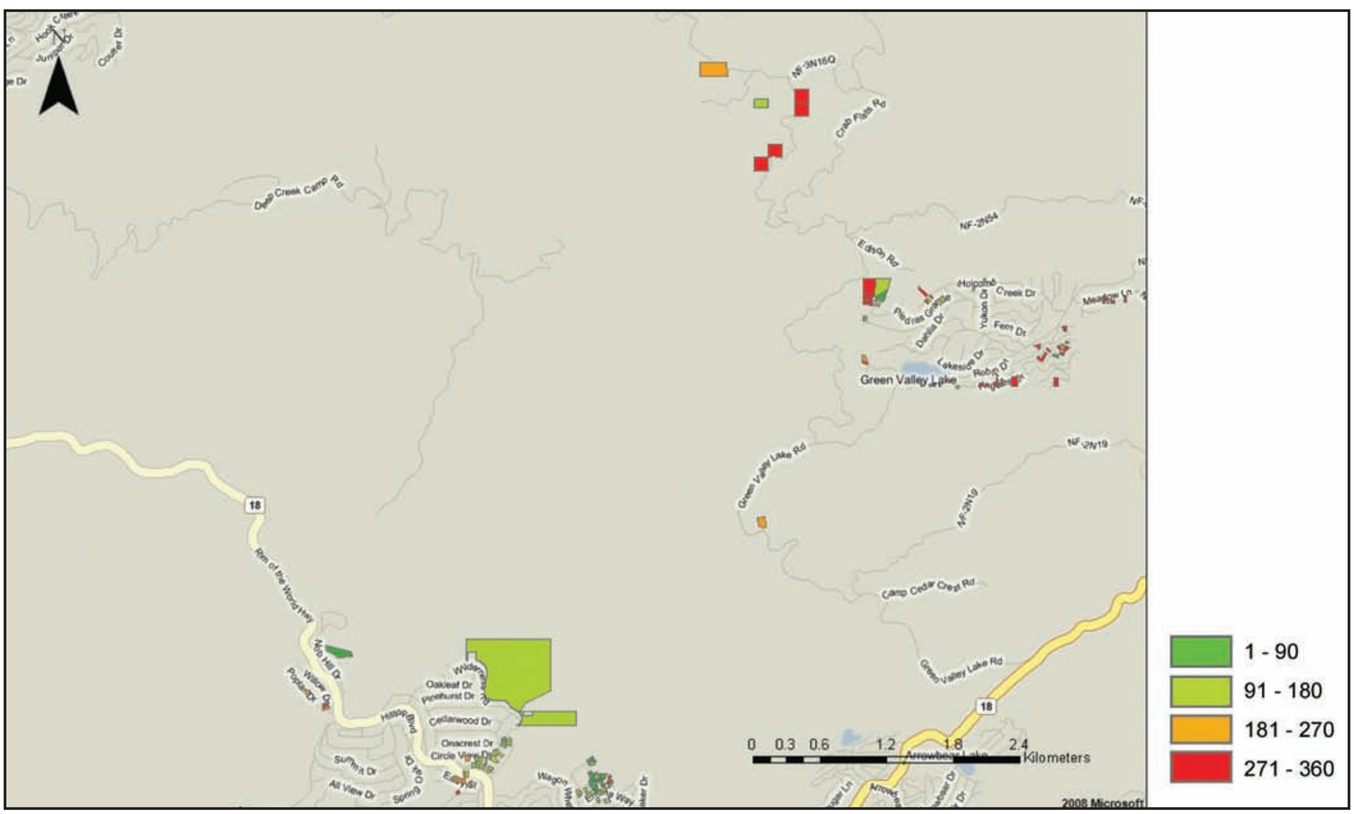

Figure 34. Close up of Slide fire destroyed parcels, showing aspect distribution (degrees).

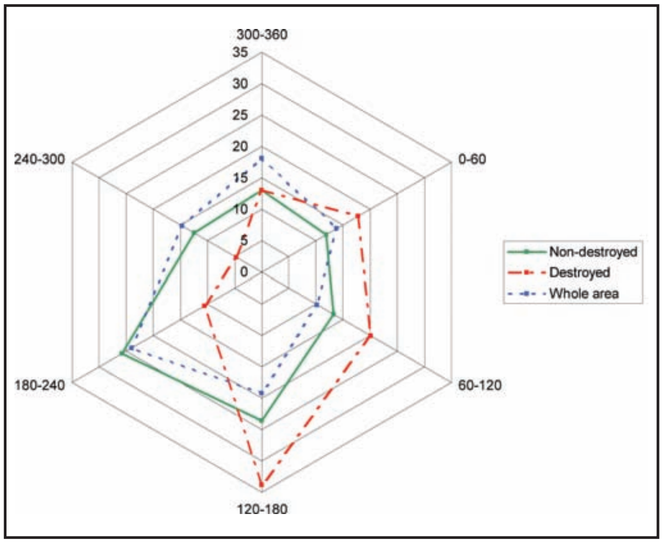

Figure 35. Distribution of aspect in San Bernardino.

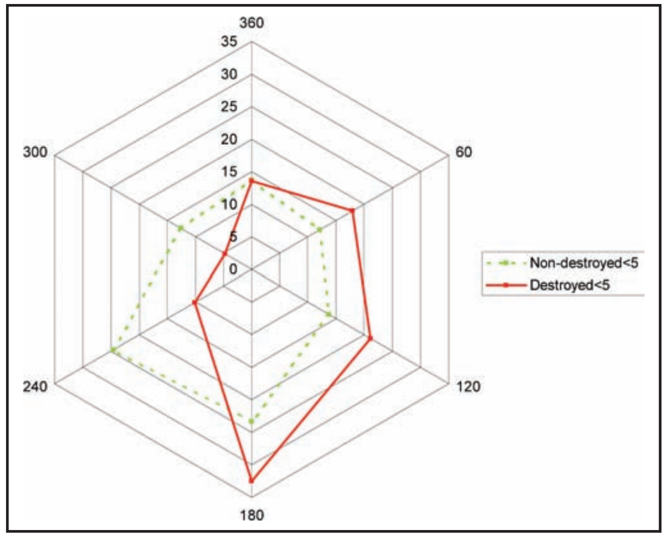

Figure 36. Distribution of aspect in San Bernardino in residential areas (< 5 acres) affected by the fire.

To examine the distribution of this area with more clarity, a graphical approach is employed. Figure 35 shows that when considering the whole region of San Bernardino, the distribution of aspect is generally fairly evenly distributed, apart from a tendency towards slopes facing south or southwest.

This distribution is similar to those parcels affected by the burn, where buildings survived. Marked as 'non-destroyed' parcels on the figure, they exhibit a tendency to be south or southeasterly facing slopes. If this is again compared to those parcels in which buildings are destroyed, there is a distinct shift in the distribution of buildings. The destroyed parcels are mainly small residential parcels (Figure 36). Within the subset of parcels <5 acres, a large community of buildings were destroyed on south facing slopes, and also east facing slopes. The parcels which survived are more likely to be on west facing slopes than those that were destroyed.

Slope

Figure 37 shows the distribution of slope throughout the San Bernardino area, along with the location of destroyed parcels, marked in black. The figure shows that this area of San Bernardino is generally split into areas of relatively low slope in the north, and relatively steep slopes in the south. A high concentration of small parcels (suggesting residential property) are found on low slopes. Interestingly, a high concentration of destroyed buildings tend to be found at the juxtaposition of very high slopes and very low slopes. The higher slopes tend to have larger parcels, suggesting agriculture or wildland environments and increased WUI burn potential. A magnification of the distribution of destroyed parcels in Figures 38 and 39 confirms that these parcels tend to be a mixture of slope angle degrees.

Examining the slope distribution graphically (Figure 40), slope angle throughout San Bernardino is extremely variable. Consequently, a relatively even general distribution of slope angles is found, with a slight decrease in the proportion of very steep angles. When this is compared with parcels affected by the burn where properties survived, there is a shift towards a greater proportion of parcels at the low to medium slope angle, particularly around 10-12 degrees. Furthermore, when compared to the parcels in which destroyed buildings are found, there is a shift towards steeper slopes. When examining residential parcels in particular (i.e., those under 5 acres in size), this distinction is even clearer, as shown in Figure 41. The majority of buildings that burned are found on slopes of 20 degrees. Larger parcels (which are more likely to be ranches) are more likely to be found on slopes of around 15 degrees.

These results were also compared statistically with the tax assessor data for slope. The chi squared values from this test are found in Table 5. Comparing characteristics of burned parcels with the distribu-

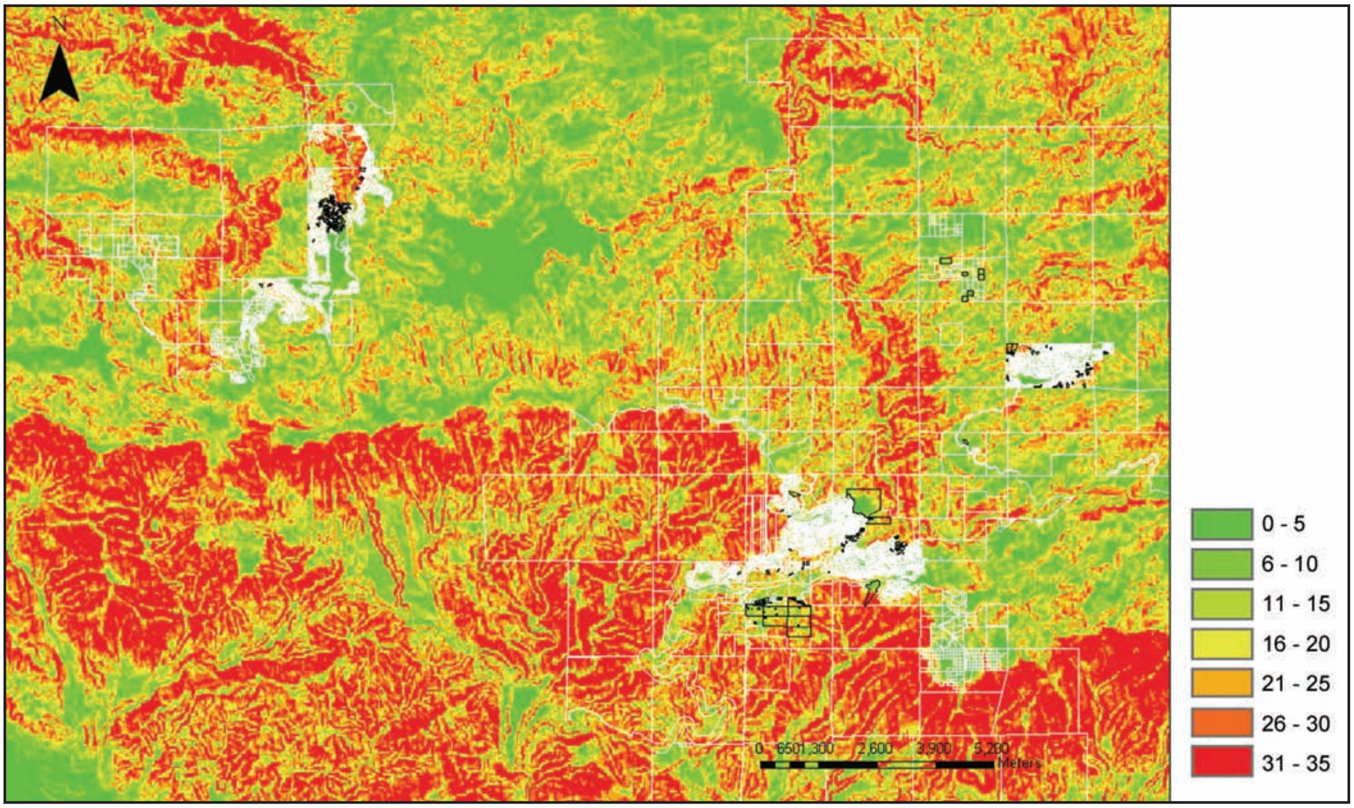

Figure 37. Distribution of slope (degrees) in San Bernardino, and overlain affected parcels (white) and destroyed buildings parcels (black).

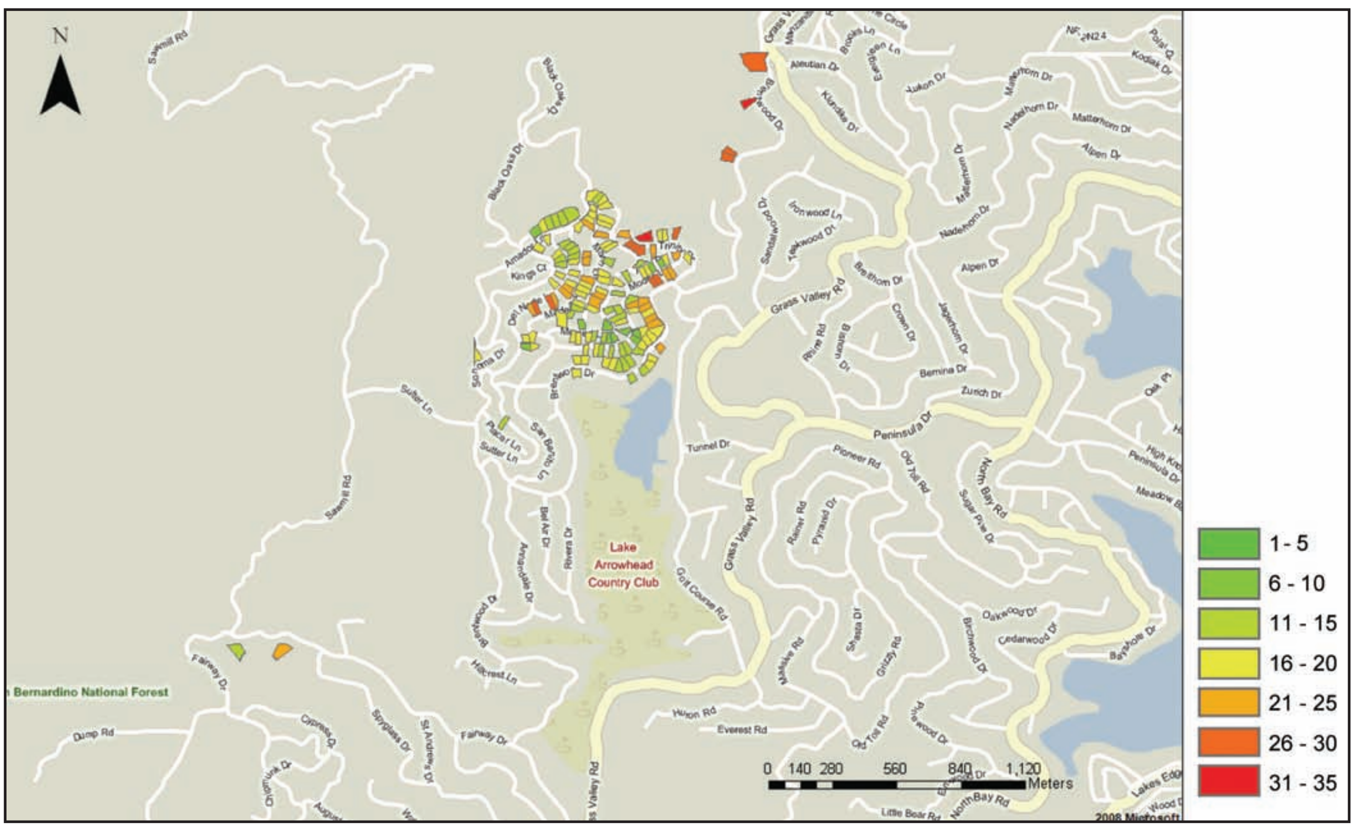

Figure 38. Close up of Grass Valley fire destroyed parcels, showing slope distribution (degrees).

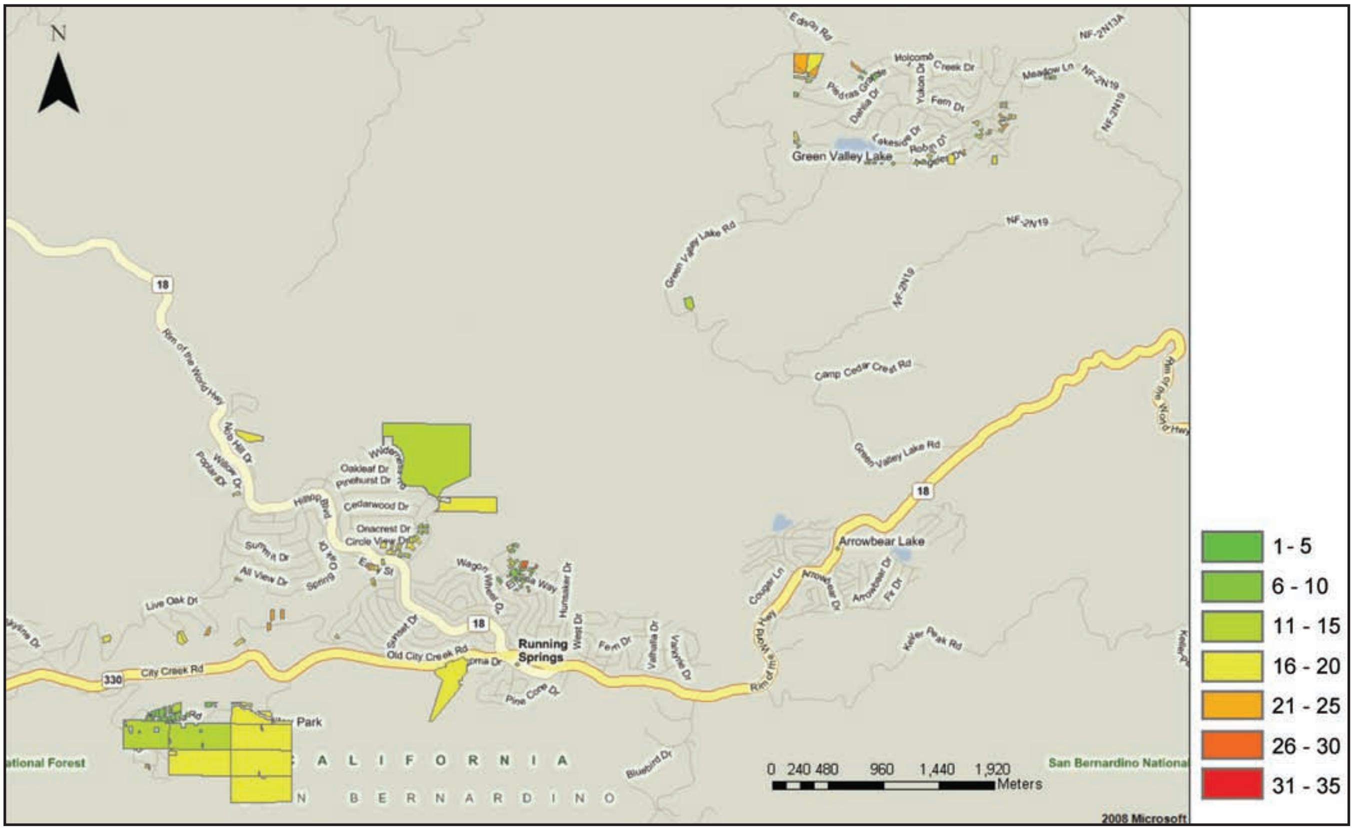

Figure 39. Close up of Slide fire destroyed parcels, showing slope distribution (degrees).

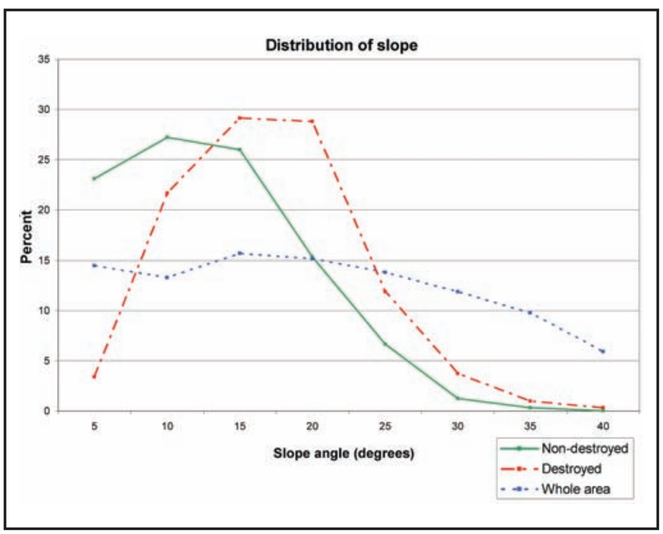

Figure 40. Distribution of slope in San Bernardino.

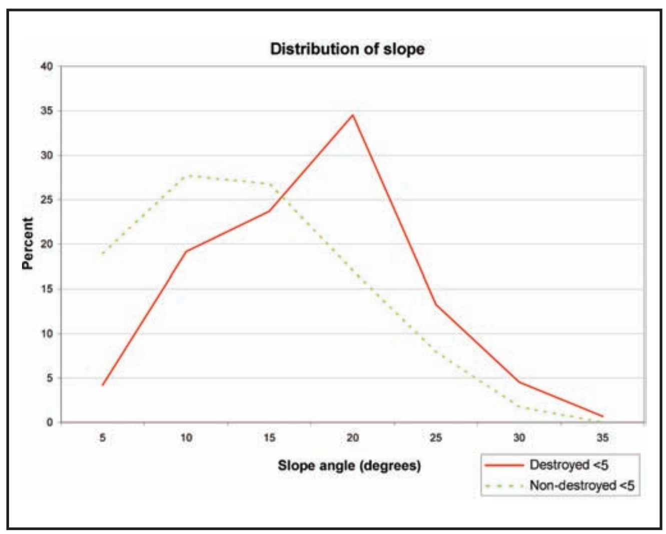

Figure 41. Distribution of slope in San Bernardino, parcels < 5 acres only.

tion of slope position and angle confirmed the findings from the NED data. In this area, slope position was a factor within parcels where houses burned. In particular, houses in the downslope position (compared to upslope, high bank or rolling) were seen to have a higher frequency of burn. Also, properties on steeper slopes showed a distinct increase in the frequency of burn, compared to other parcels in the affected area.

Table 5. Chi-squared results for significant burn and slope parameters obtained from tax assessors data

Parameter	Chi squared value	Significant at 0.05 level
Slope position (destroyed vs. non destroyed)	16.49 (4df)	Yes
Slope gradient (destroyed vs. non destroyed)	18.42 (2df)	Yes

San Bernardino Fire Summary

Two wildfire incidents were analyzed in San Bernardino:

- Grass Valley fire
- Slide fires

The Grass Valley fire occurred from October 22-29, 2007, destroying 1,200 acres of land and 175 buildings. The Slide fire burned from October 21 and was contained by October 31, 2007. It destroyed 265 buildings, and affected 13,000 acres of land. Preliminary analysis was undertaken into the distribution of burn, and destroyed structures throughout the fire, and the distribution of hazard and vulnerability factors such as elevation of parcel, aspect, slope angle and building age.

As in the Witch fires, the OES burn perimeter showed the maximum extent of the burn. Damage within this extent was variable, and was examined using aerial and ground-based surveying. Unlike the Witch fires, all the houses which burned within the Grass Valley and Slide fires occurred *within very high risk fire hazard severity zones*, categorized as such because of the topography, vegetation and fire history of the area.

The vegetative environment is characterized by pine forests. Vegetation clearance in this area of San Bernardino was not evident as it was in the case of the Witch fires. Trees were generally dense and in close proximity to buildings. An important finding in the study is that the *density of burned buildings was seen to be higher*; i.e., more clustered than the Witch fire, with a higher rate of burn in pocketed areas. Burn patterns suggesting the *domino effect of fires spreading from house to house* throughout whole neighborhoods was observed. This was found to be due to a number of factors, both environmental and structural. Characterizing this pattern and quantifying the density of burn will be a topic for future research.

The research conducted here suggests that the perimeters of urban settlement areas within the San Bernardino fires (commonly known as the *Wildland Urban Interface*) were *more prone to burn* than the center. Parcels had a high elevation in San Bernardino, which, when mixed with high slope angles and dense vegetation, made fire management a difficult proposition. The fire spread through some of the highest elevations in that part of the county. Unlike San Diego, the centers of residential areas were generally built on topographic highs, with the perimeter of the urban area situated downslope. Thus, as the perimeter of the urban area tended to burn, destroyed residential parcels had a shift towards slightly lower elevations than the average residential parcel. This was a different result to the Witch fires, suggesting that there is not a simple relationship between parcel elevation and property burn, and that settlement placement and pattern should be taken into consideration.

An interesting relationship was found between aspect of parcels and burn intensity. The fire swept through areas where there was a naturally higher proportion of southwest facing slopes. However, the *destroyed residential areas* tended to be on more *easterly facing aspects* than average, suggesting a westward progressing fire, blown by westerly winds.

Compared to the distribution of slope angles in the area, those parcels affected by the burn are more likely to be on relatively low slopes. However, considering the residential areas within this, those parcels where houses burned were more likely to be on steeper slopes than those which did not burn. Again, these were generally found on the perimeter of urban areas, at the Wildland Urban Interface.

Houses were predominantly wood frames with clapboard sidings. Roofs were generally either wood or asphalt shingle. These are traditionally not fireproof materials. No detailed comparison of building construction type and burn potential could be undertaken as the building stock was fairly uniform throughout the area. A comparison of building age yielded a preliminary result of a significant difference in burn rate between houses which were built post 2003 (3% rate of burn) and houses which were built pre 2003 (6% rate of burn). The geographic distribution of pre versus post 2003 buildings needs to be examined further.

Summary of Key Findings

In summary, this VIEWS™ field deployment for the 2007 California Wildfires has collected a unique dataset of perishable building and environmental damage data, through both aerial and on-ground vehicle-based deployments. It is the first deployment where VIEWS™ has been utilized for wildfire data collection. Preliminary analysis was undertaken using the aerial data to explore neighborhood scale relationships between burn, hazard and vulnerability factors. Research activities using the ground-based footage will be documented in a future publication.

The aerial VIEWS™ footage was used to map the occurrence of burned structures within the Witch, Grass Valley and Slide fire zones. Preliminary statistical analysis of destroyed building data has shown general relationships between burn occurrence and the slope, aspect and elevation of parcels, although this was seen to change with the type of environment the fire is in.

The Witch fires were characterized by grass and chaparral burn, with a mixture of building types impacted. The average elevation of parcels affected by burn in the Witch fire was relatively low, as the fire spread from higher elevations west into low flat valleys, where it interacted with a number of high density residential areas. In these areas, properties built on the perimeter of urban settlements, especially those on east-facing aspects, or those with relatively steep slopes, showed greater risk.

In the San Bernardino fires, the environment was very different, with higher elevations, steeper slopes, forested land cover and predominantly wooden structures with shingle or shake roofs. Here, the fire predominantly affected the very high elevation areas. The residential clusters within this were found on a range of elevations, with the settlements affected by the Grass fires on lower elevations than the Slide fires. Again, the most vulnerable residential areas were on the perimeter of urban clusters, but in this case, the elevation of burned parcels was likely to be at a lower elevation than average within the urban area, due to the center of settlements being built on local topographic highs. Destroyed buildings were more likely to be on steep slopes, as in the Witch fire, and were more likely to be found on easterly facing aspects.

These findings suggest that the characteristics of the most vulnerable buildings change depending on where the building is. Within an urban cluster, the most vulnerable areas are on the outskirts. In the case of California, because of the prevailing Santa Ana winds which tend to blow from the northeast (unless there are overriding local topographic effects) the most vulnerable aspects are eastern.

Overall, findings from the 2007 Witch and San Bernardino wildfires suggest that if key characteristics of an urban settlement are taken into consideration, a more adaptive set of fire mitigation strategies may be required than is currently in place. For instance:

- Predominant wind direction in times of high fire risk will dictate which aspects are most likely to require protection.
- Perimeters of urban areas require stricter planning considerations than those in the midst of an urban settlement.
- Combining these two factors, houses on the perimeter of an urban area on the side facing the oncoming predominant wind are most at risk.
- Houses built on steeper slopes require more protection.

It is proposed that a more refined scoring system than the existing FHSZ maps could be implemented for existing houses or planned construction projects considering a number of geographical and settlement variables. These could act as a future guide for the type of building regulations implemented.

Further study is warranted to examine the variability in urban burn intensity and pattern at a per-building scale, depending on parameters such as the type of vegetation, topography and distance from the fire front. It is possible that this could create recommendations for a more refined urban fire hazard zone system. For instance, a scoring system could be developed on a per building basis, which takes into account the particular urban settlement characteristics of an area, the proximity to urban perimeter, the predominant wind direction, aspect, slope and parcel elevation. This would dictate the type of mitigation strategies in terms of fireproof materials, retrofitting or vegetation clearance which may need to be implemented in specific areas.

With this goal in mind, on a per-building level, integrating remote sensing imagery with ground-based data collected using the VIEWS™ system can be used to identify specific building damage states, which can lead to better understanding and characterization of wildfire-specific devastation. Interpretation of both pre and post-disaster damage states through expert knowledge may yield vital information on the resilience of certain structures to wildfire events. Evidence of the importance of good building practice, and good vegetation clearance practice has already been shown using this data.

Furthermore, VIEWS™ data may help to validate the new FHSZ maps produced by CDA. In general, it was found that the zones marked as high or very high hazard corresponded with the areas which burned. However, within these zones, 'exceptions to the rule' are found, where buildings affected by the fire, in high vulnerability areas have not burned down, and vice versa. Explaining these exceptions warrants a more forensic per-building examination of building and vegetation quality.

The overarching conclusions to this preliminary study are that fire risk and fire management is a complex multi-faceted issue, which depends on the inherent geographical vulnerability of places, mixed with environmental hazard mitigation policies, and resilient building engineering. It is anticipated that these findings will form the basis of larger research investigations by MCEER's Remote Sensing Institute.

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