**Assessment and Improvement of Fire Resiliency for Structures
Located in the Wildland-Urban Interface**

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ABSTRACT

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Located in the Wildland-Urban Interface
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The purpose of this research was first to study the Wildland-Urban Interface and Wildland-Urban Intermix (WUI) fire problem, and then to design, develop and implement improved fire assessment and fire protection features for structures in the these interface fire-prone areas. Several areas of the world are prone to devastating fires that claim lives and destroy property, yet none of these compare to the property loss experienced in Southern California. It is because of the huge property loss and frequency of major WUI fires that Southern California was selected as the concentration for research and the case studies used in this paper. However, the results of the research are applicable to other interface fire-prone areas in the world.

The author is motivated by a need to dramatically improve our ability to effectively deal with what is no longer a fire “threat,” but the reality that people have chosen to live in an area of the world in which wildland fires are part of natural forest dynamics. To reduce the economic and social impacts of these inevitable fires, we need to understand the causes of fire damage, and establish methods to minimize damage when fires occur. This thesis proposes several fire protection strategies for increased fire resiliency and safety of individuals.

Following a search of fire history and analysis, three related fire assessment matrixes were synthesized (see Chapter Five). The Fire Profile Index is the principal fire assessment matrix. It was developed empirically and applied to historical fire spreads for a sense of accuracy. The intended users of the Fire Profile Index are design professionals, public agencies charged with oversight for development in the WUI, insurance agencies, building and landscape contractors, homeowners, potential homeowners, and fire service professionals. From the Fire Profile Index two derivative special-use matrixes were established for use by diverse groups. The first of these matrixes, the Developers’ Guide, is intended for design professionals, public agencies, insurance agencies, and building and landscape contractors. The second matrix is the Fire Assessment Guide, whose intended users are those concerned with development in high fire hazard areas, and who should have a fundamental knowledge of fire behavior. This group includes fire agencies, developers, homeowners, potential homeowners and insurance companies.

This thesis contributes to increased residential structure fire resistiveness and occupant fire safety in the WUI, by proposing site-specific fire assessment and corresponding design features in both structures and landscapes. Chapter Nine covers the development of noncombustible fire shields to divert airflow and diminish flames and embers blown towards structures. Wind tunnel modeling research was conducted at the Aerospace Program’s wind tunnel at California Polytechnic State University, San Luis Obispo. The results indicated wall configurations and location from structures for optimum reduction of flame and fire ember impingement.

KEYWORDS

Structure Fire Shields, Structure Safety Zones, Wildland-Urban Interface, structure fire resiliency, fire-resistiveness, Fire Profile Index, Fire Assessment Guide, Developers' Guide, Wildland-Urban Interface fire assessment, terrain influence on fire behavior, airflow directing wildfire, interface fire threat and mitigating measures, Mediterranean Climate fire threat conditions, growth in development in Wildland-Urban Interface, fire and ember barriers.

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TABLE OF CONTENTS

	Page
LIST OF TABLES	xv-xvi
LIST OF FIGURES	xvii-xxii
 CHAPTER ONE	
SECTION	
1.1 WUI FIRE BACKGROUND	1-10
1.1.1 FIRE PROBLEM TYPE.....	1-2
1.1.2 WUI FIRES FOCUS	2-6
1.1.3 INFORMATION RESOURCES	7-10
1.2 INTRODUCTION.....	11-31
1.2.1 WUI TERM.....	11-13
1.2.2 NATURAL FIRE.....	13-22
1.2.3 ANTHROPOGENIC FIRE.....	22-31
1.3 OBJECTIVES.....	32-38
1.3.1 FIRE MODELING PROGRAMS.....	32-33
1.3.2 FIRE PROFILE INDEX.....	33-34
1.3.3 STRUCTURE SAFETY ZONE.....	34-35
1.3.4 CASE STUDIES.....	35-36
1.3.5 FIRE SHELTERS	36-37
1.3.6 HOMEOWNERS GUIDELINES	37
1.3.7 CONCLUSION	38
1.4 THESIS GOALS AND METHODOLOGY.....	39-43

1.4.1	EXPERIENCE AND BACKGROUND	39-40
1.4.2	METHODOLOGY.....	41-43
1.5	CONTRIBUTIONS	44-48
1.5.1	FIRE PROFILE INDEX.....	45
1.5.2	DEVELOPERS GUIDE.....	45
1.5.3	FIRE SHELTERS	45-46
1.5.4	FIRE ASSESSMENT GUIDE.....	46
1.5.5	FIRE MODELING PROGRAMS.....	46-47
1.5.6	HOMEOWNERS GUIDELINES	47
1.5.7	STRUCTURE SAFETY ZONES.....	47
1.5.8	STRUCTURE FIRE SHIELDS	47-48

CHAPTER TWO

SECTION

2.1	WUI FIRE PROBLEM DESCRIPTION	49-53
2.1.1	INTRODUCTION.....	49-53
2.2	ANTHROPOGENIC CONTRIBUTING FACTORS.....	54-76
2.2.1	POPULATION AND DEVELOPMENT GROWTH.....	54-60
2.2.2	WUI CODE COMPARISON	60-72
2.2.3	INSTITUTIONAL INFLUENCE.....	72-75
2.2.4	FIRE EXCLUSION POLICY.....	75-76
2.3	ENVIRONMENTAL FACTORS	77-88
2.3.1	WEATHER COMPONENTS.....	77-79
2.3.2	FOEHN WINDS.....	79-83

2.3.3	MEDITERRANEAN CLIMATE.....	83-88
2.4	TOPOGRAPHICAL INFLUENCES.....	89-97
2.4.1	SLOPE.....	90-91
2.4.2	ASPECT.....	92
2.4.3	CHIMNEY EFFECT.....	92-94
2.4.4	RIDGES, NARROW CANYONS, SADDLES.....	95-97
2.5	FUELS.....	98-110
2.5.1	DEFENSIBLE SPACE.....	99-101
2.5.2	VEGETATION MANAGEMENT.....	101-102
2.5.3	DROUGHT TOLERANT/FLAMMABLE FUELS.....	103-110

CHAPTER THREE

SECTION

3.1	FIRE MODELING.....	111-115
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CHAPTER FOUR

SECTION

4.1	CASE STUDIES.....	116-125
4.1.1	INTRODUCTION.....	116-119
4.1.2	TEA FIRE CONDITIONS.....	119-123
4.1.3	GREEN MEADOWS FIRE CONDITIONS.....	123-125
4.2	CASE STUDY ONE.....	126-132
4.2.1	STRUCTURE DESCRIPTION.....	126-129
4.2.2	FIRE RESILIENCY ANALYSIS.....	129-132
4.3	CASE STUDY TWO.....	133-138
4.3.1	STRUCTURE DESCRIPTION.....	133-136

4.3.2	FIRE RESILIENCY ANALYSIS.....	136-138
4.4	CASE STUDY THREE.....	139-148
4.4.1	STRUCTURE DESCRIPTION.....	139-144
4.4.2	FIRE RESILIENCY ANALYSIS.....	144-148
4.5	FIRE BEHAVIOR ANALYSIS.....	149-155
4.5.1	INTRODUCTION.....	149
4.5.2	FIRE BEHAVIOR ANALYSIS.....	149-152
4.5.3	CHIMNEY CONVERSION FACTOR.....	152-153
4.5.4	SADDLE CONVERSION FACTOR.....	153-154
4.5.5	RELEVANCE FOR FIRE PROFILE INDEX.....	154-155

CHAPTER FIVE

SECTION

5.1	FIRE ASSESSMENT.....	156-177
5.1.1	INTRODUCTION.....	156
5.1.2	FIRE PROFILE INDEX.....	156-159
5.1.3	FIRE PROFILE INDEX USE.....	159-162
5.1.4	STRATEGY CODES.....	162-165
5.1.5	SELECTED COMMENTS.....	165-167
5.2	FIRE ASSESSMENT GUIDE.....	168-173
5.3	DEVELOPERS GUIDE.....	174-177

CHAPTER SIX

SECTION

6.1	STRUCTURE SAFETY ZONES.....	178-190
6.1.1	INTRODUCTION.....	178-180

6.1.2	DESCRIPTION.....	180-181
6.1.3	DETERMINATION OF STRUCTURE SAFETY ZONE.....	181-182
6.1.4	CALCULATIONS EXAMPLE.....	182-189
6.1.5	DISCUSSION.....	189-190
CHAPTER SEVEN		
SECTION		
7.1	STRUCTURE FIRE AND EMBER SHIELDS.....	191
7.1.1	INTRODUCTION.....	191-192
7.1.2	EMBER CATCHERS.....	192-193
7.1.3	STRUCTURE FIRE SHIELDS.....	193-195
7.2	STRUCTURE FIRE SHIELD DESCRIPTIONS.....	196-201
7.2.1	CONCAVE FIRE SHIELDS.....	196
7.2.2	CONVEX FIRE SHIELDS.....	197
7.2.3	LINEAR FIRE SHIELDS.....	198
7.2.4	INCLINE FIRE SHIELDS.....	198-199
7.2.5	HIGH PROFILE FIRE SHIELDS.....	199-201
7.3	WINDTUNNEL EQUIPMENT.....	202-203
7.3.1	TUFTS.....	202
7.3.2	SMOKE.....	203
7.4	OPERATIONAL DESCRIPTION.....	204-205
7.4.1	PHYSICAL LIMITATIONS.....	204
7.4.2	RECORDING RESULTS.....	204-205
7.5	MODEL FABRICATION.....	206-210
7.5.1	TEA FIRE REBUILD MODEL.....	208

7.5.2	MOBILE HOME PARK MODEL.....	208-209
7.5.3	GABLE ROOF MODEL.....	209-210
7.5.4	LOW PROFILE FIRE SHIELD MODEL.....	210
7.6	AIR MOVEMENT RELATIONSHIPS.....	211-212
7.7	WINDTUNNEL TESTS.....	213-214
7.8	FIRE SHIELD PERFORMANCE.....	215-223
7.8.1	CONCAVE FIRE SHIELD.....	215-217
7.8.2	CONVEX FIRE SHIELD.....	217-218
7.8.3	LINEAR FIRE SHIELD.....	218-219
7.8.4	INCLINED FIRE SHIELD.....	219-220
7.8.5	HIGH PROFILE FIRE SHIELD.....	221-222
7.8.6	STRUCTURE FIRE SHIELD RETROFIT.....	222-223
7.9	MODEL PERFORMANCE.....	224-229
7.9.1	TEA FIRE REBUILD.....	224-227
7.9.2	MOBILE HOME PARK MODEL.....	227-228
7.9.3	GABLE ROOF MODEL.....	228-229
7.9.4	LOW PROFILE MODEL.....	229
7.10	FOLLOW-UP STUDIES.....	230
7.10.1	STRUCTURE FIRE SHIELDS.....	230
7.10.2	EMBER CATCHERS.....	230
7.11	FINDINGS.....	231-233
7.11.1	MODEL SIZING.....	231
7.11.2	SMOKE USE.....	231

7.11.3	LAZER ILLUMINATION.....	231
7.11.4	PRESSURE TRANSDUCERS.....	231-232
7.11.5	TUFT ACTIVITY.....	232
7.11.6	FIRE SHIELD VORTICES.....	232
7.11.7	AIRFLOW INTRUSION.....	233
7.11.8	ENLARGED PHOTOGRAPHIC IMAGES.....	233
7.11.9	VIDEO RECORDING.....	233
CHAPTER EIGHT		
SECTION		
8.1	CONCLUSION.....	234-253
8.1.1	INTRODUCTION.....	234-235
8.1.2	INCREASING WUI FIRE PROBLEM.....	235-236
8.1.3	INTERNATIONAL IMPLICATIONS.....	236-238
8.1.4	SIGNIFICANCE OF AIRFLOW.....	238-239
8.2	FIRE ASSESSMENT CONTRIBUTIONS.....	240-241
8.2.2	FIRE PROFILE INDEX.....	240-241
8.2.3	DEVELOPERS GUIDE.....	241
8.2.4	FIRE ASSESSMENT GUIDE.....	241
8.2.5	FIRE MODELING PROGRAMS.....	242
8.3	CONTRIBUTION MADE BY MITIGATING MEASURES.....	243-252
8.3.1	STRUCTURE SAFETY ZONES.....	243-244
8.3.2	STRUCTURE FIRE SHIELDS.....	244-250
8.3.3	FIRE SHIELD EQUIVALENTS.....	250-253
BIBLIOGRAPHY.....		254-271

APPENDICES	272-346
APPENDIX	
A PLANT LISTINGS & ILLUSTRATIONS OF HARD CHAPARRAL..	272-278
B FEMA DISASTER DECLARATIONS	279-290
C SELECTED HAZARD SEVERITY ZONES OF CALIFORNIA.....	291-292
D RHINOCEROS GENERATED MODEL PLANS.....	293-295
E TEA FIRE WEATHER DATA.....	296-301
F CASE STUDY ONE ACCOMPANYING INFORMATION.....	302-307
G CASE STUDY TWO ACCOMPANYING INFORMATION	308-315
H CASE STUDY THREE ACCOMPANYING INFORMATION.....	316-322
I TABLE I.1: FIRE PROFILE INDEX.....	323-335
J TAGLE J.1: FIRE ASSESSMENT GUIDE.....	336-339
K TABLE K.1: DEVELOPERS GUIDE.....	340-346

LIST OF TABLES

TABLE	DESCRIPTION	Page
CHAPTER ONE		
1.2	Annual Fire Losses by Type and Cost.....	4
1.3	Fire Disaster Declaration in California.....	6
1.7	Modified Bond and Van Wilgen Model of Plant Fire Response Classification for California Flora.....	15-16
1.9	Fire Responses of Plants	20-21
CHAPTER TWO		
2.7	Comparison of 2008 NFPA 1144 and 1141, 2010 California Fire Code Chapter 49, 2007 California Building Code Chapter 7A, 2009 International Wildland-Urban Interface Code.....	64-68
2.8	2009 IWUIC Fire Hazard Severity Assessment.....	70
2.9	Reductions in Fire-Resistant Construction.....	71
2.14	Mediterranean Climate Areas Fire Characteristics of Wind and Fuels.....	87-88
CHAPTER THREE		
3.1	Fire and Wind Modeling Programs Description and Accessibility	112-114
CHAPTER FOUR		
4.13	Fire Behavior Analysis.....	151-152
CHAPTER FIVE		
5.1	Fire Profile Index Initial and End Sections.....	157
5.3	Fire Assessment Guide Initial and End Sections.....	169
5.4	Developers' Guide Initial and End Sections.....	175
CHAPTER SIX		
6.3	Structure Safety Zone Calculations	185-187

APPENDIX H	
H.1	Fuel Ages and Fire Severity Index.....316
APPENDIX I	
I.1	Fire Profile Index.....323-334
APPENDIX J	
J.1	Fire Assessment Guide.....336-339
APPENDIX K	
K.1	Developers' Guide..... 340-346

LIST OF FIGURES

FIGURE	TITLE	Pag
1.1	Fire Incident Reduction by Type (since 1977).....	3
1.4	October 2007 Witch Fire Perimeter in San Diego County and Rancho Santa Fe Location.....	9
1.5	Aerial Photo of Wildland-Urban Intermix.....	12
1.6	Aerial Photo of Wildland-Urban Interface.....	12
1.8	Foothill Pine in Fuel Mosaic with Chaparral and Grassland.....	18
1.10	Bunchgrass Meadow with Oak Woodland Surrounding Santa Rosa Plateau near Murietta, California.....	28
1.11	Grassland and Flowers Recovering after Tea Fire of 2008 in Santa Barbara.....	31
 CHAPTER TWO		
2.1	Spectators Viewing the Witch Fire of October 2007 in San Diego County.....	51
2.2	United States Housing Density, Year 1940.....	55
2.3	United States Housing Density, Year 2000.....	56
2.4	United States Wildland-Urban Interface, Year 2000.....	57
2.5	California Housing Density, Year 2000.....	58
2.6	California Wildland Fire Threat Zones.....	59
2.10	June 2008 Sundowner Wind Blowing Gap Fire Smoke Across Pacific Ocean Near Santa Barbara, California Area.....	81
2.11	November 2008 Santa Ana Wind Blowing Smoke Across Pacific From Freeway Complex and Sayre Fires in Southern California.....	82
2.12	February 2009 Föhn Wind Blowing Smoke Across Pacific Ocean From Black Saturday Fires, Near Melbourne Australia.....	83

2.13	Location of The World's Fire Mediterranean climates.....	84
2.15	Natural Chimneys Formed by Spur Ridges.....	93
2.16	In-Turn and Out-Turn on a Midslope Road.....	94
2.17	Map Depiction and Sketched Elevation of a Saddle.....	96
2.18	Ridgeline Saddle with Accompanying Chimney.....	97
2.19	Defensible Space and Reduced Fuel Zones.....	100
2.20	Fuel Reduction Zone for Southern California Chaparral.....	103
2.21	California Coastal Chaparral.....	105
2.22	Schlerophyll Scrub Forest in Subalpine Zone, New Zealand.....	106
2.23	Fynbos of South Africa.....	107
2.24	California Fire Behavior Potential Ranking by Fuel Type.....	108
2.25	California Land Cover by Vegetation Type.....	109

CHAPTER THREE

CHAPTER FOUR

4.1	Tea Fire Perimeter Map Indicating Locations of Case Studies One and Two, Fire Origin, Wind Direction.....	118
4.2	1993 Firestorm Locations with Green Meadows Fire Perimeter.....	119
4.3	Coastline of Southern California with Locations of Case Studies.....	120
4.4	Tea Fire Flame Lengths Near Case Studies One and Two.....	121
4.5	Flame Lofting Above Case Study #3 During Green Meadows Fire.....	124
4.6	Overhead View of Case Studies One and Two Prior to the Tea Fire.....	126
4.7	Case Studies One and Two and Local Peak Burning Direction.....	127
4.8	Case Study Two Residence After Tea Fire.....	135
4.9	Case Study Three Aerial View with Saddle and Chimney Indicated.....	140

4.10	Roof, Parapet Walls and Retaining Wall at Front of Residence.....	142
4.11	Diagram of Angle of Terrain Slope Extending to Top of Parapet Wall....	146
4.12	Case Study Three Structures with Natural Linear Inclined Fire Shield....	147
CHAPTER FIVE		
5.2	Fire Profile Index Strategy Codes.....	158
CHAPTER SIX		
6.1	Case Study Three Structures with Wind and Fire Spread Directions.....	182
6.2	Case Study Three with Contour Lines, Wind and Fire Spread Directions.....	184
6.4	Case Study Three with Structure Safety Zone Outline.....	188
CHAPTER SEVEN		
7.1	Tea Fire Scale Rebuild Model, Convex Structural Fire Shield.....	191
7.2	Concave Structural Fire Shield, with Increased Turbulence.....	192
7.3	Convex Structural Fire Shield, with Airflow to Outside of Arch.....	195
7.4	High Profile Linear Structure Fire Shield.....	197
7.5	Mobile Home Park Model with Inclined Structure Fire Shield.....	199
7.6	High Profile Incline Structure Fire Shield.....	201
7.7	High Profile Convex Structure Fire Shield.....	207
7.8	High Profile Concave Structure Fire Shield.....	214
7.9	Concave and Convex Structural Fire Shield Schematic.....	216
7.10	Environmental Example of Convex Fire Shield.....	219
7.11	Linear High Profile Structure Fire Shield at Mobile Home Model.....	220
7.12	Airflow Schematic of Linear Structural Fire Shield, High Profile Inclined Structural Fire Shield.....	222
7.13	Tea Fire Rebuild Plot Plan.....	225

7.14	Tea Fire Rebuild Rhinoceros Generated Plans.....	226
CHAPTER EIGHT		
8.1	Mediterranean Climate Areas.....	237
8.2	Tea Fire Scale Rebuild Model.....	244
8.3	Concave and Convex Fire Shields Schematic, Airflow Vectors Indicated By Arrows.....	247
8.4	Airflow Schematic of Linear Structural Fire Shield and High Profile Inclined Structural Fire Shield With Arrows Depicting Airflow.....	248
8.5	Environmental Example of Convex Fire Shield.....	249
8.6	Faux Subterranean House Under Construction, Survive the Tea Fire.....	251
8.7	Rendering of House Under Construction.....	252
8.8	Faux Subterranean House with Pool Roof.....	252
APPENDICES		
APPENDIX A		
A.1	Plant Listings and Illustrations of Hard Chaparral.....	272-278
APPENDIX B		
B.1	FEMA Disaster Declarations.....	280-290
APPENDIX C		
C.1	Santa Barbara County Very High Fire Hazard Severity Zones in Local Responsibility Areas.....	291
C.2	San Luis Obispo County Very High Fire Hazard Severity Zones in Local Responsibility Areas.....	292
APPENDIX D		
D.1	Tea Fire Rebuild Model.....	293
D.2	Gable Roof Model.....	294
D.3	Mobile Home Park Model.....	295
APPENDIX E		
E.1	Tea Fire Weather Data.....	296-301

APPENDIX F

F.1	Roofs of Case Study One and Site of Case Study Two.....	304
F.2	Case Study One Residence, Studio and Garage with Jesusita Fire in Background.....	304
F.3	Water Tank at Top of Chimney on West Side of Property.....	305
F.4	Coyote Canyon Ridgeline Protection of Case Study One Structures.....	305
F.5	Scorched Eaves on East Side of Main Residence.....	306

APPENDIX G

G.1	Location of Case Study Two After Tea Fire.....	311
G.2	Case Study Two Location as Viewed From Coyote Canyon.....	311
G.3	As Built Print of Case Study Two.....	312
G.4	Case Study Two Site Plan.....	313
G.5	Case Study Two Contour Map.....	314
G.6	Panoramic View of Case Studies One and Two.....	315

APPENDIX H

H.2	Aerial Map of Case Study Three with Contours and Location of Ridgeline Peaks Indicated.....	317
H.3	Aerial Photograph of Case Study Three with Location of Ridgeline Peak Indicated.....	318
H.4	View of Inside of Retaining Wall Forming Linear Fire Shield.....	318
H.5	Terrain Formed Incline Fire Shield.....	319
H.6	Flat Roof, Parapet Walls and Front Fire Shield.....	319
H.7	Fire Shield Retaining Wall at Front of Residence.....	320
H.8	Terrain Formed Incline Fire Shield.....	321
H.9	Palm Tree Trunks	321
H.10	Terrain Formed Incline Fire Shield.....	322

H.11	Flames Angle of 65%, Same as Slope.....	322
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APPENDIX I FIRE PROFILE INDEX

I.2	Fire Profile Index Strategy Code.....	335
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CHAPTER ONE

1.1 BACKGROUND

1.1.1 FIRE PROBLEM TYPE

America has a wide range of fire problems that have a significant impact in terms of lives lost, injuries, burned structures, environmental pollution, as well as direct and indirect costs. The National Fire Protection Association (NFPA) annually reports all fire types, including vehicles, industrial structures, high-rise buildings, outdoor, brush fires, and many more subcategories in the United States, and issues a fire loss report. For example, in 2004 the NFPA's annual study reported no significant reduction in fire losses, and even some disappointing increases from 2003 onward. Also, during the reporting year of 2003 fire related injuries totaled nearly 18,000, with most of those injuries occurring in homes. However, property damage in the next reporting year, 2004 decreased by over 20%, or \$2 billion from \$9.8 billion in 2003. This unusually large decrease was due to fewer costly conflagrations in Southern California. The NFPA has issued its fire loss report every year since 1977, and noted the following trends in 2005, "Despite the lack of significant improvement in 2003, since 1977 reported fires have declined by roughly half and associated fire deaths by nearly half, according to the NFPA" (Fire Chief 2005).

The subject of this research is limited to Wildland-Urban Interface (WUI) fires. All other fire types are considered outside the scope of this thesis. The NFPA statistics from 2003 show the extent of the impact WUI fires can have on property loss nationwide. Property loss declined by \$ 2 billion, or about 22% in 2004. The NFPA's "Fire Loss in the United States 2004" report attributed the sharp decrease to the non-reoccurrence of the two costly fires that Southern California endured in 2003 (Fire Chief 2005).

The Cedar Fire that occurred in San Diego County accounted for \$1.3 billion of property loss, and the Old Fire in San Bernardino County resulted in a loss of just under \$1 billion. The impact of these two WUI fires had a considerable impact nation-wide, apart from the devastating impact on Southern California.

1.1.2 WUI FIRES FOCUS

The cost of WUI fires in California is continually increasing, while the national overall trend has been leveling-off when adjusted for inflation and increased housing prices. The increase in fire loss in California appears to be largely due to the occurrence of WUI fires. Without consideration of WUI fires, the national statistics could be interpreted as suggesting a possible reduction in fire losses even for California. Besides the dollar cost, there appears to be a trend of a sharply reduced incidence of fires nationwide, except perhaps within areas prone to wildfires. In the NFPA's annual fire loss reports from 2003 to 2008, it is repeatedly stated that since 1977 the number of fires has been steadily declining (Figure 1.1). However, the costs in terms of fighting WUI fires are escalating at an unsustainable rate. The fire loss in terms of dollars and lives is unbearable, and the occurrence of these conflagrations is continuing without abatement.

Since the Federal Government published *America Burning* in 1973 (National Commission on Fire Prevention and Control 1973) and subsequently established the United States Fire Administration, the incidences of fire, fire-related fatalities and injuries have steadily declined. In 1973, the annual fire-related deaths reached 6,200, and in 1977, nearly 1.1 million structure fires were reported. In contrast, only 3,000 fire-related deaths occurred, and 515,000 structures burned in 2008. Fire-related injuries have also gradually declined since 1977, but have remained in the 16,000 to 17,000 range during the current decade (Karter 2009). Table 1.2 summarizes the fire loss of structures and residences within the United States, including California's numerous WUI fire losses in conflagration, or fire storms.

The data in Table 1.2 were taken from the NFPA's annual fire loss reports (i.e. 2003 to 2007). The number of structure fires and residential fires are rounded off to the nearest thousand.

Figure 1.1: Fire Incidence Reduction by Type (since 1977)
(<http://firechief.com/awareness/american-still-burning/>)

Fire loss figures for both residential and structure fire are rounded to the nearest one-tenth of a billion dollars. To simplify comparison, structure fires and residential fires were selected because of their involvement in WUI fires. It is acknowledged that vehicular and other types of fire losses occur during WUI incidents, but may not have been reported to the NFPA.

The dollar loss of structures and residences related to WUI fires is included in each category of the NFPA's Annual Fire Loss Reports (a special notation appears under the "CA WUI Impact" column for 2003, 2007, 2008, when Southern California impact was significant). WUI fires significantly impact fire losses every year. Instead of showing a 50% reduction since 1977 as most fire types have, WUI fires have continued to register an increased dollar loss.

TABLE 1.2: ANNUAL FIRE LOSSES BY TYPE AND COST

Year	Structure Fires (1,000's)	Residential Fires (1,000's)	Structure Fire Loss (\$ billions)	Residential Fire Loss (\$ billions)	CA WUI Impact (\$ billions)
2003	520K	402K	\$8.7b	\$6.5b	\$2.3b
2004	526K	411K	\$8.2b	\$5.9b	
2005	511K	396K	\$9.1b	\$6.8b	
2006	524K	413K	\$9.6b	\$6.9b	
2007	531K	414K	\$10.6b	\$7.5b	\$1.8b
2008	515K	402K	\$12.4b	\$8.6b	\$1.4b

The importance of WUI fires is not only due to losses in terms of dollars, injuries and lives, but because of the potential impact on society as a whole. In its publication entitled *Mega Fires*, The Institute for Business and Home Safety (IBHS), an association of insurers and builders dedicated to reducing the social and economic effects of natural disasters, indicates that, "...fully one-third of homes in the United States are now located in what fire safety officials call the Wildland-Urban Interface" (IBHS 2008, 3). The IBHS further states in *Mega Fires* that there are over 5 million homes in WUI areas of California alone, and that nationwide over 60% of new development is located within or adjoining WUI areas.

With more development taking place in areas prone to wildfires, exposing structures to the perils of uncontrolled fire, the WUI fire problems will only worsen.

In the summer of 2009, several “States of Emergency” were declared in California. California’s Governor Arnold Schwarzenegger declared that California has a “Year Round Fire Season.” Also, the Governor pledged that any necessary resources will be allocated in spite of the state’s budget crisis. Keeping these factors in mind, this thesis will address the influence of national and worldwide WUI fires as they continue to escalate their threat to society and the environment. WUI fires not only cause losses in terms of dollars, injuries and lives, but have an important potential impact on society as a whole.

Exemplifying this trend, the Federal Government has declared States of Emergency for WUI fires in California on an escalating basis. The number of declared fire states of emergency remained low since records began in 1953. During the last 20 years, however, the declarations have increased as can be seen in Table 1.3. The occurrence of Major Disaster Declaration, Emergency Declaration, and Fire Suppression Authorizations were obtained from the Federal Emergency Management Administration (FEMA) website for 1953 to 2009 (Federal Emergency Management 2009). The three categories of emergency declaration are grouped under the encompassing term of “Disaster Declarations” in the *California State Multi-Hazard Mitigation Plan* (California Emergency Management Agency 2007). The fire-related declarations for California have occurred in the WUI interface, or were primarily wildfires that threatened WUI areas. There have been 15 fire-related Major Disasters Declarations in California since 1953; eight of them declared subsequent to 1990. All four Emergency Declarations for California happened after 1996. Fire Management Declarations give greater insight into the escalating WUI fire problem.

Of the 111 instances of Fire Management Assistance, 106 occurred in the years 2002 through 2009. The full text of collected FEMA Disaster Declarations for California State from 1953 to 2009 can be seen in Appendix B.

Keeping these factors in mind, this thesis will address the influence of national and worldwide WUI fires as they continue to escalate their threat to society and the environment.

*Table 1.3: Fire Disaster Declaration in California
1953 to 2009*

Year	Major Disaster Declaration	Emergency Declarations	Declared Fire Disasters
2009			9
2008	1	1	16
2007	1	1	16
2006			8
2005			7
2004			22
2003	1		16
2002			12
2001			
2000			
1990s	5	2	
1980s	4		4
1970s	1		1
1960s	1		
1950s	1		
Total	15	4	111

1.1.3 INFORMATIONAL RESOURCES

The author found a plethora of information and publications relating to the WUI fire problem. Thesis resources included references on wildland firefighting, WUI or Interface Zone (I-Zone) firefighting and structural preparation. Several wildland fire-modeling programs are easily available in the public domain, such as Farsite, Behav, and BehavPlus. Many informative wildland fire and WUI fire research papers can be found online from sources such as the National Interagency Fire Center and the Rocky Mountain Research Station. However, none of these resources fully addresses the complex nature of strengthening the fire resiliency of structures in locations where the wildland meets developed areas. There appears to be a lack of authoritative data resources for either assessing the fire threat on an individual site, or for improving the fire protection design of structures once the fire potential has been assessed.

A literature search of the WUI fire problem leads directly to specific types of WUI building codes, a limited number of development requirements, and an even more limited number of design books. The best examples of the aforementioned literature are briefly discussed below. The *California Building Code (CBC) Chapter 7A* (International Code Council 2009 Feb.) is a substantial improvement on existing building codes dealing with the WUI fire problem. It certainly is a leader in the United States, because it offers a performance-based solution as an alternative to prescriptive code requirements. The emphasis of CBC Chapter 7A is on preventing structure ignition from flame and burning ember intrusion in areas prone to wildfires. It specifies, in conjunction with local jurisdictions requirements for defensible space, access, roadside clearance, ignition-resistant materials and methods of construction. The code requirements can be met in either a performance or prescriptive manner. However, as part of the California Building Code, CBC Chapter 7A offers only limited information on the design and relatively safe integration of structures into a potential incendiary environment. It is therefore the responsibility of local governments to establish fire safety requirements and procedures specifically for their communities.

For more information on WUI codes and standards a comparison of leading codes and standards, including CBC Chapter 7A is presented in Chapter Two, Section 2.2.2.

The Rancho Santa Fe community, located in San Diego County, California is a progressive leader in prescribing improved fire-resilient development in high fire hazard zones. The Rancho Santa Fe Fire Protection District is, and was, instrumental in establishing building and community Shelter-In-Place (SIP) fire protection measures for WUI areas. The WUI codes, in particular the 2006 International WUI Building Code (International Code Council 2009 Sep.), adopted into ordinance some important provisions that exceed those of the CBC Chapter 7A. An innovative aspect of the community-based SIP fire hardening concept is that structures should be located on individual lots as far as practical from the predominant flame and wind-borne ember threat. The concerns and actions of the Rancho Santa Fe officials and the jurisdiction's SIP communities gained a great deal of credence as a result of the Witch Fire in October 2007. During this fire, which burned over 1,000 homes in San Diego County, not a single home was destroyed in the SIP communities of Rancho Santa Fe (Institute for Business and Home Safety 2008). Figure 1.4 shows the perimeter of the Witch Fire and the location of Rancho Santa Fe. However, a great deal of understanding of the thermal dynamics of WUI fires, building design, and construction is necessary to translate the prescriptive and performance standards of the codes and ordinances of Rancho Santa Fe into building design guidelines.

An excellent reference on the topic of WUI defensible structure design is an Australian book, Landscape and Building Design for Bushfire Areas, published in 2003 (Ramsay and Rudolph 2006). This appears to be the first reference that addresses the design of structures in WUI areas. The authors state that the chances of a building surviving a bushfire in Australia, a brush fire in the United States, or more aptly a WUI fire lies in the understanding of the fire phenomenon, and then designing the structure and landscape accordingly.

This building design handbook clearly describes the environment in which brush fires occur, how a wildfire progresses, and how structures are first ignited and then destroyed. The authors advance a practical design approach for the application of wildfire behavior for structures and their immediate surroundings. Furthermore, they emphasize that brushfire defense should be an integral part of the design process for WUI areas, rather than a code-required add-on. However, even this reference does not specifically address the assessment of the wildland fire threat posed at an individual sites, nor does it propose design concepts that offer hardened flame and ember wash protection provisions and barriers.

Figure 1.4: October 2007 Witch Fire Perimeter in San Diego County and Rancho Santa Fe Location. (<http://www.treewind-times.com/WitchFireMap.jpg>)

Although the author examined and assimilated many papers, articles, and other related references, no specific reference was found that addresses the assessment of the WUI threat on a particular building site and then extrapolates design guideline from such an assessment. Therefore, the objective of this thesis is to add to the existing body of knowledge on WUI in the following specific areas: the use of concave and convex walls as fire barriers; the creation of a fire-profile indexing system for the assessment of site-specific fire threats; the evaluation of turbulent airflow effects on structures; the design of a fire shelter to protect the occupants of a building located in a WUI area in an emergency situation; and, determination of whether code-specified defensible space is adequate for any one development and the safety of its occupants.

1.2 INTRODUCTION

1.2.1 WUI TERM

Understanding the acronym WUI (Wildland-Urban Interface) will give insight into the unique fire problem it represents. The WUI is comprised of both wildland-urban interface and intermix communities. In both of these areas federal standards require a minimum housing density threshold of one house per 40 acres of wildland acreage. Below this threshold, the structure threat is sufficiently reduced so that the fire problem is regarded as fundamentally wildland. The United States Department of Agriculture (USDA) and the United States Department of Interior (USDI) in 2001 established this density of housing required for an area to be considered as an interface or intermix in a natural vegetated region. The wildland intermix community has at least 50% of its area covered in contiguous natural vegetation. Figure 1.5 depicts a wildland intermix community; note the lower density housing relative to surrounding wildland fuels. Essentially, wildland-urban intermix communities are locations where improved property and/or structures are scattered and interspersed in wildland areas. These may be isolated rural homes or areas that begin the transition from rural to urban land uses (Spirn 2007).

The interface refers to areas where wildland vegetation meets urban development, or where forest fuels meet urban fuels (i.e., houses, landscaping). In an interface community, housing is contiguous to wildland vegetation that covers less than 50% of the area. These communities encompass not only the urban development interface, as expressed above, but include continuous fuel situations that lead directly to urban areas (i.e., undeveloped parkland). This WUI situation is defined as an urbanized area within 1.5 miles of contiguous wildland vegetation of over 1,325 acres that is more than 75% wildland vegetation (SILVIS 2009). Figure 1.6, shows the boundary area of a wildland-urban interface community.

Figure 1.5: Aerial Photo of Wildland-Urban Intermix
(http://architecture.mit.edu/class/nature/student_projects/2007)

Figure 1.6: Aerial Photo of Wildland-Urban Interface Boundary
(http://architecture.mit.edu/class/nature/student_protects/2007)

According to Spirn (2007,8) "... a boundary area of development is where homes, particularly new subdivisions, meet public or private wildland, such as private or commercial forest land or public forests and parks. The boundary is clearly defined between suburban (or urban) and rural countryside." In summary, the WUI is the area where development, primarily housing abuts significant areas of natural fuels.

1.2.2 NATURAL FIRE

Fire is a natural feature of the wildland. As such, it cannot be eradicated, but only controlled by heroic firefighting efforts. California's chaparral and foothill woodland forests compose some of the world's most volatile and destructive WUI fire areas. Before humans harnessed fire as a tool, natural fires were started predominately by lightning strikes, and to a far lesser extent by thermal volcanic activity. Plants in the oak woodlands and chaparral wildlands effectively evolved by being exposed to relatively high frequency, low-intensity fires. Because of the fire influence in the evolutionary process, chaparral, oaks, and similar plants have become adapted, thrive, and in some cases become dependent on fire for their existence. As an example, low-intensity fires, generally started by lightning, increase the vigor of native or exotic fire-adapted plants (DeBano et al. 1998). A discussion of the fire influence on vegetation is enhanced by a discussion of plant fire response terms. Fites-Kaufman (2006, 104) argues:

The fire responses of plants are divided into two broad categories based on whether the plant is, or is not stimulated by fire. Fire-stimulated responses are those that increase with fire, such as seed germination or sprouting. Fire-stimulated plants are further divided into fire-dependent and fire-enhanced categories, while plants not stimulated by fire are either fire-neutral, or fire-inhibited. Fire-dependent responses occur only with fire, such as seed germination requiring heat, smoke, or chemicals from charcoal. Fire-enhanced responses (e.g. sprouting) are those that are increased by fire but that also occur from other types of damage to the plant.

In this section, only a limited discussion of plant fire influences will be presented.

A detailed discussion of plant fire related terms, plant flammability, and of plant contribution to the WUI area fire problem is presented in Section 2.4 (Fuels). Plant common names will be used throughout this thesis. The Binomial Nomenclature (scientific names) of plants is located in Appendix A, Plant Listings and Illustrations of Hard Chaparral for reference. There are many different plant fire adaptations, but they should be considered within limitations. Anderson (2001) argues that generalizations about the effects of fire on vegetation can be misleading. Fites-Kaufman (2006, 104) presents Table 1.7, which is a reproduction of a table of “Modified Model of Plant Fire Response Classification for California Flora,” from Bond and van Wilgen (1996, 263). The table summarizes the fire influences on the reproduction of California flora, and gives some examples of fire interplay on plant physiology. A key term in Table 1.7 is “sprouters”. Sprouters are plants that have a morphological response stimulated by fire damage to their tops, or crowns. Sprouting can take place in a number of plant structures, such as aerial stems, rhizomes, bulbs, corms, lignotubers, and roots (Fites-Kaufman 2006).

There are several beneficial effects that fire has on vegetation. These effects are significant and will help to explain why flammable vegetation exists in wildfire-prone areas. While there are many adverse effects of wildfire, such as erosion, these negative effects on an ecosystem will not be emphasized. Wildfire reduces dead vegetation, stimulates new growth, replenishes soil nutrients, improves hydrologic processes, and improves wildlife habitat. Burning reduces the number of snags, logs, woody debris, and density of trees. This process results in greater average tree size and fewer saplings, and will more generally allow these plants to survive subsequent fires (Purcell and Stephens 2005). From a landscape level, post-fire vegetation produces a complex mosaic of habitats, with irregular patches and abundant edges (Purcell 2005). As an example of fire-improved habitat, certain species of birds benefit from fire because they consistently nest in habitats similar to what is the result of low-intensity fires (Anderson 2001).

In another example, an increased aggregate of grasses and forbs are introduced due to the reduced continuity and loading of heavier fuels following a wildfire. When a fire results in plant succession back to a grass, or forb stage, herbivores and other animal species benefit, using herbaceous vegetation as cover (Purcell and Stephens 2005). Figure 1.8 depicts a fuel mosaic that is likely to enhance wildlife habitat. Note the irregular edges and succession mixture of plant species, with a reduction in chaparral dominance.

Table 1.7: Modified Bond and Van Wilgen Model of Plant Fire Response Classification for California Flora

REPRODUCTIVE STRATEGY			
		NON-SPROUTERS	
Fire-Stimulated	Sprouters	Not Killed By Fire	Killed By Fire
Fire-Dependent	Flowering only or almost entirely after fire (mariposa lily, death camas)	Fire-stimulated flowering, germination, seed release (golden-eyes)	Seed release from heat (knobcone and Bishop pines, bigpod ceanothus)
Fire-Enhanced	Species increase after fire, but establishment occurs in fire-free interval too (black oak, aspen)	Seed release and seedling establishment enhanced (ponderosa pine)	Seed germination enhanced (tobacco brush, mountain white thorn)
Not Fire-Stimulated Fire-neutral	Sprouting recruitment same following fire as in fire-free interval, continuous sprouters (scrub oak, bigleaf maple, cottonwood, sedges)	Seed germination same following fire as in fire-free interval; seed producers survive fire (Douglas fir, sugar pine)	Long-distance seed dispersal (fire weed, thistle)

REPRODUCTIVE STRATEGY			
		NON-SPROUTERS	
Fire-Stimulated	Sprouters	Not Killed By Fire	Killed By Fire
Fire-Inhibited	Sprouting recruitment less following fire than in fire-free interval	Seed germination less following fire than in fire-free interval (mature firs)	Mature & seedling individuals killed by fire; post-fire recruitment low (Sitka spruce, Santa Lucia fir, fir seedlings)

Not all the effects of fire on fire-adapted vegetation are beneficial. Anderson 2001, 4) argues that "... plants stressed through drought, disease, insect infestations, overgrazing, old age or a combination of these factors are likely to be negatively impacted by burning regardless of how they would respond if healthy." Under these stress factors, post-fire plant productivity can be adversely affected and short-term decreases in basal area of grasses, forbs, and shrubs can result. Native fire-adapted vegetation may experience phonological setbacks when the burning intensity is intense (Anderson 2001). Fites-Kaufman (2006, 111) argues that "... burned forests or shrublands may convert to herbs or grasses, at least temporarily, until shrubs and trees recolonize the area." This recolonizing may take only a few years for shrubs such as chamise , manzanitas, ceanothus, or 10 to 20 years for trees (Fites-Kaufman 2006). Also, changes in the composition of plant species to less productive plant species, with reduction in available soil nutrients, may be an undesirable consequence of natural fire (Miller and Findley 2001).

The conditions for species replacement may occur when fire burns the duff layer more completely than the surface organic soil.

The consequences of this burning is that fungal populations are usually more affected than bacterial populations. Fites-Kaufman (2006, 105) argues:

The fungal populations can remain suppressed from one to ten years after a severe fire. A shift from a microbial community dominated by fungi to one dominated by bacteria can affect plant species composition by favoring nonmycorrhizal-dependent species, or plant species dependent on mycorrhizal fungi that survive or quickly recolonize the site. Many non-native invasive plant species are not mycorrhizal dependent, and a shift in mycorrhizal dependent, and a shift in microbial community following severe fires may enhance their colonization and expansion. The shift from a microbial community fungi dominate to bacteria dominated can also limit decomposition and nitrogen mineralization since fungi play a key role in breaking down more recalcitrant organic material.

As an example, significant growth in foliage of the giant sequoias occurs after the forest floor has been cleared by thorough burning of undergrowth (Debano et al. 1998). The previous examples are short-term detrimental influences on fire-adapted plants, but the negative impacts on non-fire-adapted plants are longer term, and may result in the elimination of a species from a given area in a biome (Miller and Findley 2001). The subsequent replacement plants may increase the overall fire hazard by increasing flammability or by introducing ladder fuel plants.

A plant's response to fire can vary significantly between different fires and within the same fire. The causative fire variables involved in a plant's mortality, or survival and subsequent recovery, are fire line intensity, burn severity, burn duration, amount of soil heating, time of the year of fire occurrence, and time since the last burn. The accumulation of these fire effects are summarized in Table 1.9, which provides some specific examples of fire-adapted California native flora. Table 1.7 is adapted in abbreviated form from Table 6.1, "Plant structure and associated definitions, factors associated with fire response and examples" in "Fire and Plant Interactions" (Fites-Kaufman et al. 2006, 96). Table 1.9 concentrates on commonly known plant structures, such as bark and crown, and eliminates lesser-known structures, such as caudexes, corms, and bulbs for emphasis on the significant impacts that fire has on vegetation.

The “Fire Response Factors” column was significantly modified by the author to provide a clearer explanation of a plant’s survival, and re-growth process. Further, a concerted effort was made to select plants, mentioned in this section for inclusion in Table 1.9.

*Figure 1.8: Foothill Pines in Fuel Mosaic with Chaparral and Grassland
(www.werc.usgs.gov/pubbriefs/keeleypbfeb2007.html)*

The plant’s species, amount of growing stress, and maturity affects its fire response and significantly determines the post-fire outcome (Miller and Findley 2001). The fire variables include fuel types, fuel moisture conditions, topography, ambient temperature, relative humidity, and wind speed.

The vegetation variables include the plant community structure, age class, carbohydrate reserves, density, stress, timing of propagation and growth, and fire adaptive traits (Miller and Findley 2001). The fire and the plant variables cause the fire's heat regime to vary significantly in time and space, along with the plant's survivability. Under certain circumstances, fire can cause dramatic and immediate changes in vegetation, eliminating some species or causing others to appear where they were not previously present (Miller and Findley 2001). For instance, the bitterbrush is frequently credited with being so severely harmed by fire that it should be given complete endangered species protection (Anderson 2001). Conversely, the closed-cone conifers, the knobcone pine, Sargent cypress, and MacNab cypress of California's Mediterranean climate watershed can only produce offspring after the parenting generation has been killed by fire (Anderson 2001). The cones of these trees can remain on the tree for a decade or more until a fire opens the cone and releases the stored seeds during the post-fire period (Anderson 2001). Figure 1.8 above depicts a similar species of tree, the foothill, or gray pine in a wildland plant mosaic. The foothill pine generally does not self-prune its lower branches, making it more prone to crown fires. The closed-cone conifers, and similar trees are adamantly counter-indicated for firescaping despite being fire adaptive, because their high flammability and dense lower limbs provide a fire ladder up to their crowns.

Another significant wildland fire affect fire-adapted plants is the stimulation of buried seed and seed cones. In naturally vegetated areas, there may exist a significant reserve of seed stored in the litter, duff, and soil. The seed may have accumulated on the surface, and then gradually been buried by litter, or cached by rodents and birds. Dormancy of these seeds is imposed by an impermeable seed coat, with some of the seeds remaining viable for many years. In the chaparral plant community, seeds of snowbrush *Ceanothus* can remain viable for 200 to 300 years (Fites-Kaufman et al. 2006).

Germination of the seeds of some species occurs when the impermeable seed cuticle coating is melted, scarified, or cracked by fire. To illustrate this principle, some annual plants of California chaparral and other perennial examples, such as snowbrush, ceanothus, raspberry, geranium, and corydalis may appear on a site after a fire even though they were not present before the fire (Fites-Kaufman et al. 2006). Numerous lodgepole pine seeds are often released after heating of the canopy during a fire. This occurs because lodgepole pines have serotinous cones, requiring heat from a fire to open and release seeds from their resin-bound cone scales. The cones release their seeds unless heated to 113° to 122°F, a temperature that melts the resin-bond (Miller and Findley 2001). In the case of fire adapted annuals, which cannot grow new shoots, the plants rely on seed presence or colonizing from adjacent unburned areas (Miller and Findley 2001). Fites-Kaufman et al. (2006, 102) argues:

Seeds of some annuals in chaparral in the South Coast bioregion of California are stimulated not by heat, but by chemicals in smoke and charred wood. For example, the annual whispering bells germinates when exposed to the nitrogen dioxide in smoke. Concentrations of nitrogen dioxide sufficient to initiate germination are generated both by the fire and by the elevated nitrification in many post-burn soils. Nitrogen dioxide is also a common air pollutant.

Because these and many other plants in fire-prone environments have evolved with fire, they have become dependent on it for the propagation and survival of their species. Since these plants will burn and grow it is not possible to eliminate these fuels by burning.

Table 1.9: Fire Responses of Plants

PLANT STRUCTURES	DESCRIPTION, CHARACTERISTIC	FIRE RESPONSE FACTORS	PLANT EXAMPLES
Foliage	Moisture level, leaf thickness, shape, area	Ability of leaves to resist effects of fire	Chamise (Adenostoma fasciculatum)
Crowns	Sum of all leaves or needles of a plant	Burning intensity & resprouting ability	Ponderosa pine (Pinus ponderosa)

PLANT STRUCTURES	DESCRIPTION, CHARACTERISTIC	FIRE RESPONSE FACTORS	PLANT EXAMPLES
Bark	Bark thickness, density, volatile substances	Protection of cambium layer against plant mortality	Ponderosa pine, giant sequoia (<i>Sequoiadendron giganteum</i>)
Roots	Underground structures that absorb water and nutrients, & anchor plant	Amount of stored carbohydrates that will sustain regrowth	Mountain misery (<i>Chamaebatia foliolosa</i>), black oak (<i>Quercus kelloggii</i>)
Sprouting Structures	Buds in stem capable of sprouting	Regrowth ability of foliage after fire	Big-cone Douglas fir (<i>Pseudotsuga macrocarpa</i>) & many hardwoods
Basal burls	Woody tissue from which roots & stems originate often covered with buds	Regrowth ability of roots & stems after fire	Manzanita (<i>Artostaphylos</i> spp.), bigleaf maple (<i>Acer macrophyllum</i>)
Flowers	Plants that flower or flower more with fire	Reproductive ability following fire	Mariposa lily (<i>Calochortus</i> spp.)
Serotinous cones	Cones storing seeds: cones only open with high heat	Germination ability following fire	Knobcone pine (<i>Pinus attenuata</i>), Bishop pine (<i>Pinus muricata</i>), cypresses (<i>Cupressus</i> spp.)
Seed Banks	Supply of viable seeds buried in soil	Germination ability following fire	Bigpod ceanothus (<i>Ceanothus megacarpus</i> var. <i>megacarpus</i>)

In native flora, natural fire usually results in low-intensity burning, and may occur on a relatively frequent basis.

In prehistoric California coastal chaparral forests, tree ring readings indicate that natural fires occurred as frequently as every 66 years (Ford 2008). Low-intensity fire enhances seedling establishment of some species, including pines, because of lower plant density. The mechanism of this lowering density results in a reduced number of younger plants of a community. This occurs possibly because younger plants are more susceptible to fire than older plants. Such is the case with ponderosa pine seedlings, which are more vulnerable to fire than are older trees. Mature trees with this fire-enhanced growth pattern will experience a greater mortality from competition in the absence of fire. Interrupting the fire regime can affect the overall tree population of a species for centuries, even if only younger trees are affected (Fites-Kaufman et al. 2006). Similarly, post-fire conditions can favor species through fire-induced changes in the physical environment, such as availability of light or limitation of nutrients. For example, post-fire succession in chaparral includes an immediate growth of annual and perennial herbs along with sprouting shrubs (Miller and Findley 2001). Grasses and herbs are often able to out-compete young shrubs and saplings for water, nutrients, and light. Similarly, grassland systems respond to fire by retarding, or halting the encroachment of woodland species (Fites-Kaufman et al. 2006). This low-intensity, relatively frequent burning has produced an evolutionary effect, causing plants to adapt and depend upon fire.

1.2.3 ANTHROPOGENIC FIRE

Native Americans managed vegetation for thousands of years before the arrival of European immigrants. Although indigenous fire use throughout America was similar in purpose, California will be used as the primary example of anthropogenic fire due to its indigenous population level, the extent of burning performed, and its existing extreme fire problem resulting, in part from altered natural landscapes. Anderson (2006) estimates that California landscapes were altered by burning for hunting purposes some 11,000 years ago. At that time California's native population is estimated to have been in the vicinity of 310,000.

Between 5.6 and 13 million acres were burned annually by both natural fire, and human fire (Anderson 2006). Intentional burning by Native Americans has been credited as being the most significant type of environmental change (Williams 2008). The burning regime applied by Native Americans occurred at varying times of the year, on a reasonably regular basis for specific purposes. Williams (2008, 8) argues:

Natural fires certainly occurred but varied in frequency and strength in different habitats. Anthropogenic fires, for which there is ample documentation, tended to be more frequent but weaker, with a different seasonality than natural fires, and thus had a different type of influence on vegetation. The result of clearing and burning was, in many regions, the conversion of forest to grassland, savanna, scrub, open woodland, and forest with grassy openings.

The altering of ecosystems, the establishment of grassland areas in particular, provided many benefits to Native Americans.

Native Americans conducted purposeful burning to satisfy specific cultural objectives (Anderson 2006). Fire was an important tool and was widely used as part of their everyday life. The production of food was perhaps the most vital and widespread use of burning. Fire was used to reduce or remove forest undergrowth, thereby opening up the area for more food plants such as berries (Williams 2000). California native shrubs such as manzanita, elderberry, chokecherry, wild strawberry, blackberry, wild grape, and gooseberry are typical berry-type foods that were harvested (Anderson 2006). As further examples of fire management for food production and other cultural effects, Anderson (2006, 419) argues:

The black oak, and ponderosa pine (*Pinus ponderosa*) forests in the Sierra Nevada were managed by the Western Mono, Sierra Miwok/Mono Lake Paiute, and Foothill Yakut tribes for a least seven purposes: increasing mushroom production; facilitating acorn collection, increasing rapid elongation of epicormic branches on oaks for the manufacture of items, reducing the incidence of insect pests that inhabit acorns, promoting useful understory grasses and forbs, promoting a vegetative structure that

increases acorn production; and eliminating brush to inhibit catastrophic fires.

The use of fire to increase agricultural and cultural item production is one of the many uses of fire by indigenous Californians. However, there were other uses of fire as well.

Clearing the land with fire was the North American equivalent of slash-and-burn, which opened overgrown areas for many purposes other than agriculture, including hunting and cultural crop uses (Williams 2000). Hunting animals was made easier and quieter by driving game into open woodland areas, which were established by controlled burning (Williams 2000). Other uses of intentional fire include enhancing feed for game animals, decreasing insects and diseases of foraged food plants, and producing household items such as tools, clothing, and weapons (Williams 2008). In California, controlled burning enhanced materials for basket production. The selected species included numerous riparian plants, such as willow, bigleaf maple and hazelnut (Fites-Kaufman et al. 2006). These fire-adapted plants flourished and access to them was facilitated by burning. Dead plant material was removed and new growth promoted through the recycling of nutrients. This controlled burning decreased plant competition and thereby maintained specific plant communities (Anderson 2006). Materials for granaries and fish weirs were produced, in part from vegetation altered by Native American burning as well. The effort to intentionally burn, strongly suggests that Native Americans understood fire effects, including the reproductive response of vegetation at different levels of biological organization, ranging in scale from plant organism to landscape scales (Anderson 2006). Essentially, anthropogenic fire altered ecosystems to support Native American survival.

Indigenous Californians reduced chaparral and other densely forested areas by controlled burning.

As an example of a changed biome, the succession pattern of native chaparral growth in California's Mediterranean climate area has been altered by intentional fire. Chaparral forests were possibly the dominant, naturally selected vegetation type for many ecosystems (Purcell and Stephens 2005). Through repeated low-intensity fire or an occasional high-intensity fire, a resulting relative contraction or expansion of adjacent plant communities resulted (Purcell and Stephens 2005). For example, some grassland communities in various bioregions of California were maintained or expanded with recurrent fire (Purcell and Stephens 2005). Without recurrent fire, trees from adjacent forest or woodlands become established in grasslands and eventually shade out the grass. The result is an expansion of the forest or woodland communities into the grassland areas. In contrast, recurrent grassland fire inhibits establishment of the less fire-resistant tree seedlings (Fites-Kaufman et al. 2006). This flora type conversion by burning was likely a element to the demise of a closed-coned cypress, similar to Monterey cypress, along the San Diego coast 1,800 years ago (Keeley 2006-A). Pre-Columbian Native Americans managed forests to provide an environment of grasslands, similar to the bunchgrass, with scattered oaks as depicted in Figure 1.7. The conversion of shrublands to herb-dominated vegetation had the greatest impact of all the uses for indigenous burning (Keeley 2006-A). The establishment of greater scope of grasslands produced many benefits for Native Americans, with an accompanying reduction of the fire load. This burning by indigenous peoples changed the ecosystems they managed for centuries after their preeminence ended.

The natural fire regime, as compared with anthropogenic fire differed regarding the impact on specific ecosystems. The comparison of both types of burning differed in three significant ways. First, the time of the year was selected for specific reasons such as burning control and maximum production of food stocks (Williams 2000). For example, fires set to clear land for growing crops and stimulating berry growth were set in the early spring in the northern part of North America just as the new growth was starting (Williams 2000).

Second, the frequency of burning occurred at regular intervals, as often as every five years for a specific area (Williams 2008). As an example of frequent burning in California, Native Americans set fires each fall in the same locations to decrease snowpack and reduce forest debris in order to increase deer forage (Anderson 2006). Third, the burn intensity was generally lower because fires were set more frequently than would naturally occur. There was less time between anthropogenic fires for larger plants, such as shrubs and trees, to grow back. The more frequent burning produced lighter fuel loads. With the reduction of heavier fuels, including ladder fuels, there was an increase in surface burning (Williams 2000). For example, deer grass grew along streams and in mountain meadows. However, surface burning by indigenous people produced large patches of deer grass in lower mixed conifer forests and chaparral (Anderson 2006). Today, without frequent low-intensity fire, many colonies of deer grass are being out-competed by surrounding vegetation types (Anderson 2006).

The burning by Native Americans was managed so well, and portions of the environment manipulated so subtly, that recently arrived Europeans often compared California to a park, orchard, or garden. The recent arrivals, to a large extent, did not realize that these natural-appearing ecosystems were artificial (Barbour and Whitworth 2001). However, Post-Columbian explorers and settlers did realize that indigenous inhabitants had set these fires. When Portuguese explorer Juan Rodriguez Cabrillo anchored in San Pedro Bay in October of 1542, it was the chaparral fires that made him aware that humans occupied the coast (Anderson 2006). Fire as an ecosystem-management tool was so commonly used by Native Americans that it threatened the agricultural, ranching, lumbering, and gold mining plans of the new settlers. Edicts, agreements, and proclamations were drawn up to prohibit indigenous burning in California. Such was the case when Spanish Governor Jose Joaquin de Arrillaga, while in Santa Barbara in 1793, declared Native American burning illegal (Anderson 2006). The extent of indigenous and immigrant burning was vast, and lasted more than a century.

Written reports state that in 1881, 340,000 acres burned in California forests. None of the burned acreage was attributed to lightning, whereas hunters, campers, and the indigenous population were thought to be the primary sources of ignition (Keeley 2006-A).

The first significant impacts on California fire regimes by Europeans actually predate the arrival of larger scale permanent settlers by over a hundred years. These affects included the introduction of human diseases that decimated the indigenous population and the introduction of plants from other parts of the world (Keeley 2006-A). Dramatic changes in the landscape resulted when the Spanish visited the California coast in the 1500s and 1600s and established the Jesuit Missions in the late 1700s. During this time, a wide selection of exotic grasses and forbs were introduced (Stephens and Saugihara 2006). These nonnative plants spread rapidly, perhaps facilitated by the highly disturbed landscape resulting from a long history of frequent Indian burning (Keeley 2006-A). Further, the spread of these exotics was promoted by the Mexican vaqueros habit of expanding grazing lands by burning off the brush (Keeley 2006-A). Although both of these impacts involved the expansion of the historic ranges of native and exotic plants, they nonetheless outcompeted native herbaceous plants (Stephens 2006). With the reduction of native grasses and forbs, the resulting vegetation has different mechanisms for influencing fire regimes. The presence of the Missions also correlated with a decline in the Native American population, introduction of European land ethics, and domestic livestock. All of these changes significantly altered California flora and the accompanying fire regimes (Stephens and Saugihara 2006). Figure 1.10 shows one of the last remaining native California bunch meadow in existence. Both the decimation of indigenous people and the introduction of exotic plants were inadvertent, but were to have significant impacts on California ecosystems, which have continued to the present (Stephens and Saugihara 2006).

Perhaps the most significant affects have occurred in the Western United States, where two centuries of development has changed many of California's bioregions in both obvious and subtle ways. The disappearances of bunchgrass prairies and riparian forests are noteworthy landscape substitutions. The lack of successful seedling establishment of the blue oak and the valley oak during the Twentieth-Century is a more subtle change (Barbour and Whitworth 2001). Both of these oak species are fire stimulated. The oak woodland change is not yet noticeable because the mature tree over-stories have not yet reached their natural life expectancy (Barbour and Whitworth 2001). Fire suppression practices within the last century have been credited with this development.

*Figure 1.10: Bunchgrass Meadow with Oak Woodland Surrounding
Santa Rosa Plateau near Murietta, California
(geoimages.berkeley.edu/.../cal400/bungrass.html)*

Regulations plus fire suppression and fire prevention activities have virtually eliminated frequent low-intensity burning in WUI areas.

The consequence of these actions is that chaparral and woodlands have supplanted grasslands. This successional invasion has occurred insofar as some grassland biomes have been completely replaced (Barbour and Whitworth 2001). Further evidence is in Southern California, where the grasslands maintained by early settler and indigenous populations are frequently replaced by chaparral (Ford 2008). A misconception in the early 1900s was that chaparral succession was not a result of natural processes, but instead was caused by the careless human introduction of fire into the Southern California landscape (Ford 2008). The contrary evidence became apparent at the turn of the 20th Century. Scientists theorized that pine forests had once been the dominant plant community, and that by eliminating fire these forests could be restored. Once it became apparent that reforestation could not be accomplished, the predominant scientific opinion shifted to one explaining that fire-dependent chaparral forestation was a natural succession process (Ford 2008). This theory is supported by the argument that the Great American Forest may be more a product of European settlement than a victim of it, because wherever the settlers went, pine and fir forests followed (Williams 2000). Post-Columbian anthropogenic activity, especially in California, has generally had the undesirable effect of increasing the potential fire severity by severely limiting frequent low-intensity fires, and thereby increasing fuel loads.

Fire is an integral evolutionary component of flora in fire-prone areas. The influence of natural burning in the evolutionary process of chaparral, oaks, and similar fire-enhanced plants is now a matter of grave concern in WUI areas. The previously discussed beneficial effects and plant adaptations are an indication that wildfire is a persistent and integral component of the wildland environment. Williams (2008, 8) argues about the differing effects between natural and anthropogenic fires by stating: "Natural fires certainly occurred but varied in frequency and strength in different habitats.

Anthropogenic fires, for which there is ample documentation, tended to be more frequent but weaker, with a different seasonality than natural fires, and thus had a different type of influence on vegetation.” Indigenous Californians reduced chaparral and other dense forested areas by controlled burning. The significant ecological effects of the Native Americans were severely altered by Spanish explorers and settlers, who devastated the indigenous population and introduced exotic grasses and forbs (Stephens and Saugihara 2006). The reduction of native grasses and forbs resulted in vegetation that had different mechanisms for influencing fire regimes. The changed burning patterns of exotic plants tended to increase fire intensity compared to native flora (Stephens and Saugihara 2006). The net effect of modern anthropogenic activity on the environment has been to transform the already fire-adapted areas of California into ones with greater fuel loading, higher intensity burning, and extended burning seasons. Agee (2006, xi) argues, “California has always been and will continue to be a fire environment unmatched in North America.”

A recent example of the effects of varying wildfire burn intensities and the corresponding recovery of fire adapted and fire dependent plants was recorded in the South Coast area of California. In less than one year, from July 2008 to April 2009, three major WUI wildfires occurred within 15 miles of downtown Santa Barbara, California. The wildfire burn intensity varied from fire to fire, and within each fire in response to changing fire behavior variables, such as changes in terrain, vegetation, weather and fire suppression efforts. Flint (Flint 2010, 15) argues there was a loss of heavy vegetation, “When the fires burned away the tough, scratchy chaparral and years of dead growth trapped underneath it, what was left was nutrient rich soil with plenty of air and light for more delicate plants to thrive.” Since the fire, lush grasses, various flowering plants and new growth of plants that otherwise could not compete with the dense chaparral have grown in those areas of higher intensity burning (Flint 2010). Figure 1.11 depicts grasses and flowering plants recovering more vigorously than chaparral.

A transport of seed-rich soil occurred when top soil eroded after the chaparral burned, allowing grasses, forbs, penstemon and other flowering plants to return quickly (Flint 2010). In lower intensity burn areas, such as canyon bottoms oaks, sycamores and riparian plants recovered promptly (Flint 2010). In moderate-to-high intensity burn areas, oaks displayed new growth and were replacing chaparral (Flint 2010). This recent example of the varying burn intensity reinforces the aforementioned studies of anthropogenic and natural burning with their accompanying plant succession.

Figure 1.11: Grasslands and Flowers Recovering after Tea Fire of 2008 in Santa Barbara
(http://www.newspress.com/sbnp_content/sbnp_2009/epaper/santabarbara/index.html)

1.3 OBJECTIVES

This study will examine several issues pertinent to limiting property damage, injury, and life loss brought about by devastating WUI fires. The primary focus will be on civilians rather than first responders, because these personnel have extensive training, experience and resources that civilians do not have. Given the primary emphasis of this thesis, fire professionals will benefit from the use of the Fire Profile Index, Fire Assessment Guide, and Structure Safety Zone concept, with its accompanying mitigating measures. This thesis will endeavor to improve the fire protection knowledge of homeowners, designers, planners, and other persons with an interest in reducing WUI fire losses. The issues examined within this thesis are presented below in order of the chapters in which they appear. A brief explanation of each issue will be accompanied with its desired outcome. The desired outcome of this research is a set of recommendations for the modification of structural design, components, building layout and location, landscaping and fuel modification for improved fire survivability in WUI areas.

1.3.1 FIRE MODELING PROGRAMS

Chapter Three of this thesis will examine fire-modeling programs. The author undertook a cursory search of over 20 public domain and proprietary fire modeling programs. Two wind-modeling programs were examined to determine their ability to increase the accuracy of fire behavior predictions. All of these programs were reviewed in the initial effort of arriving at a manageable number of fire-modeling programs that could be compared and contrasted. Unfortunately, the comparing and contrasting of fire modeling programs proved beyond the scope of this thesis.

There are several good fire, wind and fuel modeling software programs available for use by fire behavior analysts and other concerned fire experts. The programs selected for fire behavior modeling were BehavePlus 5 and Wildland Tool Kit. The selected software is utilized as single-point predictors to examine the historic fire spreads of the case studies. In turn, the examination of historic fire spread is used to determine the accuracy of the thesis assessment matrix and its applicability based on real data.

Once an accurate assessment matrix is identified, the matrix can be applied to existing and future development to determine sustainability under varying fire conditions. The desired end product will enable recommendations on the modification of structural components, building layout and location, landscaping and fuel modification for improved fire safety in WUI areas.

The objective of examining several different wind-modeling programs and fire-modeling programs is to arrive at micro-level fire simulation model that can be applied to individual structures or developments in fire-prone areas. In Chapter Five, a discussion of the Fire Profile Index, a fire threat assessment matrix is presented. The Fire Profile Index is a prediction tool to determine the fire potential for a particular area or site in fire-prone areas, including WUI areas (see further discussions in Section 1.3.2 and Chapter Five). The successful outcome of selecting a fire modeling program, or a modification version, will provide quantitative values in predicting flame length, ember intrusion potential, flame spread and burning intensity for existing structures and future developments in WUI areas.

1.3.2 FIRE PROFILE INDEX

The content of Chapter Five, entitled Fire Assessment, is an assessment of the fire threat to structures and people in the WUI. An innovative concept presented in this chapter is the Fire Profile Index. The Fire Profile Index is an interface fire potential assessment tool to be used in fire-prone areas by concerned individuals or groups. The Fire Profile Index was compiled from a search of wildland and WUI fire related literature, and from the professional experience of the author. The Fire Profile Index is a catalogue of over 250 factors, which aid in assessing and improving the fire potential and fire safety of a particular site or development vicinity within a WUI area.

Two derivatives of the Fire Profile Index were developed for specific groups, and intended for divergent interpretative purposes. The WUI Fire Assessment Guide is a compilation of 38 items that assesses the fire potential in terms of flame length, burning intensity, and spread.

The incorporation of fire, fuel, and wind modeling programs in the use of the WUI Fire Assessment Guide will provide quantitative values of the fire threat to structures. The Developers Guide is a compilation of 100 essential design and construction factors for determining and improving the fire resistiveness of structures. Individual design, construction and building features known to enhance fire resistiveness, and those features known to increase burn ability are listed in the Developers Guide.

The objective of the material in Chapter Five is to determine the fire potential and fire safety components present in an interface fire-prone areas. The goal of the Fire Profile Index is to arrive at a qualitative and a quantitative analysis of the threat that an interface fire poses for these structures and occupants. A rating scale is incorporated into the Fire Profile Index to assess the fire potential of individual structures and/or encompassing development areas. The intent of the Developers Guide is to be a fire resiliency building and design reference for the establishment of increased fire safety in fire prone areas. The Developers Guide is a checklist of items affecting the fire resiliency of structures. The WUI Fire Assessment Guide is a tool for persons, knowledgeable in fire behavior, to assess the interface fire threat to structures and personnel. The Fire Assessment Guide has a numerical rating which helps in recognizing which structures are more likely to survive an interface fire. The use of these fire assessment tools and their accompanying mitigating measures, in this thesis, will significantly increase fire safety in WUI areas prone to fires.

1.3.3 STRUCTURE SAFETY ZONE

Chapter Six contains a discussion of Structure Safety Zones: a concept of adequate defensible space, determined by the flame lengths present at an examined site. With the use of the Fire Assessment Guide and computer modeling, the flame lengths are determined for a particular location by assuming a probable worst-case fire conditions. Flame lengths are computed for each directional area that a fire will travel to a specific structure. The flame lengths are doubled and applied to each exposed side of the structure.

Enhanced fire resilience design or construction mitigations, beyond those required by code and development conditions, are indicated when the existing defensible space is less than the doubled flame length distance for each exposed side. If the defensible space exceeds the minimum requirement of twice the maximum flame length, then no enhanced design and fire resilient construction features are indicated for adequate fire safety. The concept is to first establish the basis for defensible space using the Assessment Guide and fire modeling programs. This process will establish the Structure Safety Zone. Then a comparison of the existing defensible space with the recommended distances determined by the Structure Safety Zone is performed. If adequate defensible space exists or can be created on the site, then no additional mitigating design or construction features, beyond WUI code and development requirements, are indicated for reasonable WUI fire resiliency.

The desired outcome of the Structure Safety Zones concept is to provide an objective indication where fire and ember intrusion threat mitigations are indicated, beyond those required by WUI code or other development conditions. The determination of the Structure Safety Zone defensible space distances is dependent upon the use of a micro level fire-modeling program, or its equivalent. The investigation for such a program is a major challenge for this thesis.

1.3.4 CASE STUDIES

Case studies are the topic of Chapter Four. Three different fire-involved structures are included in this section of the thesis. Two of the case studies are adjoining properties within the Tea Fire burn area of Santa Barbara (November 2008). An older home that did not meet current codes and WUI building standards was burned in the fire. The neighboring property was a one-year old structure that met the current code requirement of California Building Code, Chapter 7A requirements, and it survived intact. The third case study is a home that survived the Green Meadows Fire of 1994 in the Malibu foothills of Los Angeles County, California.

Due to this WUI firefighting experience, the author developed an intense interest in the concepts of determining why some structures burn and other do not, and designing structures to withstand WUI firestorms. It was this incident that motivated the writing of this thesis.

The desired outcome of the case studies is to validate to the extent possible, the Fire Assessment Guide and the Fire Profile Index. The validation will be accomplished by comparing the historical fire behavior of each case study to the calculated fire behavior produced by the Fire Assessment Guide and the thesis-selected fire-modeling system.

1.3.5 FIRE SHELTERS

In Chapter Nine, the author proposes the use of four fire shelter designs as a last-resort fire safety measure for occupants of structures located within a fire-prone area. The first, least expensive fire shelter is the Fire Storm Shelter. This shelter is a six-foot diameter, cement storm drainpipe that is partially buried, with the top covered with soil. Easy access ramps provide access, and doors protect the pipe-end opening. The second, referred to as the Tank Fire Shelter is a concept used by the Australian populace. These shelters are a result of fire safety-conscious citizens wanting increased life safety following the February 2009 Black Saturday firestorms. As fundamental as the installation becomes, these shelters are water tanks buried on end, with access through metal hatches on the top.

A third shelter is termed the Garage or Go Shelter. This shelter is essentially a garage built as a separate structural unit with four-hour fire resistant construction. Rated fire doors are used as protection on the outside of conventional unrated garage doors. Walk-through doors and windows are also fire rated to go along with four-hour construction. Occupants of a home with a Garage or Go Shelter can make a decision to leave, or stay within the confines of the four-hour fire resistant construction of the garage. The final proposed fire shelter is the Fire Panic Shelter. This shelter is a separate four-hour fire resistant room within the structure. As the most expensive option it offers the greatest fire and life safety protection of the selected four types of shelters.

The Fire Panic room has supplemental air supply, lighting, and electronic fire detection and monitoring equipment. This room can be easily modified to also serve as a security panic room as well.

The objective of the fire shelter designs in Chapter Seven is the increased life safety afforded to occupants during wildland fires. The shelters enhance the concept of Stay and Defend and Shelter-In-Place communities, by increasing the life safety of occupants during firestorms. Outside these communities, the shelters provide a greater degree of safety and reduced fear and panic during WUI and wildland fires.

1.3.6 HOMEOWNERS GUIDELINES

Chapter Ten presents the Homeowner Guidelines, which is a compilation of items from the Fire Profile Index. The Fire Profile Index is a practical guide for structure owners, prospective purchasers and their agents of properties within WUI areas. The Homeowners Guidelines are a subset of the Fire Profile Index directing attention to less apparent, but nonetheless influential, indicating factors of fire loss in areas prone to wildland fires. Some of these contributing factors of large dollar losses are terrain features, regional fire history and neighborhood fuel loads. Other factors to be considered in assessing the WUI fire safety, found within the Homeowner Guidelines are the position of structures relative to fire origin and fire direction of travel, the particular WUI code requirements in effect when the structure or development was built, the public and private fire protection features available to the development, and the maintenance of defensible space for both the structure and immediate development, surrounding the structure.

The desired result of the Homeowner Guidelines is a user-friendly guide for use by individuals to assess the wildland threat on individual structures and developments. The usefulness of the Homeowner Guidelines is dependent upon the accuracy of the Fire Profile Index and the fire modeling program. With accurate results of the fire prediction aspects of this thesis, the usefulness of the Homeowners Guidelines will increase as a layman's guide to structural and human safety in WUI areas.

1.3.7 CONCLUSION

A significant portion of Chapter Eight presents a number of mitigating design, construction, and landscaping features that are recommended if adequate defensible space is not present. Sufficient defensible space is determined by applying the Structure Safety Zones space requirement criteria. Several configurations of flame and ember shields are presented in the form of differing arrangements of walls placed between structures and the projected direction of the oncoming severe fire. Berms and plantings are additional ways of mitigating the fire threat to structures and occupants where building code requirements and defensible space prescribe inadequate protection measures. The concept of subterranean construction is discussed with its application under the most extreme fire threats conditions.

Additional fire resilient design and construction features are presented as increased fire protection measures for structures located within intensely burning areas. A discussion of roofs, offering greater fire resistance than conventional Class A rated roofs is presented. Concrete roofs, pond roofs, sod, and green roofs are recommended as improved fire resilient designs over conventional Class A rated roofs. Conceptual fire protection measures for entire developments or large areas within the WUI are offered as improvement over existing code and development requirements. A Developers Guideline derived from the Fire Profile Index lists construction features and materials as means for meeting and/or exceeding code requirements.

The objective of this chapter is to propose enhanced fire mitigation measures for structures that are at risk of burning during WUI fires. The author is confident that these measures are useful and represent an improvement over existing design and construction techniques. This opinion is based on the author's fire service experience, literature searches, and experimental research. The credibility of this statement will increase dramatically with proof provided from wind tunnel tests, fire modeling and wind modeling programs.

1.4 THESIS GOALS AND METHODOLOGY

1.4.1 AUTHOR EXPERIENCE AND BACKGROUND

The author of this thesis is a retired career firefighter with over three decades of service with the Santa Barbara County Fire Department. Since 1974, he has acquired firefighting experience as an Engine Company Captain and Strike Team Leader for Type II and III engine companies, including several campaign fires. Within Santa Barbara County he has performed as Division/Group Supervisor and Incident Commander on WUI incidents. He also held a position on Los Padres Command Team, where he had the opportunity to observe fire behavior in differing wildland and WUI situations in and outside of Santa Barbara County, California. The author's significant WUI firefighting experience within Santa Barbara County includes the 1977 Sycamore Canyon Fire; Eagle Canyon Fire of 1978; and the Paint Fire of 1990. The Sycamore Canyon Fire was a significant WUI incident, which burned just under 200 homes in the Santa Barbara and Montecito areas (Ford 2008). The Paint Incident burned over 500 structures in a matter of hours (Ford 2008), and was of record proportions until the 1991 Tunnel Incident in Berkeley and Oakland burned nearly 4,000 dwellings units (Hills Emergency Forum 2001).

It was not until after the author retired, nearly three decades after the Sycamore Canyon Fire, when three separate and significant WUI incidents occurred in Santa Barbara County. The June 2007 Gap Fire in Goleta consumed only four structures, but had the potential for far greater destruction. The State of California declared the Gap Incident as its top priority incident, because of the potential to destroy dozens of houses in developed areas of Goleta (Nava 2008). The November 2008 Tea Fire in the Santa Barbara and Montecito communities of Santa Barbara County burned 210 structures during a windy November evening (Ford 2008). The May 2009 Jesusita Fire burned in Santa Barbara, Montecito and Mission Canyon WUI areas, destroying 115 homes (Ford 2008). This thesis will develop further discussion and reference these incidents throughout. Each fire has a significant importance to this thesis.

The incidents in Santa Barbara County are used in this paper as case studies, and as examples of fire behavior contributing greater inferred knowledge.

The author participated in the firefight for one particular incident, the 1993 Green Meadows WUI incident, which occurred in Ventura and Los Angeles Counties, California. The fire burned 39 houses and 80 outbuildings, and had the potential to burn scores more (Reed 1993). It was the actions of hundreds of firefighters, including the author and his crew that saved these houses from fierce Santa Ana wind-driven flames. Wind speeds in excess of 50 mph and heavy fuel loading of chaparral allowed the fire to drive to the Pacific Ocean in an unstoppable fashion. Firefighters could only aid evacuation; protect themselves, and save selected homes in the path of the fire. One particular structure saved by firefighters was significantly aided by its fire resilient design. This particular home and how it was able to survive the conflagrations is the inspiration for this thesis; that fire resistant design can save both lives and property. It is from this experience that the author developed a keen awareness for improved structure fire protection in WUI areas, to further educate the WUI populace in life and property safety.

The author holds a bachelor's degree in Business Administration, an associate's degree in Fire Technology and a second associates degree in Environmental Horticulture. With the acceptance of this thesis project, the author will satisfy the requirements of a Master of Science in Architecture degree at California Polytechnic State University, San Luis Obispo (Cal Poly SLO). He is a Graduate Assistant at Cal Poly, working on the wildfire portion of the California State Hazard Mitigation Plan. The author holds a technical teaching credential for fire technology, and has taught fire technology at local community colleges. The author was the past lead instructor of the Santa Barbara County Fire Department Training Academy. During this time he taught courses to firefighters and recruits on several subjects, including WUI firefighting and fire behavior. The author has recently completed course work from the Fire Behavior Analyst curriculum of the federal government to accomplished level. It is from this background that the author advances the theories presented in this thesis.

1.4.2 METHODOLOGY

A multidisciplinary approach was utilized in developing the thesis. In order to obtain a greater understanding of the most important aspects of WUI fire problem, the research began with a comprehensive literature review. The author attended fire behavior analyst and fire calculation classes, and studied fire behavior calculations and algorithms. Wildfire and wind modeling programs were reviewed for possible discovery of a micro level fire behavior tool. Also, the author attended fire rebuild presentations and conducted interviews with fire experts. Case studies of structures involved in WUI incidents provided additional insight and validity to the fire assessment matrix. Wind tunnel experiments were conducted on scale-model structures and mobile homes to simulate ember and flame flow against fire mitigating measures. Through this process, the author gained invaluable knowledge used to substantiate his thesis theories.

For the literature review, the author examined and assimilated many papers, articles, and other related references, including fire incident after action reports for pertinent information on structure fire resiliency. Following each significant fire, an after action report is written, which at a minimum summarizes firefighting efforts, fire behavior, direct and indirect fire loss, and possible applicable lessons learned. The appropriate after action reports were reviewed for each case study. Several large loss WUI fire after action reports were researched to determine several significant fire behavior factors. Historic fires may have special reports summarizing lessons learned and recommendations for mitigating future losses. For example, the Tunnel Fire in Oakland and Berkeley, California (Hills Emergency Forum 2001) and the Witch Creek Fire in San Diego, California (IBHS 2008) were reviewed, and useful thesis information obtained. The research performed gave sufficient knowledge, which partially established the validity of the Fire Profile Index. The Fire Profile Index is the fire assessment matrix, upon which the basis of this thesis was established.

Computer modeling programs were reviewed and two were selected for validating the Fire Profile Index and case studies.

The programs, provided the foundation for the Assessment Guide and Case Studies, and was incorporated within the Fire Profile Index for enhancing its accuracy. To confirm validity, the fire behavior projected by the Assessment Guide was compared to historic fire behavior. The BehavePlus and Wildland Tool Kit software was used for determining worst case fire behavior by entering data that duplicates the terrain, fuel and weather variables for a particular location. The process provided an explicit fire behavior model that was applied to building designs to determine fire resiliency.

Under these conditions several diverse mixes of building components, landscaping, or natural vegetation could determine whether a particular location was either suitable or unsuitable based on differing fire conditions. Both programs represent fire-spread phenomena of the structures and vegetation typically present in the WUI. Such software can examine historic fire spread to determine the thesis assessment matrix accuracy and its application based on real data. Once an accurate assessment matrix is identified, then it can be applied to existing and future development to determine resistance to varying fire conditions. The goal of fire modeling is to generate positive recommendations for modifying structural components, building layout, location on property, landscaping and vegetation management in order to improve fire resistance in WUI areas.

Case studies of structures affected by WUI fires were utilized as a reference and source of proof for the Fire Profile Index and Structure Safety Zone concepts. Three different case studies from fire-involved structures were examined, contributing to the validity of this paper. These WUI incident case studies are from the 1993 Green Meadows Fire, 2008 Tea Fire, and 2009 Jesusita Fire. One particular case study involves a home that survived the Green Meadows WUI Fire of 1993, which is referenced in the Background and Experience section. The author reviewed these incident after action reports and incident reviews, performed on-site investigations, and conducted interviews with occupants. In most cases, follow-up interviews were conducted with persons responsible for the property or who were present during the actual WUI fire.

The author attended lectures on fire safety, rebuilding, and after-fire preparations following the Tea Incident and Jesusita Incident in the Santa Barbara area of California. Local fire agencies, volunteer and public emergency service organizations sponsored the lectures, aimed at aiding rebuilding and recuperating from WUI fires. The lecturers were expert representatives from construction, building suppliers, designers, erosion controllers, government planning and safety agencies, and fire safety. These presentations provided valuable knowledge. The author also attended field surveys with local fire department personnel. The surveys concentrated on fire safety and structure fire resiliency in WUI burn areas of the Tea and Jesusita Fires. Selected information and photos from these surveys will be presented in later in this thesis. The author discussed the thesis with fire experts, and gained valuable insight into the WUI fire problem.

Experimental testing of the fire-related fluid mechanics of structural design features was conducted in the wind tunnel at Cal Poly SLO. The testing partially validated the conceptual effectiveness of concave, convex, and linear fire shields walls as mitigating measures for extreme fire behavior affecting structures. The effectiveness of berms to buffer wind flow as protection from flames and ember intrusions was also tested in the wind tunnel. The wind tunnel experiment trials produced evidence of the diversion of airflows, and protection from wind impact as mitigating measures. The aforementioned types of methodology contributed to the validity of this research.

1.5 CONTRIBUTIONS

Nine separate additions to the body of knowledge are included in this thesis. The contributions are presented below in an order that facilitates understanding their interrelationships. Three of the contributions result directly from the Fire Profile Index, a WUI fire assessment matrix containing over 250 indicating factors that determine the fire potential in a given area. The first of these three derivatives of the Fire Profile Index is the Fire Assessment Guide, which is intended to estimate the potential fire behavior of a given property or area. A second subset of the Fire Profile Index is the Developers Guide, which is a compilation of design and construction factors that affect the WUI fire resiliency of a structure. The Fire Assessment Guide is the third by-product of the Fire Profile Index. It is a compilation of significant fire behavior factors that indicate the vulnerability of a structure to WUI firestorms.

The remaining thesis topics that contribute to the body of knowledge are: a comparison of Fire Modeling Programs; Structure Safety Zones; and Fire Shields. The comparison of Fire Modeling Programs is an aid to selecting the most applicable fire modeling program for a specific application. The comparison of these programs ensures greater accuracy of the Fire Assessment Guide and provided validation for the Fire Profile Index. The Structure Safety Zone concept is a fire modeling based determine of an adequate defensible space. It is micro-level adapted program for a selected environment of a building or development in a WUI area. The determination of the defensible space distances is dependent on a micro-level fire modeling program, as discussed in the section of this thesis dealing with Fire Modeling Programs. The use of Structure Fire Shields is suggested as mitigating measures for increased fire protection, where adequate defensible space does not exist. All of the above contributions are optimistically presented as improvements to fire safety and fire resiliency for WUI fires.

1.5.1 FIRE PROFILE INDEX

The Fire Profile Index is the content of Chapter Five, and is the principal innovative concept presented in this thesis. It was created from a review of literature, interviews, and the professional background of the author.

The Fire Profile Index is a catalogue of over 275 factors that aid in assessing the fire potential for increased resident and first responder fire safety, and improved fire resiliency of structures in WUI areas. The Fire Profile Index is a tool intended for use by fire professionals, planners, developers, and policy makers concerned with those living and working in WUI areas. It is intended to be a fire potential assessment tool to be used in fire-prone areas by knowledgeable individuals to determine the relative fire threat present, and possible need of mitigating measures.

1.5.2 DEVELOPERS GUIDE

The Developers' Guide is a compilation of design and construction factors essential in determining the fire resiliency of structures. It is a subset of the Fire Profile Index composed of individual design, construction, and building features that are known to enhance fire resistiveness. Also included in the Developers' Guide are the characteristics that contribute to the burning potential of a structure. The intended users of the Developers' Guide are designers, contractors, developers and planners. In addition, firefighters can gain insight into the flammability of structures in WUI areas. The Developers' Guide should be used as a training aid, or during pre-action assessments. The objective of the Developers' Guide is to be a fire safety building and design reference for the establishment of increased fire safety in WUI areas.

1.5.3 FIRE SHELTERS

There are four types of fire shelters presented in this thesis and they are intended as a safety measure of last resort for occupants of structures located in WUI areas. Three of the four shelters are original designs created by the author. The Tank Shelter came into use in Australia as a result of the Black Saturday Fires of 2009. The fire shelters discussed in this thesis are proposed as last resort wildland fire life safety measures, and not intended to replace safe evacuation. In fact, they should not even be considered as an option in lieu of evacuation. Another type of occupant fire shelter offers those persons trapped by flames, or defending their homes an improved life safety option.

The three original design shelters, plus the Australian design all enhance the concept of Stay and Defend and Shelter-In-Place communities, by creating enhanced life safety of occupants during firestorms. Outside of these communities, the shelters provide a greater degree of safety and reduced panic during wildland fires. Unfortunately, the necessary development of occupant fire shelters proved to be beyond the scope of this thesis.

1.5.4 WUI FIRE ASSESSMENT GUIDE

The Fire Assessment Guide is another derivative of the Fire Profile Index. It is a complication of 100 items assessing the fire potential in terms of flame length, burning intensity, and spread. The incorporation of fire and wind modeling programs, found best suited in the Fire Modeling Programs Chapter, were used to validate the fire potential characteristic composing the Fire Assessment Guide. The intended users of the Fire Assessment Guide are firefighters and those concerned with fire behavior on structures during firestorms. Design and development professionals could benefit from this guide for determining the fire threat for a particular development. The Fire Assessment Guide is most useful after a fundamental understanding of wildland fire behavior has taken place.

1.5.5 FIRE MODELING PROGRAMS

To determine the most suitable programs for this thesis, the author examined over 20 public domain and proprietary fire modeling and wind modeling programs. The programs selected are BehavePlus5 and Wildland Tool Kit. The author used the selected software to examine the historic fire spreads for determining the accuracy of the thesis assessment matrix, Fire Profile Index. A modified program enabling a micro-level determination of fire potential, which would provide quantitative values in predicting flame length, ember intrusion potential, flame spread, and burning intensity proved not to be feasible. The use a micro-level fire modeling program could be use for increasing fire resiliency for existing structures and future developments in WUI areas. The modification of a fire modeling program, or combining a fire modeling and wind modeling program is an on-going process of the author.

The micro-level modified fire modeling program would allow recommendations on the modification of structures and their components, and proper selection of mitigating measures for improved fire resiliency in WUI areas.

1.5.6 HOMEOWNERS GUIDELINES

A third possible derivative of the Fire Profile Index was the Homeowners Guidelines. The Homeowners Guidelines were planned to be a compilation of items intended as a practical guide for structure owners, as well as purchasers and selling agents of properties in WUI areas. Further, the Homeowners Guidelines were to include a reduced number of items from the Fire Profile Index directing attention to less apparent, but nonetheless influential, indicating factors of fire loss in areas prone to wildland fires. During the development of the Fire Profile Index, the design of the index was modified so that an individual, with minimal understanding of fire behavior, could use it accurately. This design change eliminated the need for a separate Homeowners Guidelines.

1.5.7 STRUCTURE SAFETY ZONES

The Structure Safety Zones concept is a site specific determination of adequate defensible space for increased fire safety of structures from wildland fires. With the use of the Assessment Guide and computer modeling, flame lengths are determined for a particular location, by assuming worst-case fire conditions. If adequate defensible space is not present, additional mitigating design or construction features are indicated for reasonable fire resiliency. The Structure Safety Zones concept may indicate increased need for additional defensible space, or enhanced fire mitigation measures such as fire barriers. This increased need for flame and ember intrusion protection is beyond those required by WUI building codes, or local development conditions.

1.5.8 STRUCTURE FIRE SHIELDS

Several types of flame and ember intrusion mitigating measures are possibly indicated when inadequate defensible space exists. Sufficient defensible space is determined by the application of the Structure Safety Zones space requirement criteria.

Several configurations of flame and ember shields are presented in the form of differing noncombustible wall arrangements placed between structures and the projected direction of oncoming fire spread. Models of Convex Fire Shields, Concave Fire Shields, Linear Fire Shields, Incline Fire Shields and High Profile Fire Shields were tested in a wind tunnel for their ability to divert, deflect and channel airflow, which simulated ember washes and flame flow. Landscaping features, including plantings are additional forms of fire shield. Certain terrain features can be taken advantage of to increase fire resiliency. Further, subsurface construction and minimal height profile designs of building envelopes offer the greatest protection against the most severe fire threats.

CHAPTER TWO

2.1 WUI FIRE PROBLEM DESCRIPTION

2.1.1 INTRODUCTION

The WUI fire problem is a complex and unique worldwide threat. It is more than simply combining of a major wildland fire with multiple structure fires (United States Fire Administration 2002); conversely, WUI fires burning wildland fuels expose dozens, if not hundreds of structures to 100-foot flames accompanied with immense ember washes. Not only does the surrounding natural and landscape vegetation represent imminent fire threat to structures built within, but flames and embers from burning residences and vehicles can ignite surrounding structures. The occurrence of burning structures spreading the fire by radiant heat and ember production was the case in the October 2007 firestorms in San Diego County, located in Southern California (Wildland Lessons Learned Center 2008; Maranghides and Mell 2009; Maranghides 2009). Extreme fire weather, with high temperatures, low humidity, and accompanying high velocity winds fanned the flames. If these weather conditions are coupled with drought stressed plants during Mediterranean climate summers, then catastrophic conflagrations potential is set for a major WUI fire. Besides the fuels and weather, life safety issues, access problems, insufficient firefighting water, and jurisdictional conflicts represent firefighting challenges on a far grander scale than in large wildland fires or several simultaneous structure fires. During a WUI area fire, firefighters are on the defensive, reacting only to the spread of fire (Tele 2005). Most importantly, however, during the initial stages of a WUI fire, there are precious few resources available for structure protection (United States Fire Administration 2002).

In a federal audit of large interface wildfires, nearly 90% of fires indicated the protection of private property was a major reason for firefighting efforts.

The finding included that WUI homes are often difficult to protect because of remoteness, steep slopes, and narrow roads, creating dangerous situations for firefighters (United States Fire Administration 2002). In the five-year period from 2002 to 2006, 92 people were killed during wildland fire operations, and \$6.3 billion in federal funds were spent. Despite these efforts, 10,159 homes were lost to wildfires during this period (Gude et al. 2009). Complicating the WUI firefighting problem is the impossibility of constructing wildland firebreaks within developed areas; therefore, this effective wildland tactic must be replaced with a far less effective alternative in the WUI.

During the initial phases of a major WUI fire, when structures are threatened, the vast majority of firefighting resources are devoted to life safety instead of structure protection. On large incidents, evacuation and resident rescue take top priority, occupying law enforcement personnel as well as firefighters (Tele 2005). Hundreds, sometimes thousands of residents, need evacuation, and “incident excitement” may attract thousands of spectators, media and looters, thus adding to life safety concerns. Figure 2.1 is an illustration of bystanders watching the 2007 Witch Incident in San Diego County, California. As an example of these non-firefighting efforts performed by firefighters, a study of the 2007 Guejito Fire in San Diego County indicated that one-half of the firefighting resources during the first day were involved in resident evacuation (Maranghides and Mell 2009). Evacuation efforts and firefighting equipment, including bulldozers must share the same narrow roadways. In addition, resources for wildland firefighting and structure firefighting must be deployed simultaneously, significantly increasing the complexity of the effort. Initially, there can be hundreds of personnel involved in the WUI firefighting and life safety effort, with minimal resources directed towards structure protection.

Major WUI fires are nearly unmanageable incidents from their onset. Many times, precious hours, and days pass before the incident management gets the planning and resources ahead of the fire. During the initial phases, there is usually no time to plan and organize an attack, forcing incident personnel to operate with some degree of independence (Tele 2005).

*Figure 2.1: Spectators Viewing the Witch Fire of October 2007 in San Diego County.
(<http://americancity.org/magazine/article/building-under-peril-knowles>)*

Independent Action occurs when the command and control of a wildfire incident cannot keep pace with the demand for resource actions. This phenomenon is commonplace in nearly all major WUI incidents; as was the case during the 2003 California Firestorms (Mission-Centered Solutions and Guidance Group 2003). Independent action of firefighting crews during initial response is authorized by some fire agencies in their department's policies and procedures. As an example, Santa Barbara County Fire Department recognized this organizational dilemma after the devastating Paint Fire of 1990, and instituted independent action (Santa Barbara County Fire Department 1994). The Paint Fire destroyed 645 structures and ranks sixth as an all-time destructive fire in California (Office of State Fire Marshall 2010).

The organizational problem of controlling and directing major WUI fire combat efforts is evident in firefighting independent action tactics.

The tactics of structural and wildland firefighting are drastically different. A major component of structural firefighting tactics is direct fire attack with water or foam. However, in wildland firefighting personnel generally try to extinguish a fire indirectly by starving it of fuel. Usually, this is accomplished by surrounding it with a defensible perimeter of cleared vegetation or fireline (United States Fire Administration 2002). The same principle of starving a wildland of fuel is a primary reason for establishing vegetation clearance or defensible space surrounding a structure.

In a WUI fire, the firefighting tactics change when structures are threatened and lives are endangered. Firefighting resources directed to life safety and structure protection are usually not actively involved in fireline construction, which may cause the fire to grow, and increase the danger to firefighters (Tele 2005). During WUI incidents, firefighters consistently use structure triage, which groups houses into three categories for protection: houses that are safe without firefighter intervention; houses that require firefighter action to save them; and houses that cannot be saved. Efforts by firefighters to try and save more than they should realistically attempt frequently results in the loss of everything, including homes they could have saved (Brown 1994; Tele 2005).

Most structure losses occur in the first few hours of a major interface fire incident. There are several factors that contribute to this loss: insufficient vegetation management; inadequate building standards; and insufficient firefighting forces (Bailey 2007). In a major conflagration, fire protection agencies will probably not have enough equipment and manpower to be at every home; residents cannot depend totally on firefighters' help. One of the principal responsibilities of firefighters is to stop the spread of fire from house to house. As an example, one engine company is needed for every two structures in a clustered development with less than 50 feet separation, and one engine company per structure that is surrounded by vegetation (National Wildfire Coordinating Group 1991).

With the preceding requirements for engine companies, it is easily foreseeable, with hundreds of structures threatened, that the demand for adequate firefighting resources far exceeds the initial responses of even large-sized fire agencies. County of Los Angeles Fire Department, one of the most prodigious fire departments in the nation, indicates “If one home is on fire, firefighters might have to pass it by to save another in the path of the fire” (County of Los Angeles Fire Department 2010, 27).

In addition to firefighting efforts, building code standards and vegetation clearance measures are simply not enough protection for all structures located in WUI areas. Incorporating sound fire resilient design principles for structures and other mitigating measures, such as Fire Profile Index (Chapter Five), Structure Safety Zones (Chapter Six), and Structure Fire Shields (Chapter Seven), will increase life safety, increase the probability of successful human intervention, and thereby significantly decrease structure fire loss. The fire protection goal of designing new structures and retrofitting existing structures in WUI areas is to assign them to Structure Triage Group One (i.e. sufficient fire safety to survive a wildland fire without firefighter intervention) because these resources may not be available.

2.2 ANTHROPOGENIC FACTORS

2.2.1 POPULATION AND DEVELOPMENT GROWTH

The growing fire loss in the WUI is the result of both natural factors and anthropogenic factors. Anthropogenic factors arise from a combination of population growth, development, plus governmental and private policy decisions. The population growth in the United States since 1940 has disproportionately occurred in WUI areas. Higher housing densities were more clustered in 1940 than currently. By the year 2000, low and medium density housing significantly expanded into rural areas. Since the 1970s, the population in rural counties has grown faster than the population in urban areas for the first time in United States history (Redeloff et al. 2005). Furthermore, the relatively greater housing development density growth within WUI areas is supported by research. The research indicates that within the contiguous United States WUI areas cover over 277,500 square miles or 9.5% of total land area, and the housing units in WUI are calculated at 44.5 million units or 38.5% of all United States housing units (Stephens and Collins 2007).

A graphic portrayal of population growth in WUI areas, represented by housing density is shown in Figure 2.2: United States Housing Density, Year 2000; Figure 2.3: United States Housing Density, Year 2000; Figure 2.4: United States Wildland-Urban Interface, Year 2000. Comparing the housing density of 1940 (Figure 2.2) to the 2000 housing density (Figure 2.3) indicates areas of greatest housing density growth in the postindustrial era (SILVIS Lab 2009). The greater housing density growth in the contiguous United States WUI areas can be visualized by referring to Figure 2.4. The result is a proportionally greater development growth in the WUI areas. Worldwide, the WUI is experiencing rising population growth and new housing development as well. The development in fire prone areas has been driven, in large part, by the phenomenon of people moving to areas of high natural amenities, sometimes called “Amenity Migration.”

This phenomenon besides being widespread in the United States, is occurring in many other parts of the world, including the European Alps, Norway, Philippines, Czech Republic, and New Zealand. The population living in WUI areas has increased from 25 million to 140 million from 1960 to 2000 (Bailey 2007).

The United States federal government has expressed considerable concern that losses from interface wildfires will only increase as the highest growth rates in the both metropolitan and nonmetropolitan areas are projected to continue in states with extensive wildland fire hazard areas (Paterson 2007). In the Western United States, 38% of new home construction is adjacent to or intermixed with the WUI (United States Fire Administration 2002).

California has led the nation in burgeoning WUI fire problem, with the greatest population growth in since 1940. In 1940, the population of the United States was 132.2 million; California had a population of 7.9 million, nationally ranking it the fifth largest state by population. In the year 2000, the population of the United States increased to 281.4 million; California had a population of 37 million, a first place ranking (United States Census Bureau 2010). The population growth of California combined with developments in high fire hazards areas proportionately exceeds the development in WUI areas throughout the United States. A visualization of the California WUI fire threat and accompanying population is shown in Figure 2.5: California Housing Density, Year 2000 and Figure 2.6: California Wildland Fire Threat Zones.

Figure 2.3: United States Housing Density, Year 2000
(<http://silvis.forest.wisc.edu/old/Library/HousingData.php>)

An analysis by state of national WUI areas ranks California first in number of homes in the WUI at 5.1 million. Other first-place rankings include: North Carolina first in WUI land area with nearly 20,000 square miles; Connecticut first in proportion of land in the WUI (72%); and New Hampshire first in proportion of housing units in the WUI (82%) (Radeloff 2005).

Protecting the dream of those who choose to live in WUI areas has become a horrific financial nightmare for the government agencies charged with fire protection. In the 1960s, about 200 homes a year were lost to wildfire; today that figure is averaging 2400 homes per year, and is continuing to grow.

There has been a 560% population increase since 1960 in WUI areas, a jump from 25 to 140 million people (Bailey 2007). Even with the increase in concern and effort the WUI fire problem continues to escalate.

A comparison of Figures 2.5 and 2.6 shows why California has the most severe WUI interface fire problem in the nation. The principal cause is proximity of high housing densities to Extreme, Very High, and High fire threat zones. In California, all top 20 fires listed in “Fire History by Number of Structures Destroyed” occurred in densely populated WUI areas in Extreme to High Fire Threat Zones (Office of the State Fire Marshall 2010).

Increased population with accompanying development in WUI areas has contributed to the escalating wildfire interface losses.

SECTION 2.2.2 WUI CODE COMPARISON

A significant number of homeowners moving to WUI areas come from large urban areas, and consequently expect the same level of wildfire protection for their homes and property as they received from fire departments in large cities. However, this anticipated level of fire service protection does not exist in most interface locations (Bailey 2007). Regulations and development standards have been prescribed for WUI areas, and some codes and standards have been developed to promote the use of fire-resistant building materials and creation of defensible space. However, few comprehensive laws address the threat of structure ignitions from wildfire exposure (Stephens and Collins 2007). An examination of the wildfire protection afforded by prevalent WUI codes and standards will produce an insight into promulgated structure fire protection in interface areas.

The discussion of various codes will concentrate on the regulations enforceable in California. These regulations emphasize the seriousness of the WUI area fire problem, and the legislation and enforcement efforts attempting to mitigate the WUI fire threat. The fire safety principles contained within the codes apply to every WUI area, not exclusively California. Other prominent model codes will be discussed, ranging from code based on legislatively adopted standards to national and international WUI fire protection references. The intent of the WUI codes comparison is not to present a detailed assessment discussing the full implication of each code section, but rather a broad overview concentrating on the significant similarities and differences of the principal provisions of each code.

The comparison of the WUI area fire protection codes in California for both State Responsibility Areas (SRA) and local jurisdictions entails the examination of California Building Code, Chapter 7A (CBC Ch 7A), entitled “Materials and Construction Methods For Exterior Wildfire Exposure” 2009 Edition, and Chapter 49 of the California Fire Code (CFC Ch 49), entitled “Requirements For Wildland-Urban Interface Fire Areas for SRA Lands 2010 Edition. Essentially, SRA Lands are those areas within California where the primary financial responsibility for fire prevention and fire control belongs to the State of California (Office of the State Fire Marshall 2009). New editions of these codes are produced on a triennial basis (International Code Council 2010). The local jurisdictional adoption process may not occur as regularly.

In California, local jurisdictions outside of SRA Lands may, through adoption by a legislative body either enforce the California State codes as the base documents or may select a model code. A local jurisdiction is not limited to these two options, but may establish their own WUI code with California State Fire Marshall (SFM) cooperation and approval (Office of the State Fire Marshall 2009). Prominent examples of model codes are the 2009 International Wildland-Urban Interface Code (IWUIC), and two National Fire Protection Association (NFPA) Standards: NFPA 1144, Standard for Reducing Structure Ignition Hazards from Wildland Fire 2008 Edition (NFPA 1144); and NFPA 1141, Standard for Fire Protection Infrastructure for Land Development in Suburban and Rural Areas 2008 Edition (NFPA 1141). Both NFPA 1144 and NFPA 1141 will be compared to the other WUI codes, because they work in cooperation for new development and existing structures. Certain provisions of IWUIC overlap provisions of both of these codes, as explained below. See Table 2.7, with its accompanying Abbreviation Key for a condensed comparison of the aforementioned codes.

The purpose of NFPA 1144 is to provide minimum standards for design, construction, and landscaping for structures in the WUI, and reduce the probability of ignition. The standard applies to all existing structures and improvements within the WUI. The optimal goal of NFPA 1144 is to prevent ignition of residential structures, and for those structures to survive a wildfire without the intervention of firefighting force (National Fire Protection Association 2008-B).

The purpose of NFPA 1141 is to develop fire protection and emergency services in suburban and rural areas. NFPA 1141 applies to land development or changes in land use (subdivisions) within suburban and rural areas (National Fire Protection Association 2008-A). Each of these codes references the other for additional information, and they are intended as complimentary documents. The two separate documents are established to allow jurisdictional flexibility in applying the WUI standards (National Fire Protection Association 2008-A). Applicable provisions of NFPA 1141 are indicated by red lettering in Table 2.7 to distinguish them from NFPA 1144 in black lettering in the fifth column. The technical committees of NFPA 1141 and NFPA 1144 obtained guidance from USDA Forest Service and the National Wildland/Urban Interface Fire Program (Firewise Committees) (National Fire Protection Association 2008-A), National Fire Protection Association 2008-B). Both of these model codes have been officially adopted for use by state and local governments, as well as by numerous jurisdictions involved in planning Firewise Communities (National Fire Protection Association 2008-A).

The International Code Council (ICC) publishes the three codes not produced by the NFPA. The ICC designs all of the International Codes (I-Codes) to be promulgated by adoption into ordinance. The California Building Code is based upon the ICC-published International Building Code. The California State Fire Code also originates within the ICC as the International Fire Code. Both the International Building and Fire Codes are adopted with amendments by the California Legislature and become law (Office of the State Fire Marshall 2009). Additionally, the ICC publishes the IWUIC as a stand-alone adoptable model code for WUI areas (International Code Council 2009). CBC Ch 7A and CFC Ch 49 are enforceable regulations in SRA Lands and in local jurisdictions where adopted (Office of the State Fire Marshall 2009). CBC Ch 7A and CFC Ch 49 should be used in conjunction with to mitigate wildfire impact on structures in WUI areas (International Code Council 2009-C), (International Code Council 2010). NFPA 1144 and NFPA 1141 are fire prevention and fire mitigation standards, and as such do not contain substantial building or construction regulations. They rely on locally adopted building codes to set forth building requirements.

If there is any conflict between the local building code and NFPA 1144 and NFPA 1141, the more stringent fire protection requirement shall be utilized (National Fire Protection Association 2008-B).

All of the I-Codes published by the ICC, including the International Building and Fire Codes are written in full compatibility with each other (International Code Council 2009-B), (Office of the State Fire Marshall 2009). This is the expressed case with the IWUIC, which has significant agreement in code construction with CBC Ch 7A and CFC Ch 49. CBC Ch 7A and CFC Ch 49 are both prescriptive and performance based codes (International Code Council 2009-C; International Code Council 2010). The process for performance based code satisfaction is located in the California Building Code, Section 104.10 (International Code Council 2007). In the same vein, IWUIC allows alternate protection when approved by the local code official, although many sections are prescriptive in nature (International Code Council 2010). The IWUIC has several code sections that address wildfire exposure mitigating measures not mentioned in CFC Ch 49 or CBC Ch7A.

The CFC Ch 49 and CBC Ch 7A are relatively short code chapters of the California Fire and Building Codes (International Code Council 2009-C). There are many sections of the California Fire and Building Codes that apply to the California WUI codes, and expand CFC Ch 49 and CBC Ch 7A requirements for mitigating the impacts of WUI area fires. Additionally, there are several provisions of California Government Code, Public Resource Code, Health and Safety Code, and local ordinances that regulate fire and life safety in California WUI areas (Office of the State Fire Marshall 2009). The State of California and any local jurisdictions having WUI areas have far more restrictive development and activity governing code requirements than solely relying on CBC Ch 7A and CFC Ch 49 (Office of the State Fire Marshall 2009).

*Table 2.7: Comparison of
2008 NFPA 1144 and 1141
2010 California Fire Code Chapter 49
2007 California Building Code Chapter 7A
2009 International Wildland-Urban Interface Code*

CODE ITEM	2009 CBC Ch 7A	2010 CFC Ch 49	2009 IWUIC	2008 NFPA 1144 <i>NFPA 1141</i>
Fire Hazard Severity Zones	CPRC, or Local Agency CCR Title 14 Maps	CPRC, or Local Agency CCR Title 14 Maps	Triennial by Legislative Body	AHJ
Fire Threat Assessment Provisions	Not Mentioned	Not Mentioned	Construction Adjusts for Water Supply, Defensible Space, Fire Hazard Severity, Access	AHJ
Plans Acceptance	Code Official, i.a.w. SFM Standards	Reserved	Code Official	AHJ
Fire Protection Plan Required	CFC Ch 49	Alternate Site Specific Protection, & Code Official	Code Official	AHJ
Alternate Protection	Site Specific, see CBC 104.10	Site Specific, See CBC 104.10	Building Official, Fire Chief	AHJ
Retroactivity	New Construction Starting Jan. 1, 2008 Roofing, Attic Vents Starting Dec. 1, 2005	Defensible Space, Roofing, Attic Vents Starting Dec. 1, 2005	Not Legally Existing, Distinct Hazard to Life or Property	All Existing Structures
Construction Methods	SFM Standards	CBC Ch 7A	IBC, IFC Approving Authority	AHJ/ Local Bld. Code

CODE ITEM	2009 CBC Ch 7A	2010 CFC Ch 49	2009 IWUIC	2008 NFPA 1144 NFPA 1141
Ignition-Resistant Materials	Flame Spread ≤ 25 ASTM, SFM	Not Mentioned	Flame Spread ≤50 ASTM, UL	Flame Spread ≤ 25 ASTM
Defensible Space	30' Immediate 100' Very High 100' High 100' Moderate	30' Immediate 100' Very High 100' High 100' Moderate	30' Moderate 50' High 100' Extreme	30' Immediate 100' Light Fuels 200' Heavier Fuels
Maintenance of Defensible Space	Not Mentioned	Not Mentioned	Responsible Person	Responsible Person
Roofing	Class A Very High Class A High Class A Moderate	Class A Very High Class A High Class A Moderate	Class A Extreme Class B High Class C Moderate	Class A Severe Class B Moderate Class C Light
Attic Ventilation	¼- inch Mesh i.a.w. CBC Ch 15	¼-inch Mesh i.a.w. CBC Ch 15	¼-inch Mesh	¼-inch Mesh
Eaves	Enclosed No Vents Allowed	Enclosed No Vents Allowed	Enclosed No Vents Allowed	Enclosed No Vents Allowed
Roof Valleys	No. 26 Sheet Gage	No. 26 Sheet Gage	No. 26 Sheet Gage	Not Mentioned
Roof Gutters	Limit Debris	Limit Debris	Limit Debris	Limit Debris
Exterior Walls	Noncombustible/ Ignition-Resistant	Reserved	Noncombustible/ Fire Resistant/	Heavy Timber/ Ignition-Resistant/ Noncombustible 20-minute
Exterior Windows	Insulated Glass/ 20-minute Rated	Not Mentioned	Insulated Glass/ 20-minute Rated	Tempered Glass/ 20-minute Rated/ Multilayered
Doors	Noncombustible/ 20-minute Rated	Not Mentioned	Noncombustible/ 20-minute Rated	20-minute Rated/1 ¾-inch Solid Core
Decking	Ignition Resistant/ SFM Performance/ Noncombustible	Reserved	Ignition Resistant/ 1-Hour Rated/ Noncombustible	Heavy Timber/ Ignition-Resistant/ Noncombustible 1-hour

CODE ITEM	2009 CBC Ch 7A	2010 CFC Ch 49	2009 IWUIC	2008 NFPA 1144 NFPA 1141
Underfloors	Ignition Resistant/ SFM Performance/ Noncombustible	Reserved	Ignition Resistant/ 1-Hour Rated/ Noncombustible	Heavy Timber/ Ignition-Resistant/ Noncombustible 1-hour
Unenclosed Underfloors	Ignition Resistant/ SFM Performance/ Noncombustible	Reserved	Ignition Resistant/ 1-Hour Rated/ Noncombustible	Heavy Timber/ Ignition-Resistant/ Noncombustible 1-hour
Ancillary Structures	Comply with Enforcing Agency	Reserved	Ignition Resistant/ 1 Hour Rated/ Noncombustible	30' Separation/ Comply with Enforcing Agency
Vegetation Management	Not Mentioned	Reserved	Allows Possible Construction Tradeoffs	AHJ
Vegetation Control	Roadways, Electrical Transmission Lines See CPRC, CGCS	Not Mentioned	Roadways, Electrical Transmission Lines	Within Defensible Space
Access	Not Mentioned	Not Mentioned AHJ	Width $\geq$ 12' 0" Height $\geq$ 13' 6" Turnouts, Turnarounds	Width $\geq$ 12' 0" Height $\geq$ 13' 6" Turnouts, Turnarounds
Access Restrictions	Not Mentioned	Not Mentioned	Private Land Protection Specifications	Not Mentioned
Water Supply	Not Mentioned	Not Mentioned AHJ	Distance < 1,000' Flow $\geq$ 1,000 GPM Duration $\geq$ 30 minutes	AHJ
Automatic Fire Sprinklers	Not Mentioned	Not Mentioned	Required Class 1 Ignition Resistant	Required $\geq$ 30' / 2 Stories
Combustible Storage	Not Mentioned	Not Mentioned	Wood > 20' Other: IFC/Good Recognized Standards	Within 30' AHJ

CODE ITEM	2009 CBC Ch 7A	2010 CFC Ch 49	2009 IWUIC	2008 NFPA 1144 NFPA 1141
Ignition Control	Not Mentioned	Not Mentioned	Smoking, Clearance from Ignition Sources, Heat Generating, Fireworks, Outdoor Fires	AHJ
Permitting of Activities, Operations	Not Mentioned	Not Mentioned	14 Activities, Operations Listed	Not Mentioned
Spark Arresters	Not Mentioned	Not Mentioned	½-inch mesh	½-inch mesh
Liquefied Petroleum Gas	Not Mentioned	Not Mentioned	i.a.w. IFC/ Recognized Standards	NFPA 38
Dumping	Not Mentioned	Not Mentioned	Waste Material, Ashes & Coals	Not Mentioned
Land Use Limitations	Not Mentioned	Not Mentioned	Permitting by Code Official	Not Mentioned

Abbreviation Key

AHJ	Authority Having Jurisdiction
ASTM	American Standard Testing Materials
CBC	California Building Code
CBC Ch 7A for	California Building Code Chapter 7A Materials and Construction Methods Exterior Wildfire Exposure
CCR Title 14	California Code of Regulations, Title 14
CFC	California Fire Code
CFC Ch 49	California Fire Code Chapter 49 Requirements for Wildland-Urban Interface Fire Areas
CGC	California Government Code
CPRC	California Public Resources Code
i.a.w.	In Accordance With
IBC	International Building Code
IFC	International Fire Code
NFC	National Fire Codes

NFPA	National Fire Protection Association
SFM	California State Fire Marshall
UL	Underwriters Laboratory

An explanation of Table 2.7 entails a description of the layout and clarification of terms. The table has five columns; the first column from the left, titled “Code Item” indicates what code section topic is used for comparison. The second column, titled “2007 CBC Ch 7A” addresses that particular code section topic covered in the 2007 edition of CBC Ch 7A. Such is the case with the next two columns; “CFC Ch 49” and “2009 IWUIC” indicate the applicable code sections from the 2010 edition of CFC Ch 49, and the edition of 2009 IWUI codes, respectively. The fifth column, titled “2008 NFPA 1144 and 1141” addresses the particular code section in NFPA 1144 2008 Edition and NFPA 1141 2008 Edition. There are a total of 35 rows containing code section topics within the table. The 35 code section topics are selected as the more significant fire protection items contained within the documents compared, and are not an all-inclusive listing. A description of the abbreviations and acronyms used in Table 2.7 follows directly below the table. A “Not Mentioned” entry appearing either under CBC Ch 7A or CFC Ch 49 indicates that no specific language exists for that item, as it appears in the IWUIC. Likewise, a “Not Mentioned” appearing in the fifth column indicates that neither NFPA 1141 nor NFPA 1144 have language addressing that particular item. Usually, there is sufficient existing code or statute outside the short chapters of CBC Ch 7A and CFC Ch 49, but a significant exception to existing codification for “Not Mentioned” category is the provisions in the California WUI Codes for the Fire Threat Assessment Provisions of IWUIC.

For further clarification, a “Reserved” entry indicates the code section is under consideration for future inclusion of code language. A significant example of this reserved status occurred in the changes to the 2010 edition of CFC Ch 49, where code language regarding Defensible Space was inserted for the first time. The 2007 CFC Ch 47 had a Reserved status indicated for the Defensible Space section. Several other Reserved sections in CFC Ch 49 have code sections in CBC Ch 7A.

Examples of this relationship exist for Plans Acceptance, Exterior Walls, Decking, Underfloors areas, Unenclosed Underfloors areas, Ancillary Structures and Ancillary Structures. Since the CBC Ch 7A and the CFC Ch 49 are used in conjunction, and a working knowledge of these documents exists, then the Reserved entry for the CFC Ch 49 sections is essentially replaced by the language from CBC Ch 7A (International Code Council 2009-B; International Code Council 2010). The broad definition of the National Fire Protection Association for the Authority Having Jurisdiction (AHJ) is used in Table 2.7. Where public safety is concerned, AHJ can include federal, state, and local statutory authority. Those who may have jurisdiction include: insurance agency representatives, property owners or their representatives, department officials or commanding officers on government property (National Fire Protection Association 2008-B). An AHJ entry indicates that the authority for interpretation, establishment and/or enforcement of the code section rests with the broad definition of authority having jurisdiction. Under such conditions, the entity must be consulted for interpreting, understanding and approving the standard.

Chapter 5 of the IWUIC includes provisions that allow for substantial reduction of ignition-resistant construction requirements for a lower fire threat assessment. The fire threat assessment is based upon the number of days of critical fire weather per annum, the fuel type, and the slope of the terrain, defensible space and vegetation management. The relationship of these variables is expressed in Table 2.8, which is a duplication of Table 502.1 from the 2009 IWUIC. Other fire threat assessment features include the Fire Hazard Severity classifications of Moderate Hazard, High Hazard, and Extreme Hazard as determined by Table 502.1, and applying the relative adequacy of water supply, defensible space and access to arrive at a Class 1, Class 2, or Class 3 Ignition-Resistant Construction.

TABLE: 2.8:
2009 IWUIC FIRE HAZARD SEVERITY ASSESSMENT

TABLE 502.1 FIRE HAZARD SEVERITY									
FUEL MODEL ^b	CRITICAL FIRE WEATHER FREQUENCY								
	≤ 1 Day ^a			2 to 7 days ^a			≥ 8 days ^a		
	Slope (%)			Slope (%)			Slope (%)		
	≤ 40	41-60	≥ 61	≤ 40	41-60	≥ 61	≤ 40	41-60	≥ 61
Light fuel	M	M	M	M	M	M	M	M	H
Medium fuel	M	M	H	H	H	H	E	E	E
Heavy fuel	H	H	H	H	E	E	E	E	E

a. Days per annum.
b. When required by the code official, fuel classification shall be based on the historical fuel type for the area.

E = Extreme hazard.
H = High hazard.
M = Moderate hazard.

Table 2.9 is a reproduction of Table 503.2 from the 2009 IWUIC depicting the relationship of these factors. The IWUIC emphasizes the importance of defensible space by allowing a reduction in ignition-resistant construction. As an example from *Table 2.9*, if the conforming required defensible space is increased by a factor of 1.5, then a reduction from Ignition-Resistant Class 1 to Class 2 can occur in an Extreme Hazard area.

The aforementioned WUI codes and standards are the vanguard of fire protection documents protecting life and property in WUI areas; they are the world's leading standards. An impressive amount of time, thought and energy went into the development, promulgation and enforcement of these codes. Nonetheless, there are a few areas of dearth for protection of structures within these codes and standards. First, these prominent codes and references established for structural fire protection involve standards for materials, methods of construction, defensible space and in some cases, fuel modification; yet no widely disseminated code or standard exists for establishing design criteria for the shape of the building envelope to increase fire resiliency.

TABLE 2.9:
REDUCTIONS IN FIRE-RESISTANT CONSTRUCTION

TABLE 503.1 IGNITION-RESISTANT CONSTRUCTION ^a						
DEFENSIBLE SPACE ^c	FIRE HAZARD SEVERITY					
	Moderate Hazard		High Hazard		Extreme Hazard	
	Water Supply ^b		Water Supply ^b		Water Supply ^b	
	Conforming ^d	Nonconforming ^a	Conforming ^d	Nonconforming ^a	Conforming ^d	Nonconforming ^a
Nonconforming	IR 2	IR 1	IR 1	IR 1 N.C.	IR 1 N.C.	Not Permitted
Conforming	IR 3	IR 2	IR 2	IR 1	IR 1	IR 1 N.C.
1.5 × Conforming	Not Required	IR 3	IR 3	IR 2	IR 2	IR 1

a. Access shall be in accordance with Section 402.
b. Subdivisions shall have a conforming water supply in accordance with Section 402.1.
IR 1 = Ignition-resistant construction in accordance with Section 504.
IR 2 = Ignition-resistant construction in accordance with Section 505.
IR 3 = Ignition-resistant construction in accordance with Section 506.
N.C. = Exterior walls shall have a fire-resistance rating of not less than 1-hour and the exterior surfaces of such walls shall be *noncombustible*. Usage of log wall construction is allowed.
c. Conformance based on Section 603.
d. Conformance based on Section 404.
e. A nonconforming water supply is any water system or source that does not comply with Section 404, including situations where there is no water supply for structure protection or fire suppression.

Second, there is no information on external mitigating measures, such as Structure Fire Shields, discussed in Chapter Nine. Third, none of the existing standards address the location of the structure on a lot to take advantage of terrain protective features, or avoidance of terrain enhanced hazards. Fourth, structure, vegetation and terrain airflow impacts are not addressed. Fifth, none of these codes adequately set standards for structure separation in high-density subdivisions.

While some of the codes and standards contain at least limited language addressing these deficient areas, this is not so in all cases. Examples of these limited code sections with an explanation follow. NFPA 1144 does require a minimum of 30 feet of setbacks of structures from a residence (National Fire Protection Association 2008-B). A 45 feet standard has been established for sufficient protection of structures from the radiant flame of burning structures and heavy fuels (Cohen and Butler 1998; Maranghides 2009; Maranghides and Mell 2009; Institute for Business & Home Safety 2008). NFPA 1144 requires a minimum of 30 feet setback of structures from vegetated slopes, without special mitigation as determined by the authority having jurisdiction.

The required special mitigation measure may be a noncombustible wall or barrier (National Fire Protection Association 2008-B). The 30 feet setback and/or special mitigation may be inadequate depending on fuel type, slope percent, hazardous terrain features, and onsite airflow characteristics. Also, the shape and layout of the noncombustible walls are not specified. The 2009 IWUIC does consider terrain slope in the equation for determining the fire hazard category. Table 2.8, 2009 IWUIC Fire Hazard Severity Assessment is used for this purpose. Determination of the Fire Hazard Severity classification is a base component, along with adequate defensible space and available firefighting water supply for calculating the requirement for the level of ignition-resistant building materials (International Code Council 2009-B). Table 2.9, Reductions in Fire-Resistant Construction is reproduced from the 2009 IWUIC. It is used for determining the fire-resistant construction requirements. During all-too-frequently occurring circumstances, relying on the percent of slope without compensating for hazardous terrain features, structure proximity to slope, structure proximity to adjacent structures, onsite airflow characteristics, and other special fire hazards should be considered an inadequate fire protection strategy.

2.2.3 INSTITUTIONAL INFLUENCE

In a report entitled “Fires in the Wildland/Urban Interface, Topical Fire Research Series” the United States Fire Administration (2002, 17) argues, “Understanding the WUI fire problem and the environmental and political factors that contribute to the fire loss will give designers, builders and planners insight into producing more fire resilient structures.” Understanding the fire problem in WUI areas is enhanced by identifying the competing interests in play. The institutional influences exerted in the interface include: the jurisdictional overlap between the government entities; the authority yielded by insurance institutions; the homeowners; environmentalists and other special interest groups. The jurisdictional issues exists among the federal, state, and local levels of government. These jurisdictional issues include cooperative fire protection agreements and their firefighting costs, legal mandates, zoning regulations, environmental conversancy, fire and building code enforcement (United States Fire Administration 2002).

A 2006 study performed by the Department of Agriculture, Office of Inspector General found that the majority of federal government spending on large fire suppression costs is directly linked to protecting private property in the WUI (United States Department of Agriculture 2002). The federal government estimates 3% of wildland fires become larger fires and account for 95% of national firefighting costs (Bailey 2007). Furthermore, Bailey (Bailey 2007, 8) argues, “In addition, these are almost entirely Wildland-Urban Interface fires.” Federal agencies shoulder the major financial burden of protecting those WUI homes even though development decisions in WUI areas are made by local and state officials (Kenworthy 2009).

Reports from the United States Government Accounting Office and United States Department of Agriculture, Office of Inspector General accurately highlight the complexities associated with large, multi-jurisdictional fires, especially those that threaten structures and lives in WUI areas. Protecting human life and safety is the top priority of the federal government, and these reports focus on both managing fire suppression in WUI areas and cost sharing for those activities by government entities. The WUI areas that fall under a mix of ownership and jurisdictions typically involve response from federal, state, county, and local agencies. Wildfires in or adjacent to interface areas generate a larger, more aggressive response that includes wildland and structural firefighting resources. These factors add up to increased complexity and costs associated with incident response in the WUI (Rey and Hatfield 2007).

New homeowners in WUI areas often do not understand the risks associated with their environment and do not take the appropriate steps to protect their homes from wildfires (United States Fire Administration 2002). A variety of public and private institutions have taken action to reduce fire loss. Communities throughout the country have codified requirements for homeowners to construct and maintain their homes in a fire-safe manner. Other communities have considered tax credits for homeowners as a means of encouraging fire safety in the WUI. The insurance industry also has an important stake in protecting homes in the WUI.

As an example of their financial obligation, the Tunnel Fire in the Oakland Hills in 1991 caused nearly \$1.2 billion in insured property losses. Consequently, the insurance industry has considered adjusting premiums based on the assessed level of wildfire risk for a particular property (Rey and Hatfield 2007). However, insurance rates have not thoroughly and realistically adjusted premiums to represent the wildfire risk to any particular structure. As an example, a Los Angeles County Fire Department study of structure losses in Southern California wildfires has shown that with 100 feet of brush clearance, a home with a wooden roof has a 21 times greater chance of burning than a home with a non-wood roof; most fire insurance rates are only approximately 25% higher for wood roofs than for non-wood roofs. Insurance rates do not compensate for the true difference in risk (Los Angeles County Fire 2010).

The responsibility of residents to protect their own structures in the WUI falls short when people believe the government will protect them from fire. Furthermore, property owners believe that insurance companies, and federal or state disaster assistance will always be there to cover losses (Bailey 5, 2007). There is a personal disconnect between the fire threat reality and the preventative action of the homeowners. An interface wildfire always happens somewhere else and to someone else, residents may think. A case in point is the Santa Barbara foothill area in the South Coast area of California. Some homeowner associations actively opposed vegetation reduction programs until the Zaca Fire burned nearly 240,000 acres of wildland in the foothills in July and August of 2007 (Western Institute for Study of the Environment 2007). Thirty-five tons of vegetation was cleared in the Mission Canyon area of Santa Barbara on June 16, 2007, when smoke from the Zaca Fire, approximately ten miles away, drifted over the Santa Ynez Mountains above Santa Barbara. This was an extraordinary amount of brush cleared in one day, as 41 tons were cleared in all of 2006 (Neels 2009). A resurgence of vegetation reduction occurred from that time to the present as evidenced by the annual tonnage cleared (Mission Canyon Association 2010). Another example occurred in Rancho Santa Fe, California after the Witch Fire of 2007. A homeowner planted over 20 highly flammable cypress trees within the defensible space of her home; a local ordinance violation.

The homeowner was given a notice of violation from a fire inspector, who specialized in WUI inspections. The homeowner explained to fire authorities that she never thought she would get a wildfire safety inspection of her property, and that is why she knowingly planted outlawed vegetation (Knowles 2008). Leaving residents responsible for maintaining defensible space is problematic. The best structural fire protection is designed into structures; requires minimal maintenance; is activated without human intervention; and is not subject to power failures.

2.2.4 FIRE EXCLUSION POLICY

Preventing fires costs significantly less than suppressing them. As a result, fire prevention efforts in the WUI are crucial. With this observation, it is important to understand that fire plays an important role in wildland ecosystems; some plant species are fire dependent (see Section 1.2.2). However, for decades the federal government advocated the suppression of all wildfires regardless of size or location. The policy was known as the Fire Exclusion Policy, established in 1910 (United States Forest Service 2010). Following great wildfires in Montana and Idaho, the Forest Service promulgated a policy of total fire exclusion; namely, to prevent fires from starting, and putting them out as quickly as possible (Agee 2006). Over time, the fire exclusion policy created a dangerous accumulation of vegetative fuels in our forests (United States Fire Administration 2002). The fire exclusion policy is based on significant influences: increased population; extensive WUI area development; and air pollution reduction controls. Wildfire was prohibited from spreading its natural cycle of forest rejuvenation. As fire was prohibited from being used as a tool to increase the health of forests, including chaparral forests, the health of the forests declined (Bailey 2007). The Fire Exclusion Policy has been successful throughout much of the nation, except in Southern California. Here, chaparral fires are driven by Santa Ana winds, and are not usually controlled within one burn period (Keeley 2006). In addition, the diminution of forest health caused by the elimination of rejuvenating fire in chaparral forests produces an even greater fire risk for Southern California, by allowing a greater buildup of dead fuel (Bailey 2007).

The Fire Exclusion Policy of the federal government lasted from 1910 until 1995. A 1995 congressional directive authorized the Forest Service to set policy that would restore wildfire its natural ecological role of reducing hazardous fuels and forest rejuvenation (Bailey 2007). The resulting 1995 Federal Fire Policy was the first time the federal government officially recognized the essential role of fire in maintaining natural systems (Bailey 2007). Wildland Fire Use was the term coined to describe the policy allowing naturally occurring fires to burn accumulated hazardous fuels like dry brush, and trees that increase the likelihood of large, expensive wildfires (United States Department of Agriculture 2006). However, the Wildland Fire Use policy cannot be realistically applied in WUI areas, because of public safety concerns. In practice the Forest Service and other federal agencies actively suppress nearly all fires that threaten structures, even on nonfederal lands (Bailey 2007). The gain of controlling costly, catastrophic wildfires by the Wildland Fire Use policy must be measured against the drawbacks of public health, poor air quality, greenhouse gas contribution, and risk to public safety (United States Department of Agriculture 2006, iv).

Many western landowners prefer the “out of vogue” federal practice of putting out every fire as fast as possible. Perversely, some property owners argue that because after 90 years of fire suppression the federal government has made the forests more flammable, these federal agencies owe it to them to save their homes and property. They maintain that this is a government-created problem and the government should be responsible for dealing with it (Bailey 2007). Despite a long-standing recognition of the crucial fire role in many terrestrial ecosystems, uncertainties and disagreements over fire management strategies persist. For regions with a Mediterranean climate, modern fire suppression is commonly thought to increase the likelihood of large and intense wildfires. However, debates over fire suppression effects and needed landscape treatments, especially for shrublands in Australia and California, often involve a fundamental assumption about aging fuels and increasing fire probabilities (Moritz et al. 2004). Since policy decisions are unlikely to resolve the fire threat encountered in WUI areas, a significant possibility for increased fire safety comes in the form of planning and the design of structures.

2.3 ENVIRONMENTAL FACTORS

Three interacting classes of variables influence the wildland fire environment: fuels; topography; and, air mass or weather (National Wildfire Coordinating Group 2001). Weather is the most variable component changing in terms of time and space. Topography does not vary temporally, but can vary greatly spatially. The fuels component varies considerably in both space and time (Pyne et al. 1996). The predominant factor affecting direction and rate of wildfire spread is given a “driven” designation (i.e. wind-driven fire). Weather is the primary driving force behind changes in fire behavior, with wind direction and velocity changes producing significant rapid burning alterations (Tele 2005). Additionally, climate change is being credited for longer fire seasons, with scientists predicting the possibility of a year-round fire season. In 2006, a year-round fire season was declared in Texas, Oklahoma, Colorado (Bailey 2007). In the summer of 2009, several “States of Emergency” were declared in California. The California Governor, Arnold Schwarzenegger proclaimed that California has a “Year Round Fire Season” (Sullivan 2008). Nearly all climate models project warmer springs and summers temperatures across the West. This means that wildfires get larger, and longer fire seasons are likely. If development trends persist in WUI area, more homes will be threatened by wildfires (McDaniel 2006). The growing problem of interface wildfires will continue to exacerbate as more population moves out of urban centers and into the WUI, with continuing climate change (Bailey 2007).

2.3.1 WEATHER COMPONENTS

This thesis will emphasize topographical aspects and air movement effects on fire behavior. The extent of discussion on topography and airflow may not exceed that of weather and fuels. Nonetheless, the relative depth of examination of topography and airflow in the following sections and Chapters Four, Six and Seven will exceed the proportion of it compared to the amount of information on fuels and weather available in the public realm. An abundance of information exists on weather and fuels influencing fire behavior, and their effects on structure fire resiliency.

A limited treatment on weather and fuel variable classes influencing WUI fire behavior will be provided to foster a better understanding of the WUI area fire problem.

The effects of weather and fuels as two environmental variables are manifested in the designations of WUI codes in such items as roofing materials, defensible space, attic venting, exterior windows and door requirements. Table 2.7 elaborates on WUI codes and standards. Most of the items listed are influenced by fuel and weather variables. Weather components include factors of temperature, relative humidity, air movement, cloud cover, precipitation, and atmospheric stability are all elements of the air mass (National Wildfire Coordinating Group 2001). These values can change quickly significantly with differences in aspect and elevation. Air mass affects fire by regulating the moisture content of fuel, and more directly the rate of combustion (National Wildfire Coordinating Group 2001).

Atmospheric temperature affects fuel temperature and burn rate. The ease of ignition, the amount of heating required to raise fuel to ignition temperature depends on the initial fuel temperature (National Wildfire Coordinating Group 2001). Additionally, for every 18°F increase in temperature the speed of a chemical reaction doubles (Tele 2005). The most important effect of temperature is its effect on relative humidity and hence on dead fuel moisture content (National Wildfire Coordinating Group 2001). Wind is the most influential factor of the weather class when it comes to the burn rate and direction of spread (Tele 2005). Windspeed has a significant effect on fire spread, by providing increased oxygen to the fuel and materially determines the rate of spread and burn direction. A five mile-per-hour wind will impact rate of spread in the same way as a 50% slope (Tele 2005). Increased wind velocity moves flames increasingly horizontal from vertical, and can cause direct flame contact with fuel ahead of the fire. Wind affects fuels by preheating and drying them by increasing the rate of transfer of radiant and convective heat (National Wildfire Coordinating Group 2001). Convective heat plays the greater role in the spread of wildland fire as superheated smoke and gasses preheat fuels, cause spot fires, and move fire into the crowns of trees (Tele 2005). Wind propels embers carrying them further as wind velocity increases. Spotting occurs possibly ten minutes before the arrival of a flame front during a wildfire (Tele 2005).

Not only can embers destroy structures before the arrival of a flame front, but they may also ignite structures afterwards. Research has shown that the majority of houses destroyed in Australian wildfires actually survive the passage of the fire front only to burn down in the following ignitions caused by windborne burning debris. The prolonged ember attack mechanism stemming from spotting is the main cause of structural losses in the UWI (Stephens and Collins 2007).

2.3.2 FOEHN WINDS

The most significant and frequently erratic short-term variable in extreme fire behavior is wind. Increases in wind speed can accelerate fire spread faster than any other variable, including temperature, fuels, relative humidity, and changes in terrain. In Central and Southern California wind-driven fires are customarily pushed by foehn winds (Aerographer/Meteorology 2008). Foehn winds are gradient compressive winds that occur when air flows downhill from a high elevation. Their temperature is raised by adiabatic compression. Also, foehn winds are classified as katabatic winds, meaning heating and drying-out, caused by adiabatic heating of air as it descends on the lee side of mountains (Aerographer/ Meteorology 2008). Dry, unsaturated air warms on descent at a rate of almost 30°F per mile, or 10°C per kilometer of altitude (Aerographer/Meteorology 2008). During foehn wind episodes, the temperature increases well over 90°F, and wind speeds may reach 50 to 70 miles per hour (Tele 2005). Foehn winds will be used as the example driver for wind-driven fires, and representative of all winds with speeds in excess of 30 miles per hour in fire-prone areas (Fovell 2008). The Santa Ana winds, a type of foehn wind, blow through several Southern California counties. The winds occur as far north as Ventura County, frequently occur in Los Angeles County, Orange County, Riverside County, San Bernardino County, and south into San Diego County (Fovell 2008). The downslope and offshore mechanism that causes warming winds in Santa Barbara is essentially the same as that which causes the larger scale Santa Ana winds to the south and the small scale warming winds at Avila Beach in San Luis Obispo County to the north (Ryan 1991).

When meteorological conditions are favorable, this dry northeast wind blows from the windward sides of chaparral forests, and is funneled through the many passes and canyons. The wind direction changes in response to barriers, such as mountain ridges and hillsides. Foehn winds often occur at exposed places along the entire California coast from Ventura to San Diego. Subsequently, the term Santa Ana refers to the general condition of a dry northeast wind over Southern California (Aerographer/Meteorology 2008).

Every large loss WUI fire in Southern California has occurred during a foehn wind event. As an example, the 1961 Bel Air Fire in Los Angeles, California burned during an intense Santa Ana episode. Firebrands were carried over a mile in advance of the main flame front by the wind (Fovell 2008). As recent examples, all the devastating fires of 2008 in Southern California were blown by foehn winds. These fires include the Tea Fire in September, and the Gap Fire in June (Fovell 2008). Both of these fires were located in Santa Barbara County, where wind-driven fires are pushed by Sundowner winds, a variant of Santa Ana winds (Ryan 1991). Figure 2.10, shows the smoke plume of the Gap Fire being pushed offshore by Sundowner winds. The Freeway Complex Fires in Los Angeles and Orange Counties, and the Sayre Fire in Los Angeles all occurred within a couple days of the Tea Fire in November 2008. These all happened during foehn wind events (Fovell 2008). Figure 2.11 shows the smoke columns of these fires all being blown out onto the Pacific Ocean by the foehn winds. Shown in Figure 2.12 is a smoke plume blowing in a northeastern direction towards the Pacific Ocean from the January 2009 Black Saturday Fires in the Melbourne area of Australia. Note the similarities in appearance of the smoke drift size, spread, and direction from the Sundowner, Santa Ana, and Black Saturday wind-driven fire events (Fovell 2008).

Not only do foehn winds occur in California, but they are a worldwide weather phenomenon. They occur frequently in the late fall and winter in the mountain states of the western United States, Europe, and Mediterranean Climate areas of the world (Fovell 2008).

In the Pacific Northwest, Montana and Wyoming the foehn winds are known as the Chinook. In Southern California, they are known as the Santa Anas (Ryan 1991). In the Southcoast area of Santa Barbara, California, the foehn winds are known as Sundowners (Ryan 1991). Worldwide examples of foehn include: Skysweeper over Majorca, Spain; the Aspre wind over the Garonne plain of France; Bergwind over the southern cape of South Africa; as the Föhn or Southcoast over Australia. The airflow and compressive heating characteristics are similar for all these foehn winds. As an example, the direction of the Bergwind, much like the Santa Ana wind direction is locally changed due to barriers posed by the position and forms of mountain ridges on the windward side of forests. The airflow is then channelled through valleys and canyons running from the mountains (Aerographer/Meteorology 2008). Fires associated with the Bergwinds burn with higher frequency and greater intensity than without the winds (Geldenhuys 1994).

Figure 2.10 (above): June 2008 Sundowner Wind Blowing Gap Fire Smoke Across Pacific Ocean Near Santa Barbara, California Area
(<http://www.sott.net/image/9798/fire-400x300.jpg>)

The emphasis of this thesis is on Southern California, especially Santa Barbara County, but the implications and findings of the research, just like foehn winds, have far broader applications for other fire prone areas of the world. For additional information on Mediterranean Climate foehn winds names and the names of fire adapted plants refer to, Table 2.13, Mediterranean Climate Areas Fire Characteristics of Wind and Fuel.

Figure 2.11: November 2008 Santa Ana Wind Blowing Smoke Across Pacific Ocean From Freeway Complex and Sayre Fires in Southern California
(<http://www.sott.net/image/image/9798/fire-400x300.jpg>)

Figure 2.12: February 2009 Föhn Wind Blowing Smoke Across Pacific Ocean From Black Saturday Fires, Near Melbourne Australia (http://en.wikipedia.org/wiki/Black_Saturday_bushfires)

2.3.3 MEDITERRANEAN CLIMATE

Southern California has an environment well suited for large wildland fires, including chaparral forests, steep terrain, foehn winds, and a “Mediterranean climate” (Wikipedia 2008-A). A “Mediterranean Climate” is simply one that resembles the climate of the Mediterranean Basin. The Mediterranean climate areas of the world are the Mediterranean Basin, Southern California, Chile, South Africa and Australia. The worldwide locations of the Mediterranean climate all have similar fire problems, due to the climate (Minnichi and Bahre 1995). These areas are among the most flammable areas, because of their summer heat and summer droughts.

There are a number of other factors that contribute to the significance of the WUI fire problem in Mediterranean climate areas: increased population; forests with highly flammable fuels; forests areas with greater amounts of dead and drought stressed fuels; and, extreme fire weather conditions. Southern California epitomizes the most severe WUI fire problem anywhere on earth (Stephens 2006). Figure 2.13 shows the five Mediterranean climate areas with a global perspective.

Figure 2.13 Location of the World's Fire Mediterranean Climates
(http://en.wikipedia.org/wiki/Mediterranean_climate)

The latitudes of these areas are remarkably similar. They are located within a relatively narrow belt of 30° to 45° of either north or south latitude (Minchin and Bahre 1995).

A succinct description of the Mediterranean climate includes cool rainy winters and dry, hot summers. The climate's, vegetation and fire problems are similar in the five Mediterranean climate areas (Ritter 2006). Table 2.14, lists several Mediterranean climate common characteristics, including foehn wind names and fire-adapted plant identifications. In California, the Mediterranean climate exists from San Francisco south to San Diego and from the Pacific Ocean east to the foothills of the Sierra Madre Mountains (Minnichi and Bahre 1995). The weather system of the California Mediterranean climate area is characterized by winter precipitation from frontal storms moving off the Pacific Ocean, and with protracted summer drought. The coastal mountain ranges are forested with chaparral vegetation. Chaparral plants are adapted to dry hot summers and are drought tolerant. These plants can survive without any significant rainfall for upwards of six months. Because of the drought tolerance, the chaparral forests have unusually high flammable oil content and a significant percentage of accumulated dead growth (Fovell 2008).

The similarities of the Mediterranean climates are profound. The dry summers and wet winters indicative of the Mediterranean climates are found on the coast of subtropical continents and on the coast of the Mediterranean Sea (Ritter 2006). As an example of the climate similarity, a comparison of the rainfall and weather of Southern California and Perth Australia is revealing. In Southern California annual precipitation averages approximately 17 inches, and less than one inch during the summer. Winter temperatures are mild, averaging nearly 53°F during daylight. Outside of coastal areas, the temperature may drop below freezing at night (California Travel and Tourism 2010). Inland summer afternoon temperatures generally exceed 90-105°F (Minnichi and Bahre 1995). Perth, Australia experiences just less than 18 inches of rainfall throughout the year. Winter daylight temperatures average 52°F, with a 46°F minimum daily temperature. During the summer months of December to February the city only averages slightly over one inch of rainfall. The summer temperatures range from 80°F to 98°F (Minchinni and Bahre 1995). In the southern hemisphere the winter occurs during the months of June to August.

Even though the calendar months are different for the California and Australia summer, their respective fire seasons occur during the droughts of the summers (Wikipedia 2008-A).

The Mediterranean forests, woodlands, and shrub biomes are closely associated with the climate. The wet winter and dry summer seasonality of precipitation is the defining characteristic. The summer drought places a great deal of stress on the local vegetation, but plant structures have evolved and they have adapted to the climate and fire. A particular manifestation of plant adaption to the climate is sclerophyll leaves. Sclerophyll leaves are thick leathery and contain a high oil content (Fovell 2008). The shrub land forests are commonly called maquis in the Mediterranean Basin, chaparral in California, matorral in Chile, fynbos in South Africa, and mallee and kwongan in Australia. The natural vegetation of the Mediterranean climate has to survive long, hot periods of summer droughts, and cycles of fire. These plant communities are well suited to recover from the droughts, floods, and fires. Additionally all of the Mediterranean climate areas have plants that are highly flammable and often rejuvenated by fire (Wikipedia 2008-A). The scrub land forests are comparable in each of these areas. As evidence, many plants from one Mediterranean climate area can easily adapt to another Mediterranean climate area (Warhol 2007).

Another similarity of the Mediterranean climates is the association with the five large subtropical high-pressure cells of the world's oceans. The high-pressure cells shift polar in the summer and towards the equator in the winter. The movement of high pressure cells are instrumental in forming the subtropical deserts and the Mediterranean climate in these regions (Wikipedia 2008-A). The movement of the high pressure cells predominately creates rain and cooling in the winter, and the virtual absence of rain and warming in the summer (Ritter 2006). To illustrate, the Azores High is associated with the Sahara Desert and the Mediterranean Basin climate. The South Atlantic High is similarly associated with the Namibia Desert and the Mediterranean climate of the Western part of South Africa. The North Pacific High is related to the Mojave and Sonora Deserts and the climate of California.

The South Pacific High is related to the Atacama Desert and the climate of central Chile. The Indian Ocean High is related to the deserts of western Australia and southwest and south-central Australia, and the Great Sandy Desert, the Great Victoria Desert and the Gibson Desert. The deserts affect fire behavior, such as Southern California. Here, the proximity to the Mojave and Sonora deserts contributes to the drying-out of the Santa Ana type of foehn wind (Fovell 2008). Other atmospheric conditions create cloudless conditions, giving the dry summer subtropical climates many days of sunshine. The cloudless conditions that commonly occur during both the daytime and night cause significant heat gain and loss. As a result, these climates experience a large daily temperature range during the summer. The large daily temperature differential contributes to faster fire burn rates, and longer periods of rapid burning during daylight (Wikipedia 2008-A).

TABLE 2.14
MEDITERRANEAN CLIMATE AREAS
FIRE CHARACTERISTICS OF WIND AND FUELS

Mediterranean Climate Area	Foehn Wind	Fire Adapted Vegetation	Latitude	High Pressure Cell	Desert
Australia	Föhn Southcoast	Mallee Scrub Kwongan	30-35°S	Indian Ocean	Great Sandy Great Victoria Gibson
California	Santa Ana Sundowner	Chaparral	30-40°N	N. Pacific	Mojave Sonora
Chile	Puelche	Chilean Matorral Chilean Palearctic Jaral	35-40°S	S. Pacific	Atacama

Mediterranean Climate Area	Foehn Wind	Fire Adapted Vegetation	Latitude	High Pressure Cell	Desert
France	Asper	Maquis, Garrigue	40°N	Azore	Sahara
Greece	Elefsina Lyvas	Phrygana Maquis, Garrigue	35°N	Azore	Sahara
Spain	Terral Skysweeper	Tomillares Maquis, Garrigue	35°N	Azore	Sahara
South Africa	Bergwind	Fynbos	30°S	S. Atlantic	Namibia

Table 2.14 includes information on Mediterranean climate fire-adapted native vegetation obtained from the following: *Earth's Biomes, Chaparral and Scrub* (Warhol 2007); “*Wildland Fire and Chaparral Succession Along the California-Baja California Boundary*” (Minnichi and Bahre 1995); “*Mediterranean Climate*” (Wikipedia 2008-1); “*The Mediterranean or Dry Climate, in The Physical Environment: an Introduction to Physical Geography*” (Ritter 2006); and “*Bergwind Fires and the Location Patter of Forest Patches In the Southern Cape Landscape, South-Africa*” (Geldenhuys 1994). The following sources are credited for the data on Mediterranean Climate, geography and weather: “*The Mediterranean or Dry Climate, in The Physical Environment: an Introduction to Physical Geography*” (Ritter 2006); “*Mediterranean Climate*” (Wikipedia 2008-1); “*Foehn Winds*” (Aerographer/Meteorology 2008); “*The Santa Winds FAQ*” (Fovell 2008); and “*Bergwind Fires and the Location Patter of Forest Patches In the Southern Cape Landscape, South-Africa*” (Geldenhuys 1994).

2.4 TOPOGRAPHICAL INFLUENCES

The Los Angeles County Fire Department (2010, 22) in its interface wildfire safety publication, *Vegetation Management*, argues:

“The relationship between topography and fire behavior is a factor over which the homeowner has little control. He should, however, be aware of the relationship as it relates specifically to his property. Homes located in natural chimneys, such as narrow canyons and saddles, are especially fire-prone because winds are funneled into these canyons and eddies are created.”

This statement exemplifies the widespread belief among fire officials, planners and designers that only inconsequential efforts may mitigate the deleterious effects that terrain may have on fire behavior. Understanding the relationships between topography and fire behavior can lead to constructing or retrofitting structures with features that increase fire resiliency. The intent of this thesis is to advance the concept that increased fire resiliency can be accomplished, in part by recognizing the benefits of terrain features, as well as compensating for the detrimental effects. Chapter Six, Structure Safety Zones; Chapter Seven, Occupant Fire Shelters; Chapter Eight, Homeowners Guidelines; and Chapter Nine, Structure Fire and Ember Shields all advance the principles of increased fire resiliency of structures in WUI areas.

Topographical influences include the land shape, elevation, slope direction, sunlight exposure, and slope steepness. The shape of the land influences how much sunlight or shade an area receives, which affects temperature, fuels, and airflow (Tele 2005). Plant fuels respond to varying conditions of sunlight, temperature, soil composition and moisture. The layout of the landscape influences these plant variables and significantly contributes to the type and amount of fuel available (Pittenger 2002). Further, fuel moisture and consequently the combustibility of natural and landscaped vegetation varies with aspect and elevation (National Wildfire Coordinating Group 2001) (National Wildfire Coordinating Group 1994). Terrain affects airflow by increasing or decreasing velocity and redirecting it (Fovell 2008). The concept of the terrain shape modifying wind was briefly examined in the preceding discussion of Foehn Winds in Chapter 2, Section 3.3.2.

Besides channeling wind, topography can create turbulence and eddies that affect fire behavior and subsequently increases an existing fire threat (Tele 2005). Conversely, topography can reduce fire spread by offering natural fire spread barriers, such as boulders, rock slide, or bodies of water that result in reduced fire spread (Tele 2005). Every interface wildfire behaves differently due to changing combinations of variables. Since terrain remains relatively constant greater consistency in predicting fire behavior in a specific area may be achieved. Although the terrain examination offers a greater consistency potential than the other classes of interacting wildfire variables (Kushla and Ripple 1997), scant research of how topography influences fire behavior exists.

2.4.1 SLOPE

The positioning of a structure within topography is a very critical factor in fire exposure. The slope of terrain affects fire behavior and has several interactions on fuels and burning rate. Steep slopes and deep drainages promote significant preheating of fuels, producing rapid upslope and up valley fire spread. Extreme fire behavior is associated with steep sloped conditions (Los Angeles County 2010). Besides uphill fires preheating fuels, the fuels on steep slopes have lower fuel moisture, because elevation impacts how much wind and moisture an area receives. The closer the slope is to perpendicular, the greater the amount of solar radiation. The higher the level of radiation, the higher the temperature and the lower the fuel moisture will become (Tele 2005). Slope steepness is important in that it contributes to how quickly the fire will reach the crest of the landform. In this regard, the most important topographic effect is that fire spreads much faster uphill than downhill, without significant wind influence (Los Angeles County Fire Department 2010). Other fire spread variables remaining constant, a fire burning on level ground will spread twice as fast when it reaches 30% slopes, and the rate of spread will double a second time when the slopes reaches 55% (Los Angeles County Fire Department 2010).

A significant fire spread effect is portrayed when comparing uphill versus downhill rates of spread.

Fire can travel 16 times faster uphill than it can travel downhill (Payne et al. 1996). This relationship is accomplished in part by topographical wind. Topographical airflow is created by convective currents. Assuming ambient wind is constant, topographical airflow increases the fire rate of spread uphill, and decreases the rate of spread downhill in a diverse spatial mode in the leeward direction (Rehm and Mell 2009). Faster uphill fire travel is nearly a universal truth, with one known noteworthy exception. United States Forest Service personnel have documented the fastest downhill fire spread rates occurring in the Santa Barbara coastal region during Sundowner wind events (foehn winds affecting fire behavior is discussed more at length in Chapter 2, Section 3.3.2) events. Fires occurring during Sundowner wind episodes have resulted in extreme fire behavior and led to all of the destructive WUI conflagrations in the 30 mile length of the Southcoast area surrounding Santa Barbara California. The 1965 Coyote Canyon Fire and the 1972 Romero Fire were Sundowner wind-fanned fires. Hundreds of homes were lost in the Sycamore Canyon Fire in 1977, the Paint Fire of 1990, the Tea Fire of 2008, and again in the Jesusita Fire of 2009. These fires were all wind-driven large-loss incidents, and had the characteristic problems of any wind-driven fire (Fovell 2008).

Along with increased rates of spread, flame length, and heat energy release rates are correspondingly greater as the slope increases (Radtke 2004). Topographical obstacles strongly affect atmospheric airflow. Wind traveling over hills generally creates eddies (turbulence) over the crest and descending partially down the leeward side (National Wildfire Coordinating Group 1994). Another way in which slopes increase fire spread is by enhancing the transport of oxygen from the atmosphere to the fuel by reducing the depth of the laminar airflow boundary layer around the fuels (Kochanski et al. 2009). The third most significant structure-survivability predictor, following noncombustible roofs and defensible space is slope steepness (Brown 1994). In case studies of WUI fires performed by the National Fire Protection Association, structures located on slopes, exceeding 20%, experienced damage or destruction during interface wildfires (Brown 1994).

2.4.2 ASPECT

Another terrain feature affecting fire spread is aspect, or the direction a slope is orientated, and its exposure to the sun (National Wildland Coordinating Group 1994). The direction a slope faces affects the amount of solar radiation received and the peak time during which greatest radiation occurs. During the day, sunlight moves across different aspects, which causes changes in air temperature, relative humidity, fuel moisture and fuel temperature (National Wildland Coordinating Group 1994). Also, the combined effects of aspect and elevation create different microclimates that affect vegetation distribution and hence fuel type (Tele 2005). In the northern hemisphere, south and southwest facing slopes generally have greater burn intensity due to lower humidity, higher fuel temperatures, lower fuel moisture, and higher temperatures. All of the preceding fuel effects are caused by a greater incidence of sunlight striking aspect surfaces (National Wildland Coordinating Group 1994). As an example of the difference aspect makes on temperature, south slopes can be as much as 5° F warmer than north facing slopes (Tele 2005). Additionally, south aspect slopes have increased rates of mass moisture transfer from fuels to the atmosphere, which lowers fuel moistures (Kushla and Ripple 1997). Because of these factors, structures on south and southwest facing slopes are typically exposed to higher fire danger and, in particular, steep slopes will exacerbate this fire protection problem.

2.4.3 CHIMNEY EFFECT

Fires starting near the base of steep, narrow canyons, especially box canyons may react like a fire in a fireplace. Rising convection currents draw air up from the bottom of the canyon creating a “chimney effect” that results in very strong upslope drafts (Cal Fire 2002: National Wildfire Coordinating Group 2010-A). At sharp bends in canyons, wind eddies and strong upslope air movements prevail producing a chimney effect, as well (National Wildfire Coordinating Group 2001). Besides the preceding topographical features, chimney effects exist in chutes, where spur ridges or lateral ridges join main ridges, and similar terrain configurations. A spur or lateral ridge is a protrusion or finger from the side of a main ridge traversing continually from low ground to high ground (Tele 2005). Figure 2.15 illustrates natural chimneys located within a WUI area.

Figure 2.15 (above): Natural Chimneys Formed by Spur Ridges
 (<http://www.fire.lacounty.gov/Forestry/VegetationManagementMiscTopics.asp>)

Chimney effect terrain features can be identified by in-turns on midslope roads. An in-turn exists on a roadway when the apex of the curve projects into the hillside. An out-turn exists on a midslope road when the apex of a curve extends away from the hillside, on a protrusion of land or point. Out-turns experience significantly less heat and smaller flame lengths than in-turns. Terrain identified by out-turn are appreciably safer locations for structures than in-turn areas. Figure 2.16 shows in-turns and out-turns on a mid-slope road in an interface development. The chimney effect results in extreme fire behavior causing very rapid and dangerous fire spread upwards through it (National Wildfire Coordinating Group 2010-1). A severe chimney effect is created when the topography forms a steep narrow chute with three walls, which is similar to a box canyon meeting a ridge. Under chimney conditions, the normal upslope airflow is rapid and funneled into the concavity (Payne 1996).

*Figure 2.16: In-Turn and Out-Turn on a Midslope Road
(Berry Family Fire Photo Collection)*

During fires, terrain formed chimneys concentrate heat, explosive gases and updrafts (Radtke 2004). As an example of heat concentration, the temperature in chimney affected terrain may exceed several thousand degrees Fahrenheit when ambient wildfire temperature is significantly lower (Radtke 2004). The Los Angeles County Fire Department reviewed structures burned along ridge lines, and concluded that homes located where a canyon meets a ridge (a chimney) are far more likely to burn than other ridge top structures (Los Angeles County Fire Department 2010). Further study is needed to identify the multiplying effect of chimneys on flame length and heat flux so that adequate fire protection mitigation measures can be determined.

2.4.4 RIDGES, NARROW CANYONS, SADDLES

Additional topographical fire threats exist where structure are located within other hazardous hillside terrain features such as; midslopes, ridgelines, tops of ravines, narrow canyons, or saddles (Brown 1994). Structures located in these terrain features are at greater risk and are often considered “a design for disaster” (Brown 1994). In very steep and narrow canyons, radiating heat is a major factor in fire spread and structure losses (Los Angeles County Fire Department 2010). Further complicating the narrow canyon wildfire problem, fires in steep narrow canyons can easily spread to fuels on the opposite side by radiation and spotting (National Wildfire Coordinating Group 1994).

Structures located on ridge-tops are problematic and may require additional fire resiliency mitigating measures. Structures without adequate setbacks from ridgelines are frequently lost because of flame and convective heat impingement (Los Angeles County Fire Department 2010). A setback of 30 feet from a sloping edge is a nationally recognized standard (Cohen 2000; Radtke 2004; National Fire Protection Association 2008-A), but this distance may be inadequate when the slope is coupled with terrain features such as a chimney effect or saddle. Uphill winds expose structures on slopes and ridgelines to greater fire danger (Los Angeles County Fire Department 2010), and will increase the safe setback distance.

Another topographic feature encountered along ridgelines are saddles. Saddles are usually identified as relative low points, between elevated portions, along the crest of a ridge (National Wildfire Coordinating Group 2010). Saddles are wide natural paths for fire winds. As wind passes through a constricted saddle or pass in a mountain range, its speed can increase (National Wildfire Coordinating Group 1994). Once over the top of the ridgeline, the airflow through a saddle spreads out on the leeward side with possible eddy action (National Wildfire Coordinating Group 1994). Fire moves much faster through saddles than it does on adjacent slopes due to this airflow channeling effect (Tele 2005). In addition, fuels within saddles normally will ignite before adjacent areas (Radtke 2004). The author is unaware of the existence of any quantifiable method expressing the relationship of the increased airflow being channeled through saddles.

The author suspects that saddles may double ambient flame length, as experienced during WUI firefighting operations. See Figure 2.17 for illustrations indicating how a saddle is depicted on a topographical map and on a sketched elevation. Figure 2.18 illustrates terrain features of a saddle with an accompanying chimney located in a Mediterranean climate wildland area of Macedonia.

Figure 2.17: Map Depiction and Sketched Elevation of a Saddle
(<http://webmain02.fire.ca.gov>)

Figure 2.18: Ridgeline Saddle with Accompanying Chimney
(<http://www.mkdmount.org/planini/mountains1.html>)

2.5 FUELS

A wildland fire does not spread to homes unless the homes meet the fuel and heat requirements sufficient for ignition and continued combustion. Cohen (2000, 3) argues that ignition and fire spread to exposures are a proximate process primarily influenced by adjacent available fuels: “Fire spreads as a continually propagating process, not as a moving mass. Unlike a flash flood or an avalanche where a mass engulfs objects in its path, fire spreads because the locations along the path meet the requirements for combustion.” Further, Cohen (Cohen 2000-C) quotes Henry Lewis in an account of an 1848 prairie fire:

When the emigrants are surprised by a prairie fire, they mow down the grass on a patch and large enough for the wagon, horse, etc., to stand on. They then pile up the grass and light it. The same wind which is sweeping the original fire toward them now drives the second fire away from them. Thus, although they are surrounded by a sea of flames, they are relatively safe. Where the grass was cut, the fire has no fuel and goes no further. In this way, experienced people may escape a terrible fate.

Sufficient fuel was removed by their escape fire, adjacent to the wagons, to prevent burning and injury. The wagons were ignition resistant enough to avoid burning from embers (Cohen 2003). Cohen (Cohen 2000-C) further argues:

Similarly, the flammables adjacent to a home can be managed with the home's materials and design chosen to minimize potential firebrand ignitions. This can occur regardless of how intensely or fast spreading other fires are burning. Reducing WUI fire losses must involve a reduction in the flammability of the home (fuel) in relation to its potential severe-case exposure from flames and firebrands (heat). The essential question remains as to how much reduction in flammables (e.g., how much vegetative fuel clearance) must be done relative to the home fuel characteristics to significantly reduce the potential home losses associated with wildland fires.

This Section of the thesis (i.e. 2.5 Fuels) will focus on vegetation management practices, and related noteworthy fuel factors.

2.5.1 DEFENSIBLE SPACE

Commonly, Defensible Space refers to a managed vegetation area adjacent to structures where wildfire protective practices have been implemented. The primary objectives of defensible space are protecting structures from an approaching wildfire, and where firefighting can take place in relative safety (State Board of Forestry and Fire Protection 2006; California Emergency Management Agency 2010). The emphasis of structure survival during WUI fires is recognized as vegetation management by Bailey (2007, 5) who argues: “During major fire operations in the interface, most structure loss occurs in the first few hours of an incident. This is often due to a lack of effective vegetation management practices. These losses will continue until appropriate access, landscaping, and construction standards are implemented and enforced.” The California State vegetation management standards will be used as an example. The prominence of California WUI fires, and the preventative actions taken in response to this problem by private and government entities, has established these protective actions as nationally recognized “good practice”. These actions include defensible space standards.

In 2005, the California Public Resource Code required defensible space clearance increased from 30 to 100 feet (State Board of Forestry and Fire Protection 2006). In the California code, vegetation management is subdivided into two zones: Defensible Space and Reduced Fuel Zone. The Defensible Space Zone is a minimum of 30 feet outward from any portion of a structure with no flammable vegetation that can transmit wildfire to the structure. The Fuel Reduction Zone extends from the Defensible Space Zone to a minimum of 100 feet outward from a structure (State Board of Forestry and Fire Protection 2006). In this zone the fuel loading of vegetation is reduced so that a wildfire will not readily communicate fire into defensible space, or the structure. Additionally, beneficial defensible space allows firefighters to protect structures safely without facing unacceptable risk to their lives (State Board of Forestry and Fire Protection 2006). The California Emergency Management Agency indicates in its publication, *State Multi-Hazard Mitigation Plant*, that fuel reduction through vegetation management, combined with ignition resistant construction, are the crucial components for creating appropriate defensible space (California Emergency Management Agency 2010).

Although California State Law distinguishes between Defensible Space Zone and The Fuel Reduction Zone, the combined areas are commonly referred to as defensible space. Figure 2.19 is an illustration appearing in the State Board of Forestry and Fire Protection publication, *General Guidelines for Creating Defensible Space*, which depicts the two protective zones (State Board of Forestry and Fire Protection 2006).

Figure 2.19: Defensible Space and Reduced Fuel Zones
(www.fire.ca.gov/cdfbofdb/PDFS/4291finalguidelines_2_23_06.pdf)

The topography influences fire behavior, and consequently fuel reduction standards. While fuel reduction standards vary throughout WUI jurisdictions, there are some common practices that govern fuel modification treatments for ensuring creation of adequate defensible space (Los Angeles County Fire 2010). Properties with greater fire hazards, such as heavier fuel loading, steep slopes and chimneys require more clearing. Fuel loading is the amount of combustibles per area, usually expressed in tons per acre. Light fuels are grasses and forbs, and range from one to five tons per acre. Heavy fuels are considered to have a minimum stem diameter of three inches, and a fuel load range of 4 to 100 tons per acre (National Wildfire Coordinating Group 1994, 2001). Heavier fuels are generally considered to be in the midrange of the shrub class and heavy fuels at a minimum of 10 to 30 tons per acre (National Wildfire Coordinating Group 1994, 2001).

Chaparral and its Mediterranean climate equivalents are generally considered medium to heavy fuels (Scott and Burgan 2005). Fire safety can compensate for greater fire threat levels by mitigating measures, as discussed in this thesis, and by increasing defensible space. Increasing the Fuels Reduction Zone distances may accomplish sufficient fire safety for structures and occupants during WUI fires.

Variance exists in the requirements for defensible space, stipulated under extreme or intense fire threats. Besides the California State requirement of 100 feet of defensible space, the *International Wildland-Urban Interface Code* requires 100 feet of defensible space under extreme fire threat conditions (International Code Council 2009-B). Two recognized authorities recommend or require extending defensible space to 200 feet. The National Fire Protection Association in *NFPA 1144* requires extending defensible space outward to 200 feet when intense fire potential exists, as evidenced by the existence of heavier fuels (National Fire Protection Association 2008-A). Additionally, the Los Angeles County Fire Department recommends increasing the Reduced Fuel Zone from the legal minimum of 100 feet to 200 feet for improved fire protection (Los Angeles County Fire Department 2010). Consequently, the increased distance of fuel reduction may produce a typical flame length for the fuel type; although, the amount and duration of the heat output will be significantly reduced (County of Los Angeles Fire Department 2010). The reduction in heat output is an increase in structural survivability. Even with this reduction in fire threat accomplished by increasing defensible space, some structures may not be adequately protected.

2.5.2 VEGETATION MANAGEMENT

Vegetation or fuel management is the practice of controlling flammability and reducing public resistance to the controlling of wildland fuels through various methods (National Wildfire Coordinating Group 2010). Vegetation management differs from defensible space in scope and responsibility. It occurs on a broader scale, extending beyond the limits of defensible space. The responsibility of defensible space is typically borne by the property owner; whereas, vegetation management is usually the responsibility of public agencies.

Figure 2.20 depicts fuel management in Southern California chaparral forest regions beyond the state legal limit of 100 feet. Increased vegetation management distances were called for by the past Fuel Management Officer of the Santa Barbara County Fire Department after the 2008 Gap Fire, and the 2008 Tea Fire in the Southcoast area near Santa Barbara, California. Both of these incidents were Sundowner wind-driven fire events, but had drastically different outcomes. The Tea Fire burned 210 homes, damaged nine others and burned approximately 2,000 acres (Cal Fire 2010-A). The Gap fire burned a few outbuildings and threatened 3,000 homes. With over 1,000 fires burning in California, Governor Schwarzenegger declared the Gap Fire the top priority in the state because of the substantial potential to structures (Schwarzenegger 2008).

Bianchi (2008-A) argues:

Aside from attempts to predict extreme conditions, fire weather is an uncontrollable leg of this fire triangle. Topography also must be accepted as it is, and we have to deal with its influence on wildland fire behavior. This leaves the fuel leg of the fire triangle as the only factor we can reasonably modify or change. Wildland fuel is the vegetation, collectively called chaparral that covers our wildland areas. During the Gap Fire, many structures were protected from a high-intensity fire because orchards provided a break in this continuous, brush fuel bed. This is an example of fuels modification and the orchards created a buffer zone by changing the fire behavior to a less intense fire and more easily controlled. Maybe the time has come to consider creating a 200-300 foot-wide buffer zone by modifying the wildland fuels in our foothill interface areas. Contemporary vegetation management practices won't denude the area of all vegetation. But, modifying the vegetation very well may be a constructive way to interrupt this devastating fire history. Wildland vegetation already has been severely modified in the Gap and Tea fire areas. We should take advantage of this and maintain areas here where vegetation is not allowed to again re-grow into a flammable fuel bed.

In the Gap Fire area, the flammable fuel management was accomplished by the planting of avocado and citrus orchards. These orchards were a minimum of several hundred feet wide and provided an adequate firebreak during the Gap Fire. The relatively flat terrain was another factor affecting the low number of structures lost. The absence of dangerous terrain features, such as chimneys, saddles and steep slopes, prevented accelerated fire spread. Extensive areas of vegetation management can provide effective interface wildfire safety; unfortunately expansive fuel breaks are usually not feasible.

2.5.3 DROUGHT TOLERANT/FLAMMABLE FUELS

The establishment of effective defensible space and vegetation management practices requires consideration of flammable fuels. Fuels are an integral part of any wildland biome, including the WUI. All vegetation becomes potential fuel, while it is still living or after its death (National Wildfire Coordinating Group 2001). Flammability varies with type, moisture content, loading, and decadence or dead proportions (Michelson 1992). Fuel moisture is the weight of moisture contained in a plant divided by its dry weight.

*Figure 2.20: Fuel Reduction Zone for Southern California Chaparral
(www.fire.ca.gov/cdfbofdb/PDFS/4291finalguidelines_2_23_06.pdf)*

Dead fuel has no fuel moisture, and consequently burns more readily than its live counterpart (National Wildfire Coordinating Group 2001). The preceding flammability factors combine to form heat content. The heat content is the most important aspect of fuel chemistry influencing fire behavior. This value describes the amount of heat produced during combustion expressed in British Thermal Units (BTU) per pound. The heat content for all species of dead woody fuel is essentially the same (i.e., 8,500 BTU per pound) (National Wildfire Coordinating Group 1994). The presence of pitch in wood, and volatile compounds such as oils and waxes in some live fuels increases heat content, and thus flammability (National Wildlife Coordinating Group 2001). Extreme fire behavior can occur in stands of shrubs such as chaparral containing volatile compounds, a high percentage of dead material, and an optimum fuel-to-air ratio within the shrub canopy (National Wildfire Coordinating Group 2001).

A significant type of highly flammable plant is the sclerophyll leafed plants (Ritter 2006). Sclerophyll leafed plants tend to be evergreen with woody stems and tough, waxy leaves that reduce water loss (Michelson 1992). Sclerophyllous plants are drought adapted, maintaining relatively low fuel moisture, high decadent content, and frequently a high oil content; - all properties of highly flammable plants. Sclerophyllous plants occur in virtually all locales, but are most typically in chaparral-type bush biomes (Ford 2008-A). They are prominent in the forests, woodlands and scrub biomes that cover the Mediterranean Basin, and are known by several names, including marquis, garrigue and tomillares. These plants are known in California woodlands as chaparral, in Chile as matorral, in Australia and New Zealand as mallee scrub or kwongan, and in the Cape Province of South Africa as fynbos (Ford 2008-A). For explanatory purposes in this thesis, California chaparral will serve as the principal example of sclerophyllous plants. The similarities of soft-type sclerophyll plants from Mediterranean climate biomes are shown in Figures 2.21 through 2.23.

Plant species differ in their susceptibility to fire. The most important factor controlling the flammability of fuels is their moisture content.

The moisture content of dead wildland fuels is regulated by environmental factors, while that of living plants is controlled by their physiological processes (National Wildfire Coordinating Group 2001). Chaparral plants have relatively low live fuel moisture and high percentage of dead material, making them highly flammable. During the dry summer and fall months the live fuel moisture typically drops below 80% from a high of 200% to 300% moisture content for new growth in the spring (Countryman and Dean 1979).

Figure 2.21: California Coastal Chaparral
(www.geop.ucsb.edu/..cal_veg.html)

The critical level of fuel moisture for extreme fire conditions for chaparral is in the range of 70% to 80% (Dennison et al. 2008).

Narrowing this range, research conducted in the Santa Monica Mountains of Los Angeles and Ventura Counties determined the critical fuel moisture level at or below 77% for extreme fire conditions (Dennison 2008). As an example of extreme fire conditions, chaparral fueled fires have produced flame lengths in excess of 100 feet (Los Angeles County Fire Department 2010). An examination of the critical fuel moisture level of chaparral is part of Case Study Number Three in this thesis. This case study examines the 1993 Green Meadows Fire, which occurred in the Santa Monica Mountains during extreme fire conditions. The fire was a Santa Ana wind-driven event, and the live fuel moisture of the chaparral was 69.8% (Dennison et al. 2008).

*Figure 2.22: Schlerophyll Scrub Forest in Subalpine Zone, New Zealand
([www.uwsp.edu/geol/faculty/ritter/geog101_textbook/
climate_systems/mediterranean.html](http://www.uwsp.edu/geol/faculty/ritter/geog101_textbook/climate_systems/mediterranean.html))*

The most severe WUI fire dangers in California exist in proximity to chaparral biomes. A graphic representation of the fire threat posed by chaparral is indicated in *Figures 2.24 and 2.25*. *Figure 2.24* shows a map of California entitled: *Fuel Rank, Potential Fire Behavior* (California Emergency Management Agency 2010). The map shows California fire threat rankings based upon fuel types. The Southern California coast, outside of the Los Angeles megalopolis, is rated as High or Very High hazard potential. For special interest, the Santa Barbara County and San Luis County hazard potential maps are located in Appendix C. *Figure 2.25*, titled *Land Cover, Multi-Source Data Compiled for Forest and Range 2003 Assessment* shows a map of California indicating different biome locations (Cal Fire 2010). Overlaying the Fuel Rank map over the Land Cover map reveals that in Southern California the High Hazard and Very High Hazard fire threat zones decisively align with the principal vegetation type namely, chaparral (Cal Fire 2010).

Figure 2.23: Fynbos of South Africa
(<http://en.wikipedia.org/wiki/File:fynbos-landscape-1.jpg>)

Figure 2.24: California Fire Behavior Potential Ranking by Fuel Type
(http://hazardmitigation.calema.cca.gov/plan/state_multi-hazard_mitigation_plan_shmp)

Chaparral communities are widespread in both Northern and Southern California, covering about ten million acres (Barbour 2001). There are two types of chaparral communities in California. The soft chaparral or coastal sage scrub is typically herbaceous, grows in elevations from sea level to 1,800 feet and to a height of less than six feet (Santa Barbara City College 2010).

Hard chaparral is woody, grows in elevations that range from 1,000 to 5,000 feet and grows to a height of ten feet (Santa Barbara City College 2010). The fuel age of chaparral does not necessarily affect the probability of burning (Moritz et al. 2004; McDaniel 2007). Wildfires with high temperature, low humidity and Santa Ana wind conditions burn through new and old stands of chaparral with ease (McDaniel 2007). Hard chaparral has a heavier fuel loading, greater decadence, higher oil content, and consequently is a significantly greater fire threat than soft chaparral. The fuel loading of hard chaparral may exceed 50 tons per acre (Barbour 2001). To illustrate the potential energy release of hard chaparral, each 1000 acres of chaparral on the Santa Barbara side of the Santa Ynez Mountains has dead plant material with a heat content equivalent to a Hiroshima-type atomic bomb (Ford 2008-A). In recent times, this region of Santa Barbara County was the location of the 2008 Gap Fire, 2008 Tea Fire, and 2009 Jesusita Fire. A total of over 300 structures were lost in these fires (Cal Fire 2010-A). Chaparral was the primary fuel carrying these fires. The Santa Barbara area WUI fire problem is not unique, but simply an extension of the Southern California WUI fire problem.

CHAPTER 3

3.1 FIRE MODELING

Fire modeling is a necessary tool for understanding and combating interface wildfire destruction. Harry T. Gisborne, (National Wildfire Coordinating Group 2009, 15) argues:

“If you have fought forest fires in every different fuel type, under all possible different kinds of weather, and if you have remembered exactly what happened in each of these combinations your experienced judgment is probably pretty good. But, if you have not fought all sizes of fires in all kinds of fuel types under all kinds of weather then your experience does not include knowledge of all the conditions.”

Wildfire firefighters do have limited experience and must rely on weather, fuel and fire models for aid in battling the ravages of fire, particularly in WUI areas. The same applies to designers and planners, who must rely more heavily on fire behavior models if they are going to win the war with interface fire.

Models are simplifications or approximations for examining various phenomena. Models will always be estimations of reality; they can never really account for all the complexity of the phenomena investigated (National Wildfire Coordinating Group 2009). Nonetheless, Stratton, (Stratton 2006, 3) argues for the usefulness of models by referencing George Box: “All models are wrong, but some are useful.” This statement is very true when it comes to modeling fire. There are several useful wind and fire modeling programs, but all have their limitations. As an example, four of the modeling programs, listed in *Table 3.1*, are bundled into a “suite” (FireModels.org 2010), because no single modeling program is sufficient for adequately forecasting every large wildfire.

The author searched several public domain and proprietary fire modeling programs for a forecasting tool to predict an interface wildfire on a micro scale.

The author did not discover any program that could predict fire behavior on a small enough scale (100 feet or less) to evaluate the fire resiliency of a structure from an interface wildfire. In addition, two wind-modeling programs were reviewed to determine their ability to more accurately predict fire behavior under non-uniform terrain, and wind conditions. Initially all the modeling programs were assessed to arrive at a manageable number that could be compared. Unfortunately, an in-depth examination of only a few fire and wind modeling programs proved beyond the scope of this thesis. As evidence of the magnitude of comparing modeling programs, a Master of Science thesis project was accepted at the Fort Collins campus of the University of Colorado on the basis of comparing two wind modeling programs (Forthofer 2007).

The search of wind and fire modeling programs did prove useful for the fire behavior validation in Chapter 4, Case Studies and Chapter 6, Structure Safety Zones. Two fire modeling programs, BehavePlus and Wildland Toolkit were selected for their user-friendliness and ability to predict flame length. The fire behavior outputs from these two computer programs were compared with observed fire behavior of the Case Studies, and for determining adequate defensible space distances for Structure Safety Zones, in Chapter 5.

TABLE: 3.1
FIRE AND WIND MODELING PROGRAMS DESCRIPTION AND
ACCESSIBILITY

MODELING PROGRAM	Description	System Type	Provider	Cost
BehavePlus 5* (Fire Behavior)	Fire Behavior, Fire Effects, Fire Environment	Point System, No Temporal Component	FireModels.org	Free

MODELING PROGRAM	Description	System Type	Provider	Cost
FBAT (Fire Behavior Assessment Tool)	Flame Length, Rate of Spread, Fire Line Intensity, Crown Fires	Spatial System, GIS Data Used, Temporal Component	NIFTT (frames.nbii.gov)	Free
FARSITE 4.1* (Fire Area Simulator)	Fire Growth-Surface Fire, Crown Fire, Spotting, Post-Frontal Combustion	Spatial System, GIS Data Used, Temporal Component	FireModels.org	Free
FireFamilyPlu s 4.0	Fire Climatology & Occurrence Analysis	Spatial System, GIS Data Used, Temporal Component	FireModels.org	Free
FlamMap 3* (Fire Mapping & Analysis)	Maps of Spread Rates, Flame Lengths, Crown Fires	Spatial System, GIS Data Used No Temporal Component	FireModels.org	Free
FSPro*1 (Fire Spread Probability)	Fire Spread Probability	Spatial System, GIS Data Used, Temporal Component	Unknown	Unk.
Wind Ninja	Effects of Topography on Local Wind Flow, Resolution 300'	Spatial System, GIS Data Used, Temporal Component	FireModels.org	Free

MODELING PROGRAM	Description	System Type	Provider	Cost
Wind Wizard	Effects of Topography on Local Wind Flow, Resolution 100-300'	Spatial System, GIS Data Used Temporal Component	FlowWizard License @ ansys.com	\$10,000
Wildland Toolkit	Similar to BehavePlus	Point System, No Temporal Component	Wildland Toolkit (Apps Store)	\$7.99

* Member of Suite of Fire Behavior System- complimentary systems that are based on essentially the same fire models.

¹ FSPro required computing power exceeds capacity of personal computers

Table 3.1 Abbreviation & Terminology Key

GIS	Geographic Information System
NIFTT	National Interagency Fuels, Fire, and Vegetation Technology Transfer
Point System	A modeling program prediction for a given time, with a corresponding location or size
Spatial System	A modeling program prediction, displaying growth and distance using GIS data input
Temporal Component	A modeling program that can forecast covering a time span

Table 3.1 contains information on fire modeling and wind modeling programs from the following sources: “Predictive Fire Behavior and Societal Benefits in Three Eastern Sierra Nevada Vegetation Types” (Dicus, et al. 2009); “FlowWizard Pricing Email” (Elser 2010); *Fire Effects Guide* (Clark and Miller 2001); “Public Domain Software for the Wildland Fire Community” (FIRE.ORG 2010); “Fire Behavior and Fire DangerSoftware” (FireModels.org 2005); *A Comprehensive Set for Use with Tool User’s Guide, Version 1.3.0* (National Interagency Fuels Coordinating Group (2008); “Geospatial Fire Analysis Interpretation and Application, S-495 (National Wildfire Coordinating Group 2009); *Standard Fire Behavior Fuel Models* (Scott and Burgan 2005); *Guidance on Spatial Wildland Fire Analysis: Models, Tools, Techniques* (Stratton 2006); and *Clear Creek Community Protection Plan, Appendix B* (Walsh Environmental Scientists and Engineers 2008).

CHAPTER FOUR

4.1 CASE STUDIES

4.1.1 INTRODUCTION

Three case studies were selected because of their relevance to verify the accuracy of the rating system of assessing fire resiliency of structures by the Fire Profile Index and its derivatives, and for facilitating the establishment of safe distances of defensible space for Structure Safety Zones (Chapter 6). The validation will be accomplished by cross-referencing the historical fire behavior of each case study, with the fire resiliency rating produced by the Fire Profile Index. The fire behavior of Case Study Three was experienced by the author along with several members of Santa Barbara County Fire Department, and their recall will contribute to increased insight of this chapter. Case Studies One and Two had no eyewitnesses accounts available for review. The fire behavior occurring during these two case studies was deduced from the aftermath of the burning; thus the inferences drawn may not be as taken as literally.

The author conducted on-site inspections of the case study locations to examine the accuracy of witness accounts of fire behavior, terrain characteristics, structure positioning on property and structure fire resiliency features.¹ Quantification of terrain slope and landmark spatial relationships, including slope, chimneys and saddles were obtained from topographical maps, satellite mapping, witness descriptions, research and newspaper articles, incident action plans and on-site measurements. The estimates of flame length were determined by publication research, witness accounts, photographs, and measurements of landmark references. The fire resiliency of structures was determined by publication reviews, witness interviews and on-site observation. These research efforts were considered sufficient for purposes of validating the conclusions of the case studies within the scope of the thesis.

¹ The author is a 31 year veteran of the Santa Barbara County Fire Dept. in CA. He held the rank of Captain, has extensive WUI firefighting experience, performed various roles in the Plans Section of the Los Padres Incident Management Team, functioned as a fire investigator, and studied fire behavior to an advanced level.

Two of the case studies are from the November 2008 Tea Fire in the foothills of Santa Barbara, California. The first case study is a 2006 built home, WUI code compliant and an award winning “Green Building” (Berry 2010; Wormser 2008). Case Study One survived the Tea Fire without the presence of residents or firefighters. Case Study Two is located on the same driveway as the first case study, at a distance of approximately 200 feet to the north. The construction of Case Study Two was of ordinary construction built in the 1950’s, and not WUI area code compliant for new construction (LeVay 2010). Figure 4.1 illustrates the location of Case Studies One and Two within the Tea Fire Boundary and with their relative location to the fire origin and direction of peak burning period wind. This structure did not survive the Tea Fire. The Case Study Three is a residence, located in the Malibu foothills of California, that survived the October 1993 Green Meadows Fire. Figure 4.2 is a map of the 1993 Firestorms surrounding the Los Angeles basin; it includes the perimeter of the Green Meadows Fire (lefthand side, middle). The unique physical environment and fire resiliency of Case Study Three contributed to the experience of saving these structures, and is the source of the author’s motivation for this thesis. Figure 4.7 shows the location of the Case Study Three structure with the direction of fire spread and location of terrain features.

There are several significant fire environment commonalities present in the case studies. All of the case study locations are in rugged terrain in WUI areas within a few miles of the Pacific Ocean in Southern California. Figure 4.3 illustrates the positioning of the case studies to the ocean along the coastline of Southern California. The Tea Fire and Green Meadows Fire were wind-driven incidents. The Sundowner is the given name of the foehn wind driving the Tea Fire (Cal Fire Incident Command Team 10 2008). East Wind, or Santa Ana Wind, is the term for the foehn wind driving the Green Meadows Fire (Ripley 2010). Case Studies One and Two are located on a spur ridge of the Santa Ynez Mountains. Case Study Three is located in the midst of a saddle of a ridge of the Santa Monica Mountains. The Santa Monica and Santa Ynez are east-to-west orientated mountain ranges; the orientation creates an environment for the foehn winds to blow the fire downhill towards the Pacific Ocean.

Figure 4.1: Tea Fire Perimeter Map Indicating Locations of Case Studies One and Two, Fire Origin, Wind Direction. (Santa Barbara County Fire Department GIS Section)

The Tea Fire and the Green Meadows fires were considered significant wildfire interface events and required Incident Command Teams to manage them (Ripley 2010; Cal Fire Command Team 10 2008). Hard chaparral is the predominant vegetation in the fire areas (Los Angeles County Fire Department 2010), and had low live and dead fuel moistures (Dennison 2008; Cal Fire Incident Command Team 2008; Cal Fire Sep. 2010).

Figure 4.3: Coastline of Southern California with Locations of Case Studies.
(<http://maps.google.com/>)

The Coyote Fire was a wind-driven fire with Sundowner gusts exceeding 70 miles per hour (Moseley 2003). The destruction of homes quite possibly would have exceeded the count of both the Tea Fire and Jesusita Fire of over 350 homes, if the Coyote Fire would have occurred with current development density. The Sycamore Canyon Fire started in 1977 when a young man flying a large kite with wire controls got the kite tangled in the high-voltage transmission lines (Ford 2008-B); these transmission lines are shown in the lower portion of Figure 4.5. This fire burned approximately 800 acres and approximately 200 homes in less than three hours (Moseley 2003). One hundred foot flames were noted during the Sycamore Canyon Fire near the high-voltage power lines (Ford 2008-B). These same electrical transmission lines are situated approximately one-quarter mile northeast from Case Studies One and Two. The towers stands are 100 feet high.

The electrical transmission lines are shown in Figure 4.4 with flames estimated in the range of 125 to 150 feet during the Tea Fire by the author and witnesses (LeVay 2010; Berry 2010).

A historic event connected with the Sycamore Canyon Fire occurred when Francis Gary Powers, the famed U-2 pilot shot down over Russia in 1960, died heroically while guiding a disabled helicopter away from children playing in a field in Sherman Oaks, California.

Figure 4.4: Tea Fire Flame Lengths Near Case Studies One and Two
(http://www.boston.com/bigpicture/2008/11/california_wildfires_yet_again.html)

The helicopter was carrying a KNBC news crew back to Los Angeles after covering the Sycamore Canyon Fire; all three souls on board died. Indirectly these three deaths associated with the Sycamore Canyon Fire. However, very few injuries transpired during the short duration of the fire (Moseley 2003).

The Sycamore Canyon Fire occurred during a Sundowner event with extreme fire conditions similar to the Coyote, Tea and Jesusita Fires.

The weather phenomenon present during the initial stages of the Tea Fire is classified as an extreme Sundowner Wind event for this time of year (Ryan 1991). Sundowner events are characterized by foehn high-speed winds blowing downhill characteristically beginning in the afternoon. The winds are accompanied by low relative humidity, and high nighttime temperatures (Fovell 2008). Additional detailed fire weather information for the Tea Fire can be viewed in Appendix E. Appendix E contains Remote Automated Weather Station (RAWS) data from the Montecito RAWS, the closest station to the Tea Fire. During the peak burning rates of the Tea Fire winds were generally from the east to northeast direction at speeds exceeding 50 miles per hour (Department of Water Resources 2010) with gusts over 70 miles per hour (Cal Fire Incident Command Team 10 2008; Ford 2008-A). Temperatures remained in the high 70s°F, with relative humidity in the teens and low twenties (Department of Water Resources 2010). The Sundowner event lasted approximately ten hours (Cal Fire Incident Command Team 10 2008). The remaining burn periods continued to be warm and dry; however, the winds never again attained the speeds observed during the first ten hours of the fire (Cal Fire Incident Command Team 10 2008).

The Tea Fire burned in topography typical for the Southern California Coast; steep mountainous terrain. Drainages are generally deep and well defined with numerous chimneys that can stretch to the highest points of the mountains (Cal Fire Incident Command Team 10 2010). Fuels in the area of the case studies are considered hard chaparral (Neels 2010; Los Angeles County Fire Department 2010). This fuel type is generally dominated by brush species with heavy live oak concentrations in the drainages. Live fuel moistures of the chaparral were below the 60% (Incident Command Team 10 2008) critical level (Dennison 2008). The rainy season had not yet started for this Mediterranean climate environment.

A seasonal drought of approximately seven months accounted for the low fuel moistures. Fuel beds were well developed at least 20 to 40 years old. In the case of the Tea Fire many areas had been converted to ornamental vegetation and eucalyptus stands (Cal Fire Incident Command Team 10 2010). Within 100 feet horizontally of each case study ornamental landscaping vegetation replaced native vegetation (LeVay 2010; Berry 2010).

4.1.2 GREEN MEADOW FIRE CONDITIONS

Gathering fire condition information for the October 1993 Green Meadows Fire was far more challenging than for the November 2008 Tea Fire. RAWs data and a Green Meadow Incident Action Plan were unavailable. These sources would have provided readily available official incident fire environment data, including wind speed, gusting and direction, relative humidity and temperature. Several other sources of information, including research articles, newspaper articles, witness and firefighter accounts were used to obtain Green Meadows Incident fire weather and fire behavior information. During this fire the author was in command of a three person crew on a specialized interface wildfire engine, commonly called a Type III Engine (a.k.a. brush truck). The brush truck was part of a group of five similar type engines called a Strike Team. This single engine was identified as Engine 5718 for California mutual aid purposes (Neels 2010). The author interviewed members of the brush truck he commanded, and other members of the Strike Team. Also interviewed were the residents of the Case Study Three residence, along with fire officials from the Ventura County and Los Angeles County Fire Departments.

The Green Meadows Fire charred nearly 38,500 acres and destroyed 45 structures (Chronology of Southern California Wildfires 2009). The destruction was a result of the Mediterranean Climate, fuel type, low fuel moisture and weather factors. The weather conditions in the fire combat zone for Case Study Three were classified as extreme fire conditions. The temperature was approximately 100°F, relative humidity below 20% (Bell 2010; Smith 2010), and winds gusted to a minimum of 35 miles per hour (Office of Emergency Services 1994).

The Santa Ana or East winds blew steadily, and gained strength while blowing downhill towards the Pacific Ocean. The Santa Ana winds were accompanied by low relative humidity, and high night-time temperatures (Fovell 2008). During the burning in the locality of Case Study Three, the winds were generally from a northeasterly direction at speeds that were estimated in excess of 40 miles per hour (Bell 2010; Smith 2010).

The Green Meadows Fire burned in a topography that is comparable to the Tea Fire, as well as much of the Southern California Coastal area. The Santa Monica Mountains contain steep mountainous terrain, with deep drainages and numerous chimneys similar to the Santa Ynez Mountains in which the Tea Fire occurred (Office of Emergency Services 1994; Cal Fire Incident Command Team 10 2008). Fuels in the area of the case studies are considered hard chaparral. This fuel type is generally dominated by brush species with heavy live oak and sycamore in the drainages. The age of the fuel and the live fuel moistures of the chaparral were below the 70% critical level (Dennison et al. 2008). The area had below average rainfall for three years, with no significant rain for at least eight months (Kass 2010). These conditions caused the chaparral to be at critically low live fuel moisture levels.

Figure 4.5: Flames Lofting Above Case Study #3 During Green Meadows Fire (Los Angeles Times: East Ventura County Edition, Sunday October 31, 1993)

The resulting flame lengths were estimated at a minimum of 200 feet. The estimate of the flame length was based on firefighter accounts and principally on a photograph taken by a Los Angeles Times newspaper photographer. This newspaper photograph elucidating the flame length is shown as Figure 4.5.

4.2 CASE STUDY ONE

4.2.1 STRUCTURE DESCRIPTION

Case Study One is the southernmost of the two case study residences located off Mountain Drive, which is within Santa Barbara City jurisdiction. The sites are less than 200 feet apart. In addition, the houses are situated less than one mile from the origin of the Tea Fire. Figure 4.1 illustrates the proximity of the fire origin to Case Studies One and Two. Both properties view the fire origin site from below, situated on a higher elevation ridge northeast of the case studies. The site, was an actual “Tea Garden” from which the Tea Fire obtains its name. Both case studies are located within a Very High Hazard fire severity zone (Berry 2010). Figure 4.6 is an overhead view of the case study structures prior to the Tea Fire.

*Figure 4.6: Overhead View of Case Studies One and Two Prior to the Tea Fire
(<http://maps.google.com/>)*

The main residence, accompanying garage and studio, which comprise Case Study One were built in 2006, only two years prior to the fire. The roof of the main residence is at the floor level of the studio, and four feet above the floor level of the garage. The back side, or northern most portion, of all Case Study One structures are essentially at grade level, with retaining walls as the exterior walls for the garage and studio. The main residence has retaining walls within a few feet of the north exterior walls. On the south side of all structures the exterior walls are at grade level, and have doors and windows. See Figure F.2 in Appendix F for a profile photograph of these structures. The construction met the requirements of all applicable codes and ordinances including those of Santa Barbara City, California Building Code, Chapter 7A, and California Fire Code Chapter 45 (Berry 2010). Figure 4.7 is an after-fire photograph of both case studies. The structure of Case Study One is in the lower-left portion of the photo, while Case Study Two is in the upper-right corner, behind the burned pine tree.

Figure 4.7: Case Studies One and Two and Local Peak Burning Direction
(http://www.boston.com/bigpicture/2008/11/california_wildfires_yet_again.html)

Case Study One has several significant design and construction features which allowed the structures to remain virtually unscathed, without firefighters or residents present. The residents had only several minutes after awareness of the fire to safely evacuate. Responding firefighters did not have sufficient numbers, nor available time to protect the property due to the closeness of the fire origin, and the rapid spread of the fire. Case Study One structures are constructed in a similar fashion: all three are single story, flat roofed, stucco and concrete-walled, with concrete floors (Berry 2010; Wormser 2008). The main residence has approximately 50% of its area roofed with metal sheathing, and the other 50% is built-up gravel roofing. The garage and studio have built-up gravel roofing as well. The built-up flat roofed areas have 18 inch parapet walls, but not the metal sheathing area of the main residence. The flat roof shape has no attic space, and therefore no attic ventilation (Berry 2010). An illustration of the case study roofs can be seen in Appendix F, Figure F.1. The wall and ceiling insulation is cellulose material made of recycled and fire retardant-treated newspaper product (Berry 2010). The eaves are boxed with either stucco or concrete. All windows are double-paned, low E, argon gas filled (Berry 2010). These design and construction features contributed to the fire survivability of the Case Study One structures.

In addition to the aforementioned design and construction features, the landscaping played a key factor in the fire resiliency of the Case Study One structures. There are 150 feet of defensible space, measured horizontally, on the gently sloping terrain to the north and south of the structures. The slope of the hillside to the east and west exceeds 100% (LeVay 2010). Topographical maps used as a basis for the slope determination of Case Study One, are located in Appendix G, Case Study Two Accompanying Information. On the steeper west and east slopes, the defensible space is measured laterally along the slope (Berry 2010). All areas of defensible space are planted with low flammability plants, and exceed the California State minimum requirement by 50 feet (State Board of Forestry and Fire Protection 2006). The space within 30 feet of the structures consists of plantings that are within six inches of the ground. This planting, with its the low-profile, low density and high moisture content did not significantly contribute fuel to the fire (Los Angeles County Fire 2010; Berry 2010).

On the north, south and west sides of the structures, there exists a minimum of 30 feet separation from trees. On the west side of the main residence and garage there are mature eucalyptus trees within 30 feet, but no closer than ten feet. An approximate 30-foot wide concrete paving area that separates the main residence from the studio and garage. The concrete paving also serves as additional parking. On the east side of the property a 20-foot wide asphalt paved driveway accesses several properties. This common driveway separates the nearest eastern portion of the residence from the west slope of Coyote Canyon. A photograph of the common access driveway exists in Appendix F, Figure F.2. The photograph was taken from the east side of Coyote Canyon looking west towards Case Study One. The combination of adequate fuel modification, low flammable planting and hardscapes contributed to provide adequate defensible space during the Tea Fire. The structures of Case Study One may not have survived the fire without effective defensible space.

4.2.2 FIRE RESILIENCY ANALYSIS

A number of beneficial factors combined for Case Study One structures to survive the Tea Fire in a “Stand Alone” fashion; that is, without firefighter or resident intervention. One of these factors was a filled 3,000 gallon fire emergency water tank. The aboveground cylindrical water tank is located on the west side of the case study property on the east ridge of Sycamore Canyon. The water tank was located 10 feet to the west of the garage, and is situated atop a terrain-formed chimney. A photograph depicting the positioning, of the water tank in relationship to the chimney can be found in Appendix F, Figure F.3. Although none of the water was used during the fire it did provide fire protection for the garage. The location of the tank at the summit of a chimney acted as a Convex Structural Fire Shield for the garage. Further discussion of Structural Fire Shields can be in Chapter Nine. The flames and ember-laden airflow up the terrain-formed chimney were deflected away from the garage. The location of the water tank was not selected with any consideration of its potential fire shielding affect on the garage (Berry 2010).

The extreme fire behavior impacts on the structures were mitigated not only by defensible space, building materials and methods of construction, but also by beneficial terrain features and the positioning of the structures in relation to the peak burning. In Figure 4.7, the principal fire direction towards the Case Study One location is noted by “Peak Burning Direction. The peak burning direction varies from the “Fire Spread Direction” of Figure 4.6, because of the influence of terrain variables affecting the general direction of fire spread. The main fire spread direction was predominately from the northeast as indicated by the Montecito RAWs wind direction data (Department of Water Resources 2010), and by the position of the fire origin relative to the case study locations. The main body of the fire was pushed downhill by the Sundowner Wind, but significant uphill burning did occur when the fire burned up the sides of canyons and ridges.

In the proximity of the Case Study One and Case Study Two locations the general direction of the initial fire spread was altered by uphill burning from Coyote Canyon on the east side of the case studies (see Figure 4.7). Flame lengths increased due to the alignment of the wind and slope when the fire burned uphill. The impact of the radiated heat, convected heat, flame impingement, and embers on Case Study One was significantly reduced by the low vertical profile of the structures above the fire side terrain. The structure were protected by the hillside itself. Figure 4.7 and Figure F.4, (in Appendix F) show the ridgeline that protected Case Study One structures. The camera angle of photograph Figure F.4 gives the illusion of the structures being more exposed than they actually were from the peak burning of the Tea Fire. An onsite inspection and discussion with the occupants confirmed this aspect of protection afforded by the terrain (Berry 2010). The ridgeline height relative to the structure heights, in combination with the minimum 30-foot setback of the structure from the slope, significantly reduced the impact of heat, flame and embers on the structures.

Approximately two hours after the peak burning in the vicinity of the case studies, the fire spread direction reversed itself burning uphill in Sycamore Canyon against the wind.

The slope of the bases of both Sycamore Canyon and Coyote Canyon are significantly flatter than their sides, so that the impact of the slope reversal was marginal. The fire spread direction was essentially northerly (Berry 2010). The subsequent flame length, burning intensity and ember wash were of a lower magnitude than the burning down Coyote Canyon; principally, because the fire was burning against the wind. The weather conditions and fuels did not change significantly between the fire burning down Coyote Canyon and up Sycamore Canyon (Department of Water Resources 2010). As an example, the BehavePlus 5 (Fire Sciences Lab 2010) fire modeling program produced a flame length of 100 feet for the peak fire spreading uphill on the side slopes of Coyote Canyon driven by the wind. The flames lengths of the later fire burning from Sycamore Canyon against the wind was only 50 feet, as shown in Table 4.13. Identical fire behavior weather factors were used for both simulations, as the weather did not vary significantly (see Montecito RAWs data see Appendix E). Table 4.13 summarizes the input variables used for the flame length calculation for all three case studies. The significant factor accounting for the flame length differential for Case Study One and Case Study Two peak burning and subsequent burning was the impact on the slope of the direction of the prevailing wind.

Significant to the fire resiliency of Case Study One is the unique burn direction of this fire and the unintentional, yet beneficial, positioning of the structures. On the east side of the property, where the peak burning occurred, the structures were insulated from heat, flames, and embers by being partially excavated into the hillside and separated from the slope by a common driveway. The setback for the slope on the east, or Coyote Canyon, side varied from a minimum of 30 to 60 feet (Berry 2010). The north and east structure walls were cut into the hillside, thereby effectively producing a natural, or unintended, Inclined Structural Fire Shield. The flames, heat, and embers were predominately lifted up and over the structures. On the west, or Sycamore Canyon, side of Case Study One, the ridgeline setback ranged from only 10 to 15 feet (Berry 2010), while the nationally recognized standard is 30 feet from a sloping edge (Cohen 2000; Radtke 2004; National Fire Protection Association 2008-1).

The later fire spread up Sycamore Canyon scouring the underside of the eaves, but did not cause any further damage. A photograph of the scoured eaves is shown in Appendix F, Figure F.5. If the direction of the initial fire had been from the northwest of the case study location and had been pushed uphill by the Sundowner Winds, then structures may not have survived in a standalone manner.

SECTION 4.3 CASE STUDY TWO

4.3.1 STRUCTURE DESCRIPTION

Case Study Two is located to the north of Case Study One on Mountain Drive. The same fire behavior is assumed to have occurred at both Case Study One and Case Study Two locations during the Tea Fire. Figure 4.6 is a Google overhead view of the Case Study Two structures prior to the Tea Fire, showing their locations in a Very High Hazard fire severity zone (Berry 2010; LeVay 2010). Unfortunately, no other pre-fire photographs of Case Study Two structures exists, as the occupants had no time to save them as they were fleeing from the flames (LeVay 2010). The main residence and one garage were built in the 1950's and the other garage was built in 2007. The house was a ranch style floor plan of approximately 1600 square feet. An "As Built" floor plan is located in Appendix G, Figure G.2. Both case studies are pictured after the fire in Figure 4.7. The location of the structures of Case Study Two is in the upper-right portion of the photo behind the tall burned pine trees. Figure 4.8 is an after-fire photo of Case Study Two, and reveals the total destruction of all three structures. No rebuilding has taken place on the property to date. Additional after-fire photographs can be found in Appendix G, Case Study Two. Also in Appendix G is a letter entitled "Tempered By Fire" written within days of the Tea Fire by the occupant and owner of the Case Study Two property. The letter shares the emotions of a fire survivor, who lost everything but his spouse, car, computer and the clothes on his back.

Case Study Two had several significant design, construction and defensible space deficiencies that allowed the structures to burn without firefighters or residents present. An interview with the initial response Structure Protection Group Leader indicated responding firefighters did not have the opportunity to perform structure triage; let alone, protect any of the several structures located on the Mountain Drive common driveway (Blair 2010). If firefighters had been present, they would have classified the structures as a "Write Off" or, optimistically a "Prep and Go" while performing structural triage (Blair 2010).

The construction of the three structures composing Case Study Two was unrated ordinary construction as determined by California Building Code (International Code Council 2007). The roof of the residence was gabled with a Class B composition covering installed circa 1992 (LeVay 2010). The eaves of house and older garages were open. The windows were single paned, with aluminum frames. All three structures were single story structures with concrete slab foundations. The residence had board and batten siding, while, the garages had wood siding, slab foundation and shed roofs (LeVay 2010). Adequate firefighting water was available at the site, but was not used. The nearest fire hydrant, approximately 400 feet away from the residence, was installed when the property was subdivided in 2002 (LeVay 2010). An additional 15,000 gallon fire tank was located 300 feet from the residence, but was not used. The emergency water supplies were not used during the Tea Fire, possibly because the local fire agency was not aware of the presence of the tank prior to the fire (LeVay 2010). Besides the emergency water supply possibly the roof covering of Case Study Two structures did not meet current WUI code requirements for Very High Hazard fire zones.

The lack of defensible space around the Case Study Two structures was a significant factor contributing to the total destruction of the structures. On the east and south sides of the structures no unbroken 150 feet of defensible space existed, as required for new construction by Santa Barbara City Fire Department (LeVay 2010). An irrigated olive orchard and a natural stand of native vegetation flanked the east side of the structures. The native vegetation reached from the bottom of the canyon to within 10 feet of the residence (LeVay 2010). The remnants of the orchard can be seen in Figures G.1 and G.6 of Appendix G. Highly flammable plants (i.e. pine and pepper trees) with branches within 10 feet of the structure, thereby violating California defensible space standards (State Board of Forestry and Fire Protection 2006), surrounded the residence and garages on the east and south. In fact, there was a pepper tree growing through part of the bathroom on the east side of the residence. The locations of these trees are depicted in Figure G.4: Case Study Site Plan in Appendix G. The closet 30 feet on the south side of the residence had grass as ground cover, with 80-foot tall pine trees within 10 feet.

The slope of the hillside to the east and west exceeds 100% (LeVay 2010). The slope setback of the residence was approximately 15 feet and 20 feet for garages. Topographical maps of Case Study Two, which are the basis for slope determination and slope setback are located in Appendix G, Case Study Two, Figures G.4 and G.5. Adequate defensible space existed on the west and north side of the property. On the west side of the residence there existed a low ground cover, a retaining wall, and a common access driveway. Figure F.1 in Appendix F shows the driveway and retaining wall in relationship to the Case Study One residence.

*Figure 4.8: Case Study Two Residence After Tea Fire.
(Berry Family Collection of Fire Photographs)*

Between the structures there was less than 45 feet of separation. On the north and west side of the Case Study One structures a minimum of 30 to 80 feet of defensible space existed (LeVay 2010).

Much of this defensible space was provided by the common driveway, private gravel parking and driveway on the west side of the property. The 20-foot wide common driveway separated the nearest western portion of the residence from the west slope of Sycamore Canyon. A photograph of the common access driveway and retaining wall is included in Appendix F, Figure F.2.

4.3.2 FIRE RESILIENCY ANALYSIS

Case Study Two probably had the peak burning flame front and ember wash attack come from the northeast, up the west side of Coyote Canyon. The combination of severely limited defensible space, inadequate slope setback, and the wind becoming aligned with steep terrain were probable reasons why the structures burned. There existed a number of hazardous conditions that contributed to the burning of Case Study Two structures. Several of these factors concerned themselves with building construction and location. The combination of inadequate fuel modification, highly flammable trees touching buildings, and slope closeness all contributed to the burning of the structures. Unfortunately the adequate separation provided by the parking area, common and private driveways did not influence the survivability of the structures. There may have been a better chance for the structures to survive the fire, if the main path of the fire had been from the west, up the east side of Sycamore Canyon, where adequate defensible space existed.

The extreme fire behavior impacts on Case Study Two structures were not mitigated by defensible space, building materials and methods of construction, as in Case Study One. There were no beneficial terrain features, or positioning of the structures, with adequate setbacks from the intense fire coming from Coyote Canyon. The orchard on the west slope of Coyote Canyon was ineffective as a fire break, because the stand of natural vegetation, adjoining it, allowed the transmission of fire to the structures. In Figure 4.7, the principal fire spread towards the Case Study Two location is noted by “Peak Burning Direction”. The structures of Case Study Two experienced the same intense fire behavior as did Case Study One due to the alignment of wind and slope (see Figure 4.7).

However, the impact of the radiated heat, convected heat, flame impingement, and embers on Case Study Two was significantly greater than Case Study One, due to the exposed profile of the structures to airflow. The residence had unprotected attic vents, open eaves and single paned windows. The vents could have allowed embers to intrude into the limited attic space. The single pane windows would readily allow radiant heat inside the structure . Also, single pane windows breakout easily during fire situations (National Fire Protection Association 2008-A).

The structures were not protected by the hillside, and the highly flammable trees and limited defensible space produced a critically destructive fire environment. The ridgeline setback varied from 10 feet to 20 feet (LeVay 2010), but unfortunately the California pepper trees in the intervening space produced no protective setback (LeVay 2010). These trees offered an easy path for the fire to enter the structures. Unfortunately the adequate separation provided by the parking area, common and private driveways did not influence the survivability of the structures. There may have existed a better chance of the structures surviving the fire, if the main path of the fire had been from the west, up the east side of Sycamore Canyon, where adequate defensible space existed.

The path of the fire during the later stages proceeded in a northerly direction up the canyon against the wind from Sycamore Canyon towards the case study site. This subsequent burning had no practical consequence for Case Study One, as the structures had already burned. The subsequent flame length, burning intensity and ember wash were of a lower magnitude; principally because the fire was burning against the wind. Weather conditions and fuels did not change significantly from peak burning (Department of Water Resources 2010). The later fire would have attacked the structures from the west, where adequate defensible space and low flammability plants existed. The height, density and low flammability of the vegetation would not have contributed to the fire spreading into the structures. Table 4.12 compares the length of the flames during the peak burning period in Coyote Canyon to the later spread burning in Sycamore Canyon.

Table 4.12, again emphasizes that the direction of the prevailing wind impacting the different slopes accounted for the flame length differential during the peak burning and subsequent burning.

On the west, or Sycamore Canyon, side of Case Study Two the slope setback ranged from a minimum of 30 feet for the residence to a minimum of 80 feet for the garages (LeVay 2010). Beside the separation distance, a six-foot tall retaining wall provided further flame and ember protection. An after-fire photograph of the retaining wall and access driveway can be seen in Appendix F, Figure F.1. The nationally recognized standard of 30 feet setback from a sloping edge (Cohen 2000; Radtke 2004; National Fire Protection Association 2008-1) was more than met on the west side of the structures. On the east side of the property, where the peak burning occurred, the structures were directly exposed to the heat, flames and embers by the close proximity of the slope and highly flammable trees. The structure setback from the slope on the east or Coyote Canyon side varied from a minimum of 10 to 20 feet (LeVay 2010). If the initial fire path had been from the northwest of the case study location and had been pushed uphill by the Sundowner Winds, the structures could possibly have survived with human intervention, and adequate firefighting water. Obviously, the adequate defensible space on the east side of the structures had no affect on the survivability of the burned structures. All sides of any structure and all its potential fire hazards must be mitigated if the structure is to survive a WUI fire.

SECTION 4.4 CASE STUDY THREE

4.4.1 STRUCTURE DESCRIPTION

Case Study Three is associated with similar fire hazards as Case Studies One and Two. It is situated among the Santa Monica Mountains of Malibu, nearly halfway up the California coast from downtown Los Angeles to Santa Barbara. This case study is located in rugged terrain, surrounded by native fuels, experiences a Mediterranean Climate and has similar fire weather as the previous two case studies. The residence and accompanying structures of Case Study Three survived the 1993 Green Meadows Fire. The location of Case Study Three is within a Very High Hazard fire severity zone (Gonzales 2010). Similarly, the preceding two case studies are located in a Very High Hazard fire severity zone, because of their comparable fire hazards. All of these case studies exemplify the WUI fire problem of Southern California.

Figure 4.9 is an overhead view of the case study with the location of a terrain-formed chimney, and the location of the high points on a ridgeline that form a saddle. An onsite inspection, and study of aerial photographs and topographical maps indicates that Case Study The residence lies midway between the peaks forming a saddle, and at the lowest elevation of the saddle. The low point of the saddle has the greatest airflow velocity and turbulence (National Wildland Coordinating Group 2001). Adding to the case study fire problem is the existence of an approximately one-half mile long dry drainage that forms a chimney, and terminates in front of the residence. Figure 4.9, and Figures H.2 and H.3 in Appendix H depicts these terrain features. The fuel type was hard chaparral, and at the time of the Green Meadows Fire was classified as fire critical old age (Dennison 2008). Table H.1 in Appendix H lists this information and other fire particulars from the Old Topanga Fire and Green Meadows Fire. The fuel, terrain and weather conditions combined to produce extreme fire conditions, which the structure of Case Study Three withstood, with the help of firefighters from Engine 5718.

The main residence, garage and studio were built in circa 1978. The residence, approximately 4,000 square feet (Kass 2010) is ordinary, non-rated construction with stucco exterior walls.

*Figure 4.9: Case Study Three Aerial View with Saddle and Chimney Indicated.
(GoogleEarth.com)*

The majority of the roof is flat with two to three-foot parapet walls, and sloped roofs over small areas of the front entry, east bedroom and rear entry (Kass 2010). The sloped roof areas at the front of the residence are in alignment with the slope on the east side of the property. The house has 8 to 12-foot high ceilings with no attic space or eaves. There are concealed spaces caused by ceiling elevation and pitch changes (Kass 2010). On the east side of the residence is a 5 ½ feet high cinder block and stucco covered retaining wall. The wall varies from 6 to 10 feet from the exterior walls of the house. At the time of the Green Meadows Fire the windows were single paned.

Photos of the roof, the parapet walls and the retaining wall in the front of the house are shown in Figure 4.10. Additional photographs of these features can be seen in Appendix H, Figure H.4, H.5 and H.7. Figure H.8 shows the vegetation atop the slope, east of the residence, held back by the retaining wall.

A guest house exists on the south side of the residence, adjacent to an emergency firewater storage tank. At the time of the Green Meadows Fire, the studio was approximately 1,000 square feet, with wood exterior siding, with a metal shed roof. Metal-sided walls were completed several years after the fire (Kass 2010). A partial photograph of the guest house is shown in Figure H.8. The guest house is adjacent to rock formations and the south incline of the saddle, within which the residence is centered. At the time of construction the structures met the requirements of the Ventura County Fire Department for development in a Very High Hazard fire severity zone (Kass 2010).

The terrain surrounding the structures varies considerably on different sides of the residence. The north and south sides of the residence are at first level, then gently slope uphill. The south perimeter of the residence has a paved driveway and parking area, providing 30 to 50 feet of noncombustible separation between the structures and the landscaping. On the west side of the property the slope drops off at more than 100%. The structure-to-slope setback varies from 30 to 45 feet on this side of the residence. On the east side of the structure the slope is approximately 65%, where the terrain formed chimney exists. There are retaining walls only on the east side of the structure. A topographical map (Figure H.2, Appendix H) is the basis for the slope determination. These terrain features significantly influence the fire behavior affecting the Case Study Three structures.

There was 50 to 100 feet of defensible space, measured horizontally, on the gently sloping terrain to the north and south of the structures. The defensible space was increased to over 200 feet on the north side of residence by “burning-out” activities performed by the Santa Barbara County Fire Department personnel before the arrival of the main body of the fire (Bell 2010).

An estimated 150 feet of defensible space existed on the south side of the property, which was a combination of pavement and exposed rocky terrain with low vegetation density. The east side consisted of a sparsely planted area of irrigated fruit trees, measuring between 150 to 190 feet to the structures. The closest 30 feet had low growing ground cover and succulent plantings (Kass 2010) that did not significantly contribute fuel to the fire.

*Figure 4.10: Roof, Parapet Walls and Retaining Wall at Front of Residence
(MesKimen Thesis Collection)*

Figure H.5 illustrates the type of planting existing at the time of the Green Meadows Fire (Note, the eucalyptus trees did exist at that time) (Kass 2010). During the Green Meadows Fire, this area required no additional treatment from firefighters. The west side of the structures had a minimum of 150 feet, measured on the slope, of defensible space provided by reduced fuel loading performed by the owners (Kass 2010). After the initial fire spread in a westerly direction over Case Study Three structures, a secondary fire burned uphill in an easterly direction on the westside of the structures.

The Engine 5718 firefighters attempted unsuccessfully to increase the defensible space, but were prevented from doing so by prevailing flame lengths and heat (Smith 2010). The adequate slope setback on the westside of the residence did not allow flame contact to any of the structures.

Case Study Three had design and construction features along with aid from firefighters allowed the structures to remain virtually unscathed during the Green Meadows Fire. At the time of construction, the structures met all applicable code and ordinances for Very High Hazard fire severity zone (Kass 2010). The residence had no eaves, no attic vents and ample defensible space. The roof of the residence was flat with parapet walls. These roofing features allow less turbulent airflow, and therefore less flame and ember impacting the roofline. At the front of the residence, the retaining wall and sloping terrain did not allow direct embers or flames impact on windows. Figure H. 10 illustrates the effect of the sloping terrain obstructing the line-of-sight viewing of residence windows. The effective defensible space of the east side of the case study was increased by the terrain slope and the retaining wall. The slope setback on the west side of the residence was effective in limiting radiant heat, flame and ember intrusion onto the structure.

Case Study Three had a 10,000 gallon emergency water tank (Kass 2010), which provided sufficient water to extinguish burning vegetation, and an incipient fire discovered in a concealed space of the residence. However, since the plumbing on this emergency water tank prohibited the Santa Barbara County Fire crew from using its full flow capacity, they used the water to replenish the water in the tank of Engine 5718. The palm tree canopy fires, that were within 10 feet of the house, were extinguished with this water. At the time of the fire the palm treetops were approximately 15 feet tall, so the burning canopies were at roof level, causing concern to the fire crew. Fortunately, there were no structure openings within 15 feet of the burning canopies (Kass 2010). The palm tree fires were extinguished quickly, and the trees were saved. A photograph of the palm tree trunks, 17 years later is available in Appendix H, Figure H.9.

Water from the tank of the fire engine was used to extinguish a concealed space fire above the ceiling just inside the front door. The structures of Case Study Three could not have survived the Green Meadows Fire without the available firefighting water supply.

4.4.2 FIRE RESILIENCY ANALYSIS

A number of extraordinary factors combined, severely testing the fire resiliency of the Case Study Three structures. Dangerous fire weather existed with high temperature, low fuel moisture, low relative humidities, high fuel loads and high winds. As an example, firefighter accounts indicated that despite temperature exceeding 100°F, no perspiration showed on their clothing, just salt stains. This phenomenon occurred due to rapid evaporation of sweat caused by the low humidity and wind (Smith 2010). These weather, slope and fuel conditions are discussed in greater detail in Section 4.12. The terrain effects of a saddle and chimney amplified the flame lengths to the 200-foot flame lengths seen in Figure 4.5. A flame length of 200 feet was determined by the flames photograph, depicted in Figure 4.5 and with aerial photographs and onsite landmark measurements. Without the terrain-amplifying effects of the chimney and the saddle, the flame length would have been 90 feet. The fire condition variable values used for generating the 90-foot flame length can be viewed in Table 2.13.

The peak burning of the Green Meadows Fire, near Case Study Three was during the afternoon of the second day of the fire. The peak fire was driven by a Santa Ana Wind traveling in a southwestern direction as illustrated in Figure 4.9. The Engine 5718 crew could not see the main head of the fire. It appeared that several strips of fire, coming off the perimeter of the main body of fire, were funneled through the saddle in which Case Study Three is located. The combination of flame fronts and ember washes lasted for a minimum of 40 minutes (Smith 2010). A typical flame front passes much more rapidly, but authorities differ on duration. For example, a flame front can pass as quickly as 1 to 2 minutes (Cohen and Butler 1998), or pass through in a period of between 5 to 10 minutes (Ramsay and Rudolph 2006).

The unusually long-lasting flame front attack was presumed to be a result of the broadening flank of the fire, producing strips of flames, which were funneled towards case study residence by a combination of the saddle and chimney.

Since the fire had been burning a day before, there was ample time for the residents in this area to self-evacuate (Kass 2010). The Santa Barbara County Strike Team entered the area as assigned by a Division/Group Supervisor of the Green Meadows Incident Operations Division. The crews of the strike team had sufficient time to “prep” individual structures, including Case Study Three structures. As an example of the preparation, a safe strip firing-out (burning of vegetation) north of Case Study Three increased the defensible space from approximately 75 to 300 feet. The firing-out significantly reduced the fire loading within the saddle. This action increased the survivability of Case Study Three structures.

The flat roof portion of the residence, along with its parapet walls, had beneficial effects contributing to the fire resiliency of the residence. Lack of attic and attic vents vastly reduced the possibility of ember intrusion into the structure. The parapet walls and the flat roof presented a low airflow impact shape, allowing the flames to traverse above the residence without any visible fire consequences. The retaining wall on the east side of the residence essentially performed two functions. First, it separated the structure from the terrain that formed the fire shielding protection, and second, it presented a lower vertical profile of the building envelope to the approaching fire from the east. The parapet walls combined with the sloping terrain formed a natural Inclined Fire Shield that amplified the uplifting of the airflow and flames over the roof. Figure 4.11 depicts the angle formed by the slope of the terrain and the horizon, continuing beyond the retaining wall to the top of the parapet wall. The angle shown in Figure 4.11 is indistinguishable from the angle of the flames formed with the horizon going above Case Study Three (Figures 4.5, and H.11). Figure 4.12 is an aerial photograph of the terrain-formed Inclined Fire Shield and the retaining wall. The retaining wall is the thin white line to the east of the residence. An in-depth discussion of Fire Shields is found in Chapter Seven.

Additionally, the retaining wall and the incline of the terrain protected the wall openings from direct flame and ember contact. These terrain and construction factors combined to significantly increase the fire resiliency of the residence.

*Figure 4.11: Diagram of Angle of Terrain Slope Extending to Top of Parapet Wall.
(MesKimen Thesis Collection)*

The initial wind-driven fire spread, with the greatest flame lengths burned uphill towards the structures from the east, as illustrated in Figure 4.9. Approximately 40 minutes later, a secondary fire spread burned against the wind and uphill towards the case study structures from the west (Smith 2010). There was no flame contact and insignificant ember impact on the west side of the case study structures. The adequate slope setback of 30 to 45 feet on the west side of the residence produced this result during the latter secondary fire spread. Upon arrival of Engine 5718, one resident of Mipolomol Road informed the crew that another strike team had withdrawn from the area allegedly, because the area was possibly too hazardous for firefighters to safely defend. This evaluation of the potential hazard was accurate, because the Santa Barbara County firefighters were put at too great a risk defending the structures on Mipolomol Road.

To illustrate, the fire was so severe that flames overran three of the five Santa Barbara County fire crews. Embers burned through the wildland protective clothing of firefighters making them unusable, as shown in Figure H.11 (Smith 2010). As a result of the overwhelming combination of heat, exhaustion, smoke and flames, nearly half of the 16 members of the strike team were dispatched back to Santa Barbara County, and did not continue to fight the Green Meadows Fire. In this sector of the Green Meadows Fire, the Santa Barbara County firefighters came too close to becoming fire loss statistics.

Figure 4.12: Case Study Three Structures with Natural Linear Inclined Fire Shield.
(<http://maps.google.com>)

Because the main body of the fire had passed through the area, Santa Barbara County Fire strike team was assigned to another location.

The Engine 5718 crew was forced to stay behind in the vicinity of Case Study Three, as a compressed air leak was discovered coming from the engine, after the flame fronts and ember washes passed through. Investigation revealed that a combination of embers and/or heat melted a plastic brake line coupling in a front wheel well of the engine. The loss of air pressure resulted in the brakes being applied. Consequently, the engine could not move until air pressure was restored. The crew waited with their engine at the case study location until repairs were made.

During this time, Engine 5718 pump was still operational, because the drive engine and separate pump engine were in working order. The vehicle just could not move. The Engine 5718 crew continued to inspect the residence and other structures for post-fire front ignition. An indication of a possible fire was observed. There was charred wood on the door jamb of the front door. An incipient fire was discovered burning in a concealed space above the ceiling, just inside the front door. A 200-foot length of hard rubber hose was pulled to the front door; a specialized brush tool was used to cut a hole in the ceiling and wall for access to extinguish the flames. Fortunately, the Engine 5718 crew was available onsite, and discovered the fire before it had a chance to burn-down the residence. The concealed space fire occurred some 40 minutes after the fire fronts and ember washes had passed and external fire dangers were eliminated. During WUI fires, increased structure survivability can occur when patrols or inspections continue for upwards of two hours after the main body of the fire has passed.

SECTION 4.5 FIRE BEHAVIOR ANALYSIS

4.5.1 INTRODUCTION

A wildfire threat approaching a structure is similar to a fight in a Mixed Martial Arts (MMA) contest. During a MMA contest, a fighter has to face the threats of submission (tap out), knockout, disqualification, or referee stoppage (technical knockout). An occurrence of any one of these factors ends the contest directly. A fighter may make it through every hazard posed by his opponent only to lose the contest in the end by points. It takes only one of these developments to lose the battle, not a combination of them. So, it is with an interface wildfire. A structure may burn by ember intrusion, flame impingement, or radiant heat. Any one of these factors can destroy a structure quickly. Yet a structure may survive every one of these threats only to burn in a delayed fashion due to a hidden fire. In a similar fashion, a residence may have adequate defensible space, built code with compliant materials and methods of construction yet still may burn down, because of an absence of fire-mitigating design features. Structures within WUI areas must be protected adequately from all fire threats to ensure their survival. The following information relating to the influence of extraordinary terrain features on flame length is pertinent to the survivability of a structures that is exposed to a WUI fire. Additional information for increasing structure fire resiliency is contained in Chapter Five, Fire Profile Index; Chapter Six, Structure Safety Zones; Chapter Seven, Structure Fire Shields.

4.5.2 FIRE BEHAVIOR ANALYSIS

Table 4.13, Fire Behavior Analysis provides a summary comparison of the actual fire behavior based on flame lengths, and the fire behavior predicted by fire modeling programs. The BehavePlus and Wildland Tool Kit fire modeling programs were selected because of their widespread use, availability and user friendliness. Only single point prediction models were needed because of their ability to generate flame lengths under specific fire condition at a predetermined location. The utility of using fire modeling is the identification of significant variations from expected fire behavior and historical fire behavior.

The existence of significant variation from projected fire behavior indicates the presence of some other variables, not represented in their algorithms. These extraordinary fire behavior variables will be addressed in this section.

Universally, fire modeling algorithms consider three general fire behavior variables: weather; fuels; and terrain. The weather variables include temperature, relative humidity, wind direction, and speed. Two separate fuel classification systems were used for comparison namely *Standard Fire Behavior Fuel Models: A Comprehensive Set for Use with Rothermel's Surface Fire Spread Model* (Scott and Burgan 2005) and *Aids to Determining Fuel Models For Estimating Fire Behavior* (Anderson 1982). The terrain factors include slope, aspect, and wind direction-to-slope variation. The two selected fire modeling programs take into account an extensive list of fire behavior variables, except those that apply to chimneys and saddles. The author knows of no fire modeling programs that take into account these two extraordinary terrain features. It is assumed that these variables account for the difference in modeled flame lengths and observed flame lengths.

Table 4.13 has six columns comparing the modeled flame lengths to the observed flame lengths. The first column, titled "Fire Behavior Factor" lists the fire behavior variables. The second and third columns include fire behavior variable values for the initial burn period of Case Study One and Two. The initial fire was pushed uphill by the wind towards these case studies from Coyote Canyon. The fourth column, titled "Tea Fire Secondary Burn" lists fire variable values that occurred approximately two hours after the initial burn period of Case Studies One and Two. The Tea Fire Secondary Burn was located in Sycamore Canyon, and the fire spread uphill against the wind. The fifth column, "Case Study Three" lists the variables of the initial fire as it spread towards Case Study Three during the Green Meadows Fire. This fire was pushed uphill by the wind and channeled towards Case Study Three by a combination of a chimney and saddle. The sixth column, titled "Green Meadows Fire Secondary Spread" includes the burn variables existing after the main body of fire passed by. This fire spread against the wind, uphill towards Case Study Three.

The Fire Behavior Analysis Table 4.13 contains 14 rows of data and information. The first 10 rows contain input variables used for fire modeling. The last four rows contain the comparative data portion of the table. The “BehavePlus 5” and “Wildland Tool Kit” rows indicate the values derived from the fire factor variables input to the respective fire modeling programs. The “Observed Row” describes the flame lengths observed by photographs and personal accounts. The fourteenth row, titled “Special Terrain Influence” is derived by dividing the modeled flame lengths by the observed flame lengths. Special terrain influences are the fire behavior factors attributed to chimney and saddles. Any value above 1.25 is considered a significant variation from the modeling programs. There may be a number of variables accounting for the difference. However, this thesis suggests these significant variations from the modeling programs are caused by extraordinary terrain variables, consisting of saddles, chimneys, and a combination thereof.

*TABLE 4.13:
FIRE BEHAVIOR ANALYSIS*

Fire Behavior Factor	Case Study One	Case Study Two	Tea Fire Secondary Spread	Case Study Three	Green Meadows Fire Secondary Spread
Weather					
Temperature	70° F	70° F	70°F	100° F	100° F
Relative Humidity	20%	20%	16%	10%	10%
Wind Speed	50 mph	50 mph	50mph	40 mph	40 mph
Wind Gusts	70 mph	70 mph	70 mph	55 mph	55 mph
Wind Direction	40-45° NE	40-45° NE	40-45° NE	75-80° ENE	75-80° NE

Fire Behavior Factor	Case Study One	Case Study Two	Tea Fire Secondary Spread	Case Study Three	Green Meadows Fire Secondary Spread
Terrain					
Percent Slope	110%	110%	100%	65%	120%
Aspect	East	East	West	East	West
Wind:Slope Variance	15°	15°	165°	15°	165°
Fuel Type					
Scott & Burgan	SH5	SH5	SH5	SH5	SH5
Anderson	4	4	4	4	4
Flame Length					
BehavePlus 5	85 Feet	85 Feet	47 Feet	92 Feet	62Feet
Wildland Tool	87 Feet	87 Feet	46 Feet	95 Feet	70 Feet
Observed	125 Feet	125 Feet	45 Feet	200 Feet	55 Feet
Special Terrain Influence	1.5	1.5	1	2.5	1

4.5.3 CHIMNEY CONVERSION FACTOR

The conversion factor for a terrain-formed chimney increasing the ambient flame length is derived primarily from the box canyon chimney at the north end of Coyote Canyon in Santa Barbara, during the Tea Fire of November 2008. Figure 4.4 is a photograph of the flames at the west side of the chimney formed at the end of this box canyon. The fire modeled flame length, without the influence of the chimney is 85 feet. The observed flame length in the area was in the range of at least 125 feet to 150 feet.

Witness accounts indicate that the flame lengths could have been as much as 200 feet (LeVay 2010). The flame lengths possibly could have been greater than those pictured in Figure 4.4. The flames and high voltage towers are at midslope of the wall of Coyote Canyon, and not at the ridgeline, where wind speeds could be three to four times greater (Sharples et al. 2007). With greater wind speed, flame lengths could have been even greater. Due to these factors, the influence of a box canyon chimney is safely estimated at a minimum of 1.5 to 2.0 times greater than the modeled or expected flame length.

The influence of a terrain-formed chimney should be considered in the design and site placement of a structure. The existence of a chimney can be determined by an in-turn on a midslope road (See, Section 2.4.3) or by a topographical map, aerial photography, and by onsite observations. The influence of the chimney on flame length varies with the steepness of the slope, and the ratio of drainage area to chimney area. The larger the drainage and the more defined the side of the chimney, the greater the influence of the chimney. Under severe potential fire hazard conditions, a structure should not be located near the top of a chimney. A structure exposed to the effects of a chimney should have its defensible space or slope setback increased by the amount of the estimated conversion factor for flame length, and increased concentration of embers. See Chapter Six, Structure Safety Zones, for more details on determining the recommended defensible space based on flame length. If increased defensible space is not possible, then the use of mitigating factors or combination of defensible space and mitigating factors should be applied.

4.5.4 SADDLE CONVERSION FACTOR

The conversion factor for a saddle is primarily determined from the photograph of the flames pictured in Figure 4.5, and firefighter accounts. The flames pictured are those which occurred at Case Study Three in the course of the Green Meadows Fire, November 1993. Case Study Three structures, especially the main residence, are located within a steeply shaped saddle, and at the top of a well-defined chimney. The Terrain Influence conversion factor of 2.5 appearing in Table 4.13, is a combination of a saddle and chimney.

Firefighter accounts indicate that a minimum of 50-yard wide strips of fire were coming off the ever-expanding fire flank. The fire passing over the residence lasted for approximately 40 minutes (Smith 2010), and much of it was came from an area north of the chimney. Unfortunately, it is not known whether the flames that were photographed in Figure 4.5 were at their maximum, or what influence of the chimney effect had relative to saddle effect. Nonetheless the airflow channeling effect of a saddle, and the corresponding increase in flame length and ember quantity are significant.

The influence of a saddle depends on the relative proportions of ridges contained in the saddle and the side wall steepness of the saddle. The size of the ridge, the height of the saddle, and the steepness of the walls, determine the influencing flame length factor. Wind speeds between 3 to 4-times the slope windspeed occurring at the top of ridges also contribute to increased flame length within the saddle (Sharples et al. 2007). For the Case Study Three fire behavior evaluation, an estimated reduction of 0.5 in the flame length conversion factor is attributed to the existence of the chimney. Consequently a saddle produces a conservative conversion factor of 2.0 to 3.0 of the expected flame length. A structure exposed to the extra fire hazard posed by a saddle should have its defensible space or slope setback increased by double the amount of the estimated increase in flame length. Also, any increased concentration of embers must be taken into account. See Chapter Six, Structure Safety Zones, for more details on determining increased defensible space based on flame length. If increased defensible space is not possible, then additional mitigating factors should be considered. See Chapter Seven, Structural Fire Shields, for additional information on increased structure fire resiliency. If a saddle poses severe fire behavior threats, then structures should not be located within its confines.

4.5.5 RELEVANCE FOR FIRE PROFILE INDEX

The findings of the case studies are incorporated in the Fire Profile Index, Fire Assessment Guide, and the Developers Guide of Chapter Five.

Any of the significantly weighed factors in the Fire Profile Index (i.e., in the value range of at least 40 points), and the Fire Assessment Guide (i.e., double negatives) are heavily influenced by case studies, firefighter observations, and research. As an example, Case Study Two had several significant interface fire hazards that led to its burning in the initial stages of the Tea Fire. The lack of defensible space and inadequate steep slope setback on the Coyote Canyon side of the structures, single pane windows, wood exterior siding, roof misaligned with slope, and unprotected attic vents were chief among them. The most serious hazards identified in Case Study Two were the lack of defensible space on the east side of the residence, and its accompanying inadequate steep slope setback. Flame and embers had unobstructed access to the structures via a pronounced fuel ladder and virtually no setback from the steep side of Coyote Canyon. The existence of just one of these factors can result in the loss of a structure during an interface wildfire. These and other structure hazards are discussed in the following chapters, along with mitigating measures to increase fire resiliency.

CHAPTER FIVE

5.1 FIRE ASSESSMENT

5.1.1 INTRODUCTION

The Fire Profile Index and its ancillary assessment indexes, which include Fire Assessment Guide, and Developers Guide are instruments that assess the interface fire threat, structure fire resiliency and direct the user towards possible mitigating measures. Each of these assessment guides are targeted to users. The Fire Profile Index is a comprehensive fire assessment tool; it totals the entered values of a range of attributes to indicate the WUI fire threat. Additionally, the Fire Profile Index conveys the relative feasibility of a structure surviving an interface fire. The Developers Guide is a tool intended for design professionals, architects, developers and planners of structures and developments within WUI areas. The Developers Guide evaluates the hazard posed by interface fires. The Fire Assessment Index, as the name implies, assesses the fire potential in WUI areas, and is geared towards fire service personnel and other persons involved in combating potential interface fires.

5.1.2 FIRE PROFILE INDEX

The intended consumers of the Fire Profile Index include knowledgeable WUI residents, developers, designers, policy makers and fire service personnel. The Fire Profile Index includes 250 items that evaluate the fire resiliency of structures, located within WUI areas. Due to the length of the Fire Profile Index, it is located in Appendix I as Table I.1. The accompanying strategy codes, explaining possible mitigating strategies are shown as Figures 5.2 and I.2 in Appendix I. For reference, the initial and ending sections of the Fire Profile Index are shown in Table 5.1. The Fire Profile Index is in a spreadsheet format that includes point ranges, or stated points, for each of the fire threat or fire remedy attributes. The spreadsheet format facilitates an accounting of the fire resiliency factors affecting a structure.

**TABLE 5.1: FIRE PROFILE INDEX
INITIAL AND END SECTIONS**

Category	Subcategory	Attribute	Strategy Code	Attribute Definition	Point Range	Value
FUELS						
	Structures	Wall Construction	①④⑤⑥⑦	Combustibility of wall materials	1-5 points	3
		Roof Construction	①④⑤⑥⑦	Combustible roof, non-rated	300 points	
		Roof Shape	①④⑤⑥⑦	Airflow turbulence generated by Shape	1-20 points	10
		Interior Fire Loading	①④	Amount and flammability of contents	1-5 points	3
		Structure Size	①④⑤⑥⑦	Aggregate volume of combustible materials	1-10 points	5
		Structures Proximity	①④⑤⑥⑦	Separation distance between structures		
		Select One Attribute Category		Under 30 feet	60 points	
				30-45 feet	10 points	
				Over 45 feet	1 point	1
		Development Proximity	①④⑫	Development within Two miles without fire spread barrier	1-5 points	3
		Combustible Decking	①⑦	Amount and quantity of decking materials	1-5 points	3
		Combustible Fencing	①⑦	Amount of fencing within 10' of Structures	1-5 points	3
	Natural Plants					
	(native & exotic)	Mineral Content of Leafs	②③⑪⑭	Mineral content of of leafs	1-3 points	2
		Volatile Oil Content	②③⑪⑭	Ability of oils within plants vaporizing	1-3 points	2
		Fuel Moisture	②③⑪⑭	Percent weight of a particular fuel that is composed of water	1-20 points	10
		Density of Foliage	②③⑪⑭	Mass and shape of foliage	1-3 points	2
		Canopy Density	②③⑪⑭	Closeness of leafs	1-3 points	2
		Foliage Proximity to Ground	②⑨⑪	Quantity of plant material from 18 inches to 6 feet high	1-3 points	3
		Understory	②③⑨⑪	Amount of combustible plant matter beneath trees	1-3 points	2
		Aerial Ability	③⑬⑪⑭	Proportion of plant surface area to mass	1-3 points	1
	Rekindle	Structure re-ignition	①②⑤⑫⑦	Re-ignition of structure after initial fire extinguished	1-10 points	5
	Area Ignition/ Blowups	Fire in ravine or valley igniting within minutes	①②③④⑤⑫⑦	Near simultaneous area ignition within a matter of minutes	1-10 points	5
	Spotting	Embers igniting fires ahead of main fire	①②③④⑤⑫⑦	Small areas ahead of main body of fire ignited by embers.	1-10 points	5
	Rate-of-Spread	Rapid rate of spread	①②③④⑤⑫⑦	The rate of progress of the main body of fire exceeding normal	1-20 points	
	Last Burn	Previous interface burn	①②⑤⑫	> 15 year interval since last burn	20-40 points	
SPECIAL HAZARDS						
	High Value Structures	Public buildings, churches, hospitals, historic, museums	①②⑤⑫⑮	Structures, within 5 miles of projected, whose loss would affect functioning of community	1-10 points	
	High Life Value Structures	Schools, hospitals, churches, theaters	①②⑤⑫⑮	Structures, within 5 miles of projected, where large numbers of people congregate	1-10 points	
	Cultural Assets	Museums, gardens, theaters	①②⑤⑫⑮	Locations, within 5 miles of projected that are valued by community for cultural benefit	1-10 points	
	Hazardous Materials	Oil refineries, nuclear plants, chemical many	①②⑤⑫⑮	Unusually highly toxic, reactive, flammable materials within 5 miles	1-10 points	
	High Tension Wires	Above ground high voltage lines	①②⑤⑫⑮	Lines & towers representing electrocution & aircraft hazard within immediate fire area	1-10 points	5
	Utilities	Transmission lines of utilities	①②⑤⑫⑮	Natural gas lines, electrical lines, oil & gas pipelines within projected fire area	1-10 points	
	Railroads	Trains & tracks	①②⑤⑫⑮	Railroad trains and tracks within projected fire area	1-5 points	
TOTAL VALUE						684

STRATEGY CODES	
①	Limit Ember Intrusion
②	Structure Safety Zone
③	Fuel Modification/Defensible Space
④	Provide Structural Fire Shields
⑤	Lower Wind Turbulence of Building Envelope
⑥	Lower Fire Profile Index Value
⑦	Establish Adequate Egress
⑧	Adequate Water Supply
⑨	Cleanup Litter/Leafs
⑩	Independent Fire Water Supply
⑪	Limb-up Trees/Bushes
⑫	Provide Adequate Separation
⑬	Remove Plants
⑭	Reduce Quantity
⑮	Shelter-In-Place
⑯	Take Advantage of Benefit
⑰	Noncombustible/Fire Resistive Construction

Figure 5.2: Fire Profile Index Strategy Codes

The first column of the Fire Profile Index is termed “Category”, and includes 11 groups of assessment items: Fuels; Weather; Terrain; Services; Development; Construction Features; Landscaping Features; Human Factors; Fire Protection; Fire Behavior; and Special Hazards. The different groupings within the category classification vary with respect to their impact on fire resiliency. In the second column, termed “Subcategory”, each group is divided into several subgroups of evaluation items. Each subgroup has multiple attributes that are listed in the third column, titled “Attributes”. An assessment item or attribute is singularly rated, and assigned points in the “Value” column. The fourth column is the “Strategy Code”.

“The Strategy Code” lists possible mitigating strategies for individual attributes. In the fifth column, titled “Subcategory/Attribute Definition”, is a description of an attribute as an aid to understanding, and selecting an appropriate point value. The sixth column, titled “Point Range” is the range of points suitable for each Subcategory/Attribute. The last column, titled “Value”, is the point value selected from the range of points given for each attribute.

5.1.3 FIRE PROFILE INDEX USE

The Fire Profile Index is intended to be used by a person with WUI fire problem knowledge, but certainly not to the level of an expert in interface fire behavior. The index is designed to be used with simplicity and ease of use in mind. For explanatory purposes, a hypothetical Model WUI Code (Chapter 2, Section 2.2.2) compliant structure located in a Very High Hazard hazard severity zone, typical of Southern California, has been selected as an example. The Fire Profile Index produces an easily understood representation of the fire threat for any particular structure. At the bottom of the Fire Profile Index is a row titled “Total Value”. On the right-hand portion side of this row is the cumulative total of the values entered for each Attribute.

The cumulative value of the Fire Profile Index can exceed 1,000 points. A total value below 500 points groups the structure in Category I, indicating that the fire resiliency will likely be maintained throughout a severe firestorm. A point total of between 500 and 750 indicates that the structure is likely to survive a severe interface firestorm with the aid of trained and adequately equipped personnel. This point total places a structure within Category II. A total point value of over 750 indicates that the structure is unlikely to survive a severe fire storm, even with the aid of trained firefighting personnel. This is a structure located in a Category III fire threat environment. A Category III assessment is an indication that the structure will be a likely “write-off” in a structure triage situation (Section 2.1 of Chapter 2) performed by fire service personnel. The aforementioned categories are general and flexible; however, the Fire Profile Index is intended to be used with discretion.

The selection of a suitable point value for each fire threat assessment attribute is essential for the proper use of the index. A probable worst case scenario representation should be used for each attribute point value selection. Attribute values should reflect the historically extreme values for temperature, relative humidity, wind events, as well as live and dead fuel moistures. These fire behavior variables should be selected regardless of the usual time of year that they typically occur. Devastating interface fires have occurred in Southern California during November, December, January and spring due to atypical fire weather and fuel moistures. Examples are the Tea Fire and Jesusita Fires in the Santa Barbara area of California. The Tea Fire occurred in November and the Jesusita Fire in May. The Malibu Road Fire occurred in January 2007. These fires occurred outside the usual Southern California peak of the fire season months of August through October (Cal Fire 2010-A).

An appropriate attribute, based on situational factors, that has a stated point value (not a range of points) should have its point value entered in the Value column. Stated point values occur for attributes in cases where the user is required to select one point value from a combination of numbers. The stated point value is identified by “Select One Attribute Category” in the Attribute and Strategy Code column, followed by an option to select point values. To illustrate, Figure 5.1 has one (1) point entered for a structure with a separation distance of greater than 45 feet. The point value can be found in the ninth row down in the Fuels group. This choice of a structure separation distance entailed the selection of one distance range from the Point Range column. There are three distance ranges given for the Structure Proximity Attributes: Under 30 feet; 30-45 feet; and Over 45 feet. For this example, the residence has over 45 feet of separation from any other structures; therefore, one (1) point was entered in the Value column. Stated point values are indicated because the different attribute classifications vary significantly according to their impact on fire resiliency. The fire resiliency variance is reflected in the corresponding point value differences.

Different fire threat or fire benefit attributes vary significantly with respect to their influence on fire resiliency.

This variance is reflected in the point value of the attributes. When a range of points is encountered in the Point Range column, caution should be exercised when determining the point value entered in the Value column. The higher the number selected, the more significant the impact on fire resiliency. An attribute with a positive value, black numbers in the Point Range column, indicates that it increases the fire threat to structures. These attributes, whose presence contributes to the threat of lost structures during interface fires, are located throughout the Fire Profile Index. Inversely, the higher the number an attribute has, the more it benefits the fire resiliency of the structure. A negative value listed in red numbers in the Point Range column indicates a beneficial attribute. The majority of the beneficial fire protection characteristics are listed under “Beneficial Construction”, “Beneficial Landscaping”, and “Fire Protection”; however, there are beneficial factors listed elsewhere as well.

If the user believes an attribute has a relatively greater influence on fire resiliency than expressed in the point range/stated value, then a point value outside the suggested range/stated value may be entered in the Value column. Discretion should be exercised in selecting values outside the suggested point ranges and stated point values, as a distorted appraisal of the fire resiliency of the particular structures may result. Further, if a user cannot determine the specific point value from the range of points, then a midrange value selection is appropriate. To illustrate the selection of a midrange value, the example structure has a mildly pitched gabled roof, and the midrange point value selected is 10 points, which is entered in the Value column. The third row down the Fuels group is the Roof Shape attribute, and it has a point value range of 1 to 20 points. In this case, the user can not determine the severity of the airflow turbulence generated by the roof shape, and consequently a midrange point value of 10 is appropriate. The Fire Profile Index is designed to provide a suitable evaluation of the fire resiliency of a structure by selecting a midrange value from the Point Range, while allowing discretion to be used by knowledgeable persons.

There are several Fire Profile Index attribute choices that are optional entries.

These optional entry attributes are exceptional characteristics that have a profound impact on the fire resiliency of a structure, and may not be present at individual evaluation sites. The optional entries are identified by gray background in the Subgroup or Attribute column, and gray background in the Point Value column. These optional entry attributes can either be a fire resiliency benefit or impairment. As an example, the attribute of a combustible roof within the Structures subgroup has a Point Range value of 300 (see the third row of Table 5.1). If a structure within a defined fire hazard severity zone has a combustible roof, then 300 points are entered in the Value column. Combustible roofs, if still existing, in a WUI setting are the principal contributor to the failure of structure fire resiliency (Wildland/Urban Interface Fire Working Team 1997). The 300 point rating is the highest rating of any attribute within the Fire Profile Index. The 300 points credited in the Value column will automatically move the structure one whole classification upward, as for example from a Category II to Category III. In this example, only one optional entry attribute rated, “High voltage wires” applied. High voltage electrical wires are an attribute within the Special Hazards Group. For this example, it is assumed that there are high voltage electrical lines within a quarter-mile of the residence, and therefore five (5) points were entered into the Value column (see, Table 5.1). The Fire Profile Index is designed to provide simplicity and flexibility, as the preceding examples indicate. A person knowledgeable of WUI area fire problem can easily use the index to evaluate structure fire resiliency. With careful attention to detail an increased assessment accuracy of the fire threat can be achieved.

5.1.4 STRATEGY CODES

The strategy codes are a list of 17 mitigating measures for improving the fire resiliency of building structures. There are 17 individual strategy codes listed in the fourth column of the Fire Profile Index. Each Strategy Code is designated by a circled number (i.e. ①) followed by a short definition of the code. For any attribute, whether it represents a threat or benefit, there may be multiple strategy codes listed, indicating that there may be a combination of factors working in conjunction as mitigating measures.

The strategy codes can be found in Appendix I as Figure I.2, and in this chapter as Figure 5.2. Each of the strategy codes is listed with its numerical identification and definition. An explanation of the strategy codes follows:

- ① ***Limit Ember Intrusion:*** A primary cause of a structure that is substantially WUI substantial code-compliant burning has been identified as the intrusion of embers into the structure (Institute for Business and Home Safety 2008). Ember intrusion can occur in concealed spaces, attics, roof underlayment, architectural features, and interior spaces. All of these areas require additional protection.
- ② ***Structure Safety Zone:*** These are areas of defensible space that are double the flame length, of the predicted worst-case fire behavior factors, predicted on all sides of a structure. The concept of Structure Safety Zones is developed in Chapter Six.
- ③ ***Fuel Modification/Defensible Space:*** Assures that the adequate defensible space criteria is met. This increase may be beyond code requirements due to such factors as terrain-influenced fire behavior. Defensible space is a crucial to structure interface fire survival, second only to noncombustible roofs (Brown 1994).
- ④ ***Provide Structural Fire Shields:*** Fire Shields are an effective fire resiliency mitigating measure, and are treated in Chapter Nine.
- ⑤ ***Lower Wind Turbulence of Building Envelope:*** Involves the concept of limiting the turbulence caused by the shape of the building envelope. Contributing structural components include walls, roof, and other architectural features.
- ⑥ ***Lower Fire Profile Index Value:*** An encompassing term derived from use of a combination of strategies listed within the Fire Profile Index to increase the fire resiliency of structures.

- ⑦ ***Establish Adequate Egress:*** Safe resident egress and first responder access may be ensured by a number of factors (i.e., modified traffic flow, pavement width, minimal road grade, straightness and driveway turnouts)
- ⑧ ***Adequate Water Supply:*** Includes sufficient fire flow characteristics such as quantity, residual pressure, firefighting access to water supply and system reliability.
- ⑨ ***Cleanup Litter/Leafs:*** The defensible space maintenance activities that are intended to reduce the amount of highly combustible dry lighter fuels, breakup the ground fuel basis of fuel ladders, reduce ember production and ember reception, and the transference of fire to structures.
- ⑩ ***Independent Fire Water Supply:*** An adequate emergency water supply independent of any existing municipal water system. An independent water supply includes fire authority-approved methods of delivery from stored water to water systems to backup power for fire pumps.
- ⑪ ***Limb-up Trees/Bushes:*** Clearance of limbs and branches from the ground to a minimum of six feet in an effort to prevent crown fires and breakup potential fuel ladders. Also, this process reduces ember production and lessens the fuel load.
- ⑫ ***Provide Adequate Separation:*** An effort undertaken to prevent fire exposure to structures from adjoining fuels, including structures. A minimum of 45 feet of separation from adjoining structures and heavier fuels is recommended (Cohen 1995, Cohen 1999-A).
- ⑬ ***Remove Plants:*** Vegetation management meant to eliminate plants that contribute fuel to fire spread, thereby reducing the fuel load.

- ⑭ ***Reduce Quantity:*** Vegetation management designed to reduce the fuel load within defensible space and vegetation management areas.
- ⑮ ***Shelter-In-Place:*** A practice of providing a fire safe refuge for residents, in locations approved by the local fire authority.
- ⑯ ***Take Advantage of Benefit:*** A Fire Profile Index attribute or mitigating measure, that will have a beneficial impact on a the fire threat of a structure.
- ⑰ ***Noncombustible/Fire Resistive Construction:*** An indication that noncombustible construction and/or fire-resistive construction is recommended as a mitigating measure.

5.1.5 SELECTED COMMENTS

The Fire Profile Index reflects the author's fire service experience and research into the fire resiliency of structures threatened by interface fire. A few of the attributes are worthy of mention for a deeper understanding of their complex interactions. The "Fuels" group of the Fire Profile Index contains several assessment items that contribute fuel, or otherwise enable fire spread. This group of hazards includes structural components that will ignite easily and burn readily. Four of these items have a significant influence that warrants special mention. First, structures contribute significant fuel loading, as much as 300 times that of natural fuels (National Wildland Coordinating Group 1990). Second, structures rather than vegetation have been repeatedly designated as the primary source of fire spread (Institute for Business and Home Safety 2008). Third, combustible roofs, located within an interface area, are the greatest contributor to the fire resilience failure of structures (Wildland/Urban Interface Fire Working Team 1997). Fourth, the proximity of structures to fuel is a crucial consideration for fire resiliency. Studies have shown that radiant heat and flame impingement from a burning structure or other fuels can easily ignite adjoining structures (Cohen 1995; Cohen 1999-A).

The Fire Profile Index assesses 60 points for structures that are located within 30 feet of each other. This number of points assessed for close structure proximity is the fourth highest number of points in the Fire Profile Index. Structures contributing to the spread of interface fire is a significant consideration in evaluating the WUI fire threat.

After combustible roofs, defensible space or fuel modification is the second most significant contributor to the failure of a structure's fire resiliency (Brown 1994). A study of the 2003 Cedar Fire in San Diego, California revealed that 90% of the surviving structures had flammable vegetation removed within 30 feet. Additionally, supporting data from the 1981 Atlas Fire in California indicated that 95.5% of the surviving homes had brush clearance around structures (Kent 2005). A minimum of 100 to 200 feet of defensible space may be warranted in a typical WUI setting (Los Angeles County Fire Department 2010). The Fire Profile Index recognizes the benefit of increased defensible space by allowing a 40-point reduction for defensible space exceeding 100 feet. The index incorporates the impact of inadequate defensible space by an assessment of 200 to 300 points, which is sufficient to move a structure up one entire category of increased fire danger. Consequently, inadequate defensible space is a significant indicator of structure fire resiliency, and the Fire Profile Index recognizes this relationship.

The Fire Profile Index recognizes the importance of fire threat mitigating measures by allowing point reductions. There are nearly 100 attributes included in the Index that represent beneficial impacts on interface fire threat. These attributes vary in their impact on fire resiliency, and corresponding point value. Increased defensible space, which can provide a 40-point reduction, was mentioned previously. Natural fire breaks (i.e. rivers, rock outcroppings), fire authority produced fuel breaks and development landscaping (i.e., orchards, parks, cemeteries) are in point parity with defensible space. An appropriate and properly installed Structure Fire Shield (Chapter Nine) is allocated a point reduction of 150 points. A High Profile Structure Fire Shield produces a 250-point benefit in the Index point total. A Structure Safety Zone, discussed in Chapter Six, represents another 250-point reduction.

The fire point value impact of combining a High Profile Structure Fire Shield with a Structure Safety Zone is 500 points, which is a sufficiently significant reduction under most circumstances to place a structure within a Category I fire resiliency category. It is the author's opinion that it is highly probable that the combination of these two mitigating measures should allow a structure to survive a fire storm in a "stand alone" fashion (i.e., without aid of fire personnel or others).

5.2 FIRE ASSESSMENT GUIDE

The Fire Assessment Guide is derivative of the Fire Profile Index. Its purpose is to assess the fire threat affecting structures and firefighter safety in WUI fire situations. It is a compilation of 38 items that evaluate fire potential and structure fire resiliency. Figure 5.3 shows the beginning and ending sections of the Fire Assessment Guide. Due to its length and formatting, the remainder of the assessment guide is found in Appendix J, as Figure J.1. The items that evaluate fire threat include flame length, burning intensity, and fire spread. The assessment of structure fire resiliency is determined by the likelihood of a structure withstanding a severe interface firestorm. Firefighter safety is concerned with adequate defensible space and the possible use of the property as an escape zone.

The Fire Assessment Guide has been designed to aid in assessing fire resiliency at any scale; an area as large as an entire subdivision, or as small as a single structure. The fire modeling and wind modeling programs discussed in Chapters Three and Four form the basis of the Fire Assessment Guide. In addition, research performed by the author is fundamentally integrated into the Guide. The intended users of the Fire Assessment Guide are firefighters and persons with a fundamental understanding of fire behavior. Additionally, planning and design professionals can benefit from using this guide for determining the fire threat of any area of concern.

The first column of the Fire Assessment Guide is termed “Category”, and includes six groups of assessment factors: Development; Fuels; Weather; Terrain; and Mitigating Measures. The different groupings within the Category classification vary with respect to their impact on fire behavior and on mitigating measures. In the second column, termed “Subcategory”, each group is further divided into attributes for evaluating purposes. Each subgroup has multiple attributes that are listed in the third column, titled “Attributes”. An assessment item or attribute is assigned a unit value of plus or minus. The fourth column, entitled “Subcategory/Attribute Definition”, contains descriptions of attributes as a guide to selecting the appropriate attribute value.

**TABLE 5.3: FIRE ASSESSMENT GUIDE
INITIAL AND END SECTIONS**

Category	Subcategory	Attribute	Subcategory/Attribute Definition	+	-	--
Development						
Development	Hazard Zone	Medium	Fire Authority designated medium (least severe) fire hazard severity zone	+		
		High	Fire Authority designated high (middle severity) fire hazard severity zone		-	
		Very High	Fire Authority designated very high (most severe) fire hazard severity zone			--
	WUI Building Code	Non-Code Compliant	Area not subject to provisions of WUI building code & ordinances			
		Compliant	Area subject to provision of WUI code before 2003		-	
		Compliant	Area subject to provision of 2003, or newer WUI code or newer	+		
	Structure Separation	< 30' Separation	Structures with < 30' separation from other structures & other heavy fuels			--
		30' to 45' Separation	Structures with 30' to 45' separation from other structures & other heavy fuels		-	
		> 45' Separation	Structures with > 45' separation from other structures & other heavy fuels	+		
	Structure Density	High Density	> 100 Structures per square mile			--
		Medium Density	20 to 100 Structure per square mile		-	
		Low Density	< 20 Structures per square mile	+		
Fuels						

Category	Subcategory	Attribute	Subcategory/Attribute Definition	+	-	- -
Terrain	Solar Aspect	South & West	Structures located on west & south facing slopes			- -
		East	Structures located on east facing slopes		-	
		North	Structures located on north facing slopes	+		
Mitigating Measures						
Mitigating Measures	Defensible Space	Structure Safety Zone	Increased defensible space > 2X flame length of worst case scenario	+ 10		
	Structure Fire Shields	Standard	Low Profile Structure Fire Shield appropriately installed	+ 5		
		High Profile	High Profile Structure Fire Shield appropriately installed	+ 10		
	Other		Fire Agency Approved systems (i.e. Foam Systems, Reflective Material, Deluge)	+ 5		
Totals						

The fifth column, “Point Range”, includes three value categories: a green Plus Sign (+), an orange Negative Sign (-), and a red Double Negative Sign (- -). Many of the attributes have varying levels of intensity, such as high, moderate, or low. When there is an choice of unit value present, the user selects the appropriate level of intensity, with its corresponding unit value. Near the bottom of the Plus Sign column are four mitigating measures with either plus five (+5) or plus ten (+10) values. These higher numerical values indicate the relative effectiveness of the mitigating measures.

The unit value accumulation of pluses and minuses within the Fire Assessment Guide is a straightforward procedure. Initially, the unit value of the pluses, minuses, and double minuses of each column are totaled. Then the pluses, minuses and double minuses are combined to arrive at a single value, expressing the fire threat of the area of concern. A minus has the same unit value as a plus, and their sum when combined is a zero unit value. A double minus has twice the unit value of a minus or a plus. The cumulative value of the pluses and minuses and double minuses of the Fire Assessment Guide has a range from minus 56 to plus 44. The plus 44 value would require significant contribution from the positive impact of mitigating measures, and would require the structure or development to be located in a low fire threat environment.

Once a cumulative value has been obtained, the interpretation of this value falls within the following guidelines. A total unit value below 15 minus points places a structure or development in Category I. A Category I classification indicates that the fire behavior and mitigating measures for fire resiliency will likely be maintained throughout a severe firestorm, and the property could be used as safe escape zone for firefighters. A unit point value between 16 and 30 minus points classifies a structure or development as a Category II. Within a Category II, the fire behavior and/or mitigating measures are likely to produce a fire environment in which the structure or development would be expected to survive a severe interface firestorm with the aid of trained and properly equipped personnel. Furthermore, the property may provide a safe escape zone for firefighters.

A total value exceeding minus 30 indicates that the structure is unlikely to survive a severe firestorm, even with the aid of trained firefighting personnel, thus categorizing it as a Category III. A Category III assessment indicates that the structure will likely be a “write-off” in a structure triage situation (Section 2.1 of Chapter 2). Additionally, a Category III environment poses a significant threat to the safety of firefighting personnel. The preceding categories are designed to be general, flexible, and used with discretion. They are meant to provide an understanding of the fire threat to firefighters and structure interface fire resiliency. The Assessment Guide is not intended to be used to replace standard firefighting safety precautions, but to augment them by increasing situational awareness.

An accurate unit value reflecting the worst-case scenario for each fire threat assessment attributes is an essential prerequisite for the usefulness of the Fire Assessment Guide. The determination of the worst-case fire threat is based on weather, terrain, and fuel fire behavior variables. A wildland fuel type, indicated by the natural predominate vegetation in the area of concern should be determined by a person knowledgeable of fuel types. Any of the nationally recognized fuel type classifications could be used; i.e., the *National Fire Danger Warning System Fuel Classification* (Deeming et al. 1977); or the *National Forest Fire Laboratory (NFFL)*, also known as the “Original 13 Fuel Models”, which is updated in *Aids to Determining Fuel Models For Estimating Fire Behavior* (Anderson 1982); or the newer *Standard Fire Behavior Fuel Models: A Comprehensive Set for Use with Rothermel’s Surface Fire Spread Model* (Scott and Burgan 2005). Once the fuel type has been determined, then the live fuel and dead moisture factors should be determined. Following the selection of the fuel type a determination of the level of fuel moisture, fuel loading, dead percentage, and continuity can be made. A similar process should be followed in the case of cultivated fuels. Following the preceding procedures, the appropriate unit value for each of these fuel factors can be determined. Fuel-related attributes are most influential in determining the threat of non-wind-driven fires. Flame length, energy release and spotting potential are chief concerns for firefighter safety (Tele 2005), and are directly related to fuel factors.

Weather information for use in selecting Fire Assessment Guide values should be gathered from the weather service or fire authority to determine the historical worst-case scenario. Temperature, relative humidity and wind event conditions, including speed and direction are the minimum factors to be considered. Wind event conditions are associated with the loss of large numbers of structures in fires and firefighter injuries (Fovell 2008; Tele 2005). A foehn wind or cold front movement can drastically change fire behavior. Foehn winds are discussed in Chapter Two, Section 2.3.2. Cold fronts during fire season, are a weather phenomenon more common outside Mediterranean Climate areas (Fovell 2008). Real-time weather information can be obtained online from the National Weather Service, or from fire incident weather, or from a portable weather kit. If high winds or sudden wind shifts are predicted, then necessary precautions should be taken for personnel safety (Tele 2005), and adjustments made for structure protection.

To determine the Fire Assessment Guide values for topography, such as slope, aspect, saddles and chimneys, topographical maps may be used. This information should be augmented by onsite observations. Terrain influences have a significant affect on structure fire resiliency and firefighter safety. The third most significant structure-survivability predictor, after noncombustible roofs and defensible space is slope steepness (Brown 1994). Structures on south and southwest-facing slopes are typically exposed to higher fire danger, and in particular, steep slopes will exacerbate the fire protection problem. A setback of 30 feet from a sloping edge is a nationally recognized standard (Cohen 2000; Radtke 2004; National Fire Protection Association 2008-A). This distance may be inadequate when the slope is coupled with terrain features such as a chimney effect or saddle (Los Angeles County Fire Department 2010). The Los Angeles County Fire Department reviewed structures burned along ridge lines, and concluded that homes located in terrain where a canyon meets a ridge (a chimney) are far more likely to burn than other ridge top structures (Los Angeles County Fire Department 2010). Additional information on terrain features and their affect on fire behavior are discussed in Chapter Two, Sections 2.4 to 2.4.4 and Chapter Four, Sections 4.5 to 4.5.4. To combat this threat, the identification of the particular threat of a saddle or chimney to structures should be determined onsite.

After the identification of a terrain based fire threat, tactical adjustments affecting the survivability of a structure and firefighter safety can be facilitated.

5.3 DEVELOPERS GUIDE

The Developers Guide along with the Fire Assessment Guide is a derivative of the Fire Profile Index. The Developers Guide assists in increasing the fire resiliency of structures in WUI areas through the appropriate application of construction and design features. It is a compilation of 100 items of structural design, methods of construction, defensible space provisions, and mitigating methods that promote fire resiliency. Figure 5.4 shows the entire Developers Guide. The guide is in a checklist format, so that several items of concern can be viewed simultaneously. The Developers Guide is a tool intended for use by design professionals, architects, developers and planners. Additionally, the Developers Guide could be used as a training aid by firefighters during pre-action assessments of structure fire threats. In summary, the Developers Guide is intended to be an aid for improving the fire resiliency of retrofit projects, the post-fire rebuilding of structures, and for new structures in the WUI areas.

The objective of the Developers Guide is to increase awareness of the fire resiliency of buildings, and to establish a design reference for increased fire safety in interface fire prone areas. The most significant contribution may be to fire safety in retrofitting existing structures and the post-fire rebuilding of structures in areas prone to interface fires. The Developers Guide is a compilation of design and construction factors essential for determining the fire resiliency of structures. As a subset of the Fire Profile Index, and the Guide suggests design, construction, and building features that are known to enhance fire resistiveness. Also, included in the Developers Guide are the characteristics that contribute to the burning potential of a structure.

The first column of the Developers Guide is termed “Category”, and includes five groups of fire resiliency factors: Construction Features; Landscaping Features; Beneficial Construction; Beneficial Landscaping; and, Mitigating Measures. The first two categories of “Construction Features” and “Landscaping Features” are a watch-out list of problem areas related to design, construction, and landscaping issues.

**TABLE 5.4: DEVELOPERS GUIDE,
INITIAL AND END SECTIONS**

Category	Subcategory	Attribute	Subcategory/Attribute Definition
Construction Features	Problems Areas		
	Building Envelope		
☐		Trapped Airflow	Overhangs on flat surfaces
☐		Alcoves	Room or wall protrusions from axis of structure
☐		Combustible Decking	Increases turbulence below decking, increases ignition possibility & increases fuel loading
☐		Second Story Decking	Increases turbulence below decking, increases ignition possibility of adjacent portion of structure
☐		Solar Shading	Combustible shading (i.e.sun screens, porches, awnings)
☐		Windward Angular Surfaces	Wall facing windward/fire exposed side increases wind pressure & turbulence
☐		Large Floor Areas	Structures with floor area over 1600 square feet
☐		Crawl Spaces	Accessible areas where upright walking is impossible
☐		Concealed Spaces	Walled-in areas not accessible
☐		Porches	Increases wind turbulence
☐		Raised Foundations	Allows embers and brands under house
☐		Venting	Unprotected vents for attic, floor, & concealed spaces allow ember intrusion
☐		Soffit Vents	Allows embers into confined spaces
☐		Multistory Structures	Increases surface area exposed to air movement & greater wind pressures

Category	Subcategory	Attribute	Subcategory/Attribute Definition
☐			
Mitigating Measures			
☐	Defensible Space	Structure Safety Zone	Minimum of 2X flame length distance of defensible space each side
☐	Fire Spread Inhibitors	Structure Fire Shield	Noncombustible walls/berms effectively placed to protect structures
☐	Ember/Fire Inhibitors	Lipped Walls	Noncombustible walls with outward-facing rounded overhand at top
☐	Shelter-In-Place	Occupant Fire Shelters	Safe fire resistant areas with adequate ventilation, lighting, power
☐	Structure Coverings	Foam	Application of foam fire barrier on structure exterior
☐	Structure Coverings	Reflective	Application of reflective foil on structure exterior
☐	Structure Coverings	Insulation	Application of insulating noncombustible material on structure exterior
☐	Fire Extinguishment	Fire Sprinklers	Automatic fire sprinklers for interior & exterior application
☐	Fire Extinguishment	CAF Systems	Compress Air Foam systems that are applied to exterior of structures
☐	Fire Extinguishment	Water Application	Ability of fire agencies & occupants to apply water from stored supply
☐	Fire Extinguishment	Extinguishment System	Stored water with pump, independent power supply & equipment for application
☐	Fire Detectors	Flame/Fire Detectors	Flame and fire detector with independent power supply
☐			

Construction and landscaping features in these first two groups represent items that are threats to fire resiliency. The subsequent three categories are composed of mitigating measures that increase the fire resiliency of structures. The “Category” column has a check-off box inserted on the left-hand side. The check-off box is intended to facilitate the identification of any noteworthy feature from the development point of view. The check-off box can be checked if the user thinks the item is of concern. If problem areas are identified, then the mitigating measure portion of the Developers Guide should be referenced for possible remedies. Additional mitigating measures are located in the Fire Profile Index.

In the second column, termed “Subcategory”, each group is divided into several subgroups of fire resiliency factors. Each subcategory more often than not, has multiple attributes that are listed in the third column, entitled “Attributes”. In the fourth column, titled “Subcategory/Attribute Definition”, is a description of an attribute offering insight into its effect on fire resiliency. On the bottom of each “Subcategory” bracket a blank row is provided for notes and/or addition of attributes. Likewise, there are three blank rows at the very bottom of the Developers Guide for additional notes, or the entry of attributes.

Individual design, construction and building features known to enhance fire-resistiveness, and those features known to increase burn-ability are also listed in the Developers Guide. Probably the worst-case scenario of fire threat factors should be used for the design and construction of buildings in WUI areas. Fire threat attributes or fire benefit attributes vary significantly with respect to their influence on fire resiliency. Those attributes that contribute to the threat of structures burning during interface fires, are located in the beginning portion of the Developers Guide in the “Construction Features Problem Areas” and “Landscape Features Problem Areas” sections. The beneficial fire protection characteristics are listed under “Beneficial Construction”, “Beneficial Landscaping”, and “Mitigating Measures”. The Developers Guide does not make a distinction between degrees of impact of an attribute on fire resiliency.

The Fire Profile Index, should be referenced as an aid for determining an attribute's relative influence on fire resiliency. The use of the Fire Profile Index and its derivatives by architects, developers and planners is intended to contribute towards improving fire safety in WUI areas prone to fire.

CHAPTER SIX

6.1 STRUCTURE SAFETY ZONES

6.1.1 INTRODUCTION

The California Emergency Management Agency indicates in its publication, *State Multi-Hazard Mitigation Plant*, that fuel reduction through vegetation management, combined with ignition-resistant construction, is crucial for creating appropriate defensible space (California Emergency Management Agency 2010). Structure Safety Zones are a method of determining whether the defensible space is adequate. They are areas of sufficient defensible space that should allow an ignition-resistant structure to survive a severe interface firestorm, without the intervention of trained firefighters. After combustible roofs, inadequate defensible space or inadequate fuel modification is the second most significant contributor to the failure of fire resiliency (Brown 1994).

Recognizing defensible space as a significant feature of fire resiliency is a notable principle of this thesis. The Fire Profile Index of Chapter Five highlights the benefit of increased defensible space by allowing a 50-point reduction for defensible space exceeding 100 feet. The index incorporates the impact of inadequate defensible space by an assessment of 200 to 300 points, which is sufficient to move a structure one entire category of increased fire danger. Conversely, the presence of a Structure Safety Zone reduces the total point value of the Fire Profile Index by 250 points. This 250-point movement can shift a structure one category safer in the fire resiliency classification of the Fire Profile Index. The fire resiliency categories are elaborated in Chapter Five (Sections 5.1.2 and 5.1.3).

In 2005, a retroactive increase of defensible space in fire-prone areas, from 30 feet to 100 feet minimum, was legislated in California (State Board of Forestry and Fire Protection 2006). The 100-foot minimum includes the Defensible Space Zone extending 30 feet from the structure. In this zone, the vegetation should not transmit fire to a structure. The Reduced Fuel Zone continues outward from 30 feet to 100.

This zone contains vegetation that will not readily communicate fire into the Defensible Space Zone or to structures. For ease of description, this thesis defines defensible space as being a combination of the Defensible Space Zone and the Reduced Fuel Zone. For elaboration of these terms, refer to Chapter Two, Sections 2.5.1, Defensible Space and 2.5.2, Vegetation Management.

Also in 2005, the State of California approved new building codes calling for greater ignition-resistant requirements for roofs, vents, siding, and decking (Miller 2007). Nonetheless, interface firestorms continued to burn hundreds of homes annually in spite of stringent WUI building code requirements and increased defensible space. As an example, in 2008 and 2009, nearly 335 homes burned in the Santa Barbara area of Southern California (Ford 2008). A significant number of the burned structures were both California- and local jurisdiction-code compliant, having a minimum of 100 feet of defensible space and ignition-resistant construction. Scores of structures burned in spite of their compliance. The Structure Safety Zones section addresses this issue with the objective of reducing this type of loss.

Nationally recognized leaders in the field of WUI structure survivability have stated that 100 feet of defensible space may be inadequate, suggesting that a 200-foot minimum of defensible space is necessary. The National Fire Protection Association in *NFPA 1144* requires extending defensible space to 200 feet when intense fire potential exists, as evidenced by the existence of heavier fuels (National Fire Protection Association 2008-A). The Los Angeles County Fire Department also recommends increasing the Reduced Fuel Zone from the legal minimum of 100 feet to 200 feet for improved fire protection (Los Angeles County Fire Department 2010). While the benefit of an increased fuel reduction distance may result in a typical flame length for the fuel type, the amount and duration of the heat output will be significantly reduced (County of Los Angeles Fire Department 2010). This reduction in heat output results in an increase of structural survivability.

Properties with greater fire hazards, such as heavier fuel loading, steep slopes, and chimneys, may require more defensible space than the Los Angeles County Fire Department and the National Fire Protection Association recommend. Structure Safety Zones will not only increase structure survivability through increased defensible space, but will also help to increase occupant and firefighter safety. Additionally, more defensible space allows firefighters to protect structures, without facing unacceptable risks to their lives (State Board of Forestry and Fire Protection 2006). The preceding statements allude to the recognition that the present approach of “one size fits all” in respect to defensible space does not adequately address all fire situations in WUI areas.

6.1.2 DESCRIPTION

Adequate defensible space, as determined by Structure Safety Zones, initially involves a site-specific evaluation of the fire threat posed to structures. The Structure Safety Zones defensible space distances are calculated by the greatest flame length possible on each dissimilar hazard side of the structure, and adding 100 feet to that distance. If the calculated flame length exceeds 100 feet, then the flame length is doubled. The calculation of flame lengths include several fire behavior factors, such as variations in topography, airflow, relative wind direction to uphill slope, and fuel. These conditions exist in differing combinations and impact on fire behavior relating to structures. The fire behavior variable factors needed are selected from the extreme range, comparable to the 97th percentile if the data were analyzed, of historic unfavorable fire danger records of weather, including temperature, relative humidity, wind gusting speed and direction. For fuels, the selection of live and dead fuel moisture should be based on the similar extreme range of historic records. The dominant fuel yielding the greatest flame length should be determined, and used in the flame length calculations. The topography factors include slope percentage, aspect, and presence of special terrain influences of chimneys and saddles. Also, the relative alignment of fire winds to uphill slopes should be included in the flame length calculations. Figure 6.3 illustrates the use of worst-case fire behavior weather and fuel factors from Case Study Three.

The adding of 100 feet of defensible space is supported by the fact that structure ignitions are rare when structures are over a distance of 100 feet from flames (Cohen and Butler 1998). Additionally, research by Jack Cohen and Bret Butler in “*Modeling Potential Structure Ignitions from Flame Radiation Exposure with Implications for Wildland/Urban Interface Fire Management*”, indicate that a distance of 120 feet was sufficient to prevent radiant heat ignitions to structures from fire with 20-foot flame heights (Cohen and Butler 1998). The doubling of the flame length to determine the defensible space distances that apply when flame lengths exceed 100 feet is the result of adding a safety factor. The increased distance is a safety factor needed for two reasons. The first is that possible errors or underestimations of flame lengths, caused by unforeseen fire behavior factors can occur. The second, is that greater radiant heat flux values are yielded when extreme flame lengths are present (Cohen and Butler 1998).

6.1.3 DETERMINATION OF STRUCTURE SAFETY ZONE

A fundamental knowledge of structure fire resiliency and fire threats are desirable before flame length calculations are performed. A broad perspective of fire resiliency and fire threat can be obtained from the Fire Profile Index, Developers Guide, and Fire Assessment Guide, all of which are discussed in Chapter Five. Once a sound perspective of the fire behavior of a site has been gained, the flame length calculations may be performed. The calculations of flame lengths can be derived from computer modeling programs (discussed in Chapter Three and applied in Chapter Four), or manual methods, as described in the *Fireline Handbook Appendix B: Fire Behavior* (National Wildland Coordinating Group 2006). The first step in determining flame length requires the selection of several fire threat directions from various fire hazard locations surrounding the structure. Figure 6.1 illustrates the determination of fire threat directions drawn on an aerial photograph of Case Study Three. For the existence of special terrain features, such as chimneys and saddles, and then the multiplying by conversion factors from Chapter Four, Table 4.13, Fire Behavior Analysis should be applied to the applicable flame lengths.

Figure 6.1: Case Study Three Structures with Wind and Fire Spread Directions.
(<http://maps.google.com>)

Following the calculation of flame length with the aforementioned methods the distances derived from the flame length calculations plus the radiant heat protection distances then become the Structure Safety Zones measurements. These distances are then applied outward from the structure to the corresponding specified locations from which they were derived. Defensible space boundaries are then formed by lines connecting the directional points, as depicted in Figure 6.4. This process is described in detail in Section 6.14, which uses Case Study Three as the example.

6.1.4 CALCULATION EXAMPLE

The Case Studies Three structures and the fire conditions, existing during the Green Meadows Fire, are the examples used for determining a Structure Safety Zone.

This example was selected because of the presence of special terrain features, and the author's familiarity with the structures and fire environment gained from compiling Case Study Three. An aerial photograph of the structures and surrounding terrain are shown in Figure 6.1. In Figure 6.2, contour lines have been added to identify slope percentages, and the special terrain features of a saddle and a chimney. An enhanced illustration of the chimney, on the east side of the case study structures, and of the saddle is depicted in Figure 4.9, located in Chapter Four. Both Figures 6.1 and 6.2 have several possible dissimilar fire hazard locations identified by a direction and number (i.e., Direction #1). The possible dissimilar fire hazard locations were chosen with consideration given to the presence of special terrain features and knowledge of foehn wind events in the area causing wind-driven fires.

The special terrain features of the Case Study Three example have a significant influence on the airflow. The terrain consists of a saddle and chimney combination on both the east and west sides of the structure. The predominant airflow, including winds, would be channeled through the saddle, and intensified in velocity and turbulence as it passes through (National Wildland Coordinating Group 1994). During fires, the airflow will direct and concentrate the flames and embers with through the saddle. The foehn winds occurring in the region where Case Study Three exists are called East Winds, because they blow from east to west (Gonzales 2010). The East Winds are part of the foehn wind events occurring in Southern California, called Santa Ana Winds (Fovell 2008; Ryan 1991). Foehn winds and their effect on fire behavior are discussed in Chapter Two, Section 2.3.2. In the Case Study Three example this wind direction, and the presence of a combination of a chimney and a saddle, with its accompanying conversion factor of 2.5 (line 14, Special Terrain Features of Table 6.3) is the explanation why the flame length calculations for Directions #1 through #3 are 200 feet (line 15, Flame Length of Table 6.3).

*Figure 6.2: Case Study Three with Contour Lines, Wind and Fire Spread Directions
(gis/library.calpoly.edu)*

Also, the East Wind events influence the airflow on the west side of the Case Study Three example structures. The locations of fire threat Directions #4 thru #6 were significantly influenced because of the saddle and the accompanying chimney on the west side of it. During periods of dangerous fire weather the East Wind events are in effect. A strong onshore or westerly recovery wind occurs following an East Wind events. The recovery winds reverse the flow of the foehn wind events (Fovell 2008), and have been recorded in the 15 to 30 miles per hour range (Crosby 1996). The recovery wind velocity range was taken from records of the Calabasas Malibu Fire of 1996, which was a similar fire to the Green Meadows Fire in terms of fuel, terrain, weather and location. The wind velocity, occurring during the Green Meadows Fire, is the wind used for the easterly fire threat direction. The recovery wind velocity is the wind initially used for the westerly fire threat direction.

The Case Study Three structures were protected by a more than 30-foot setback from the steep slope on the west side. The flames, stopped before they reached the level of the structures, which were shielded from the radiant heat of the flames by the steep slope itself (Cohen and Butler 1998). These structures were also protected from convected heat and embers by the steep slope setback. A setback of 30 feet from a sloping edge is a nationally recognized standard (Cohen 2000; Radtke 2004; National Fire Protection Association 2008-A) is further supporting evidence that the setback protected the structures.

*TABLE 6.3:
STRUCTURE SAFETY ZONE CALCULATIONS*

Fire Behavior Factor	Direction #1	Direction #2	Direction #3	Direction #4	Direction #5	Direction #6
Weather						

Fire Behavior Factor	Direction #1	Direction #2	Direction #3	Direction #4	Direction #5	Direction #6
Temperature	100° F	100° F	100°F	100° F	100° F	100° F
Relative Humidity	10%	10%	10%	10%	10%	10%
Wind Speed	40 mph	40 mph	40 mph	15 mph	15 mph	15 mph
Wind Gusts	55 mph	55 mph	55 mph	30 mph (55 mph)	30 mph (55 mph)	30 mph (55 mph)
Wind Direction	70-75° NE	80-85° E	40-45° NE	250°-255° WSW (80-85°)	270-275° W (80-85°)	310°-315° NNW (80-85°)
Terrain						
Percent Slope	65%	65%	65%	110%	110%	110%
Aspect	NE	E	SE	W	W	NW
Wind:Slope Variance	15°	15°	15°	15° (180°)	15° (180°)	45° (100°)
Fuel						
Anderson Fuel type	4	4	4	4	4	4
Live Fuel Moisture	77%	77%	77%	77%	77%	77%
Flame Length						
BehavePlus Flame Length	92 Feet	92 Feet	92 Feet	62 Feet (80 Feet)	62 Feet (80 Feet)	62 Feet (80 Feet)
Wildland Tool Flame Length	95 Feet	95 Feet	95 Feet	70 Feet (81 Feet)	70 Feet (81 Feet)	70 Feet (81 Feet)
Special Terrain Influence	2.5	2.5	2.5	none	none	none

Fire Behavior Factor	Direction #1	Direction #2	Direction #3	Direction #4	Direction #5	Direction #6
Calculated Flame Length	238 Feet	238 Feet	238 Feet	65 Feet (81 Feet)	65 Feet (81 Feet)	65 Feet (81 Feet)
Structure Safety Zone Distances	476 Feet	476 Feet	476 Feet	181 Feet	181 Feet	181 Feet

Additionally, the East Wind flame and ember dispersion is increased on the west side of saddle, thereby not allowing a channeling effect of airflow to occur on the east side of the saddle. Consequently, there is not a special terrain influence of the saddle influencing fire behavior. The multiplying effect of the computed flame length for a special terrain feature is inapplicable. The opposite of the setback shielding effect can occur on the uphill side of a structure. A structure can be exposed to the increased radiant exposure of an extensive flame area on its uphill side (Cohen and Butler 1998). This is the case on the western side of Case Study Three structures. Consequently, there is a 2.5 flame length multiplying factor for the flame lengths from the easterly directions. The East Winds carry the convected heat, smoke, and embers in a westerly direction causing the most significant fire problem to be from the east.

The bottom row of the Structure Safety Zone Calculations, Table 6.3, is the “Structure Safety Zone Distances”. The Safety Zone distances are the sums of the flame lengths plus the defensible space distance of 100 feet, or double the flame length, depending on whether the flame lengths are greater than 100 feet.

Figure 6.4: Case Study Three with Structure Safety Zone Outline
(<http://maps.google.com>)

Table 6.3 includes the flame length entries from two fire behavior modeling programs, BehavePlus 5 and Wildland Tool Kit. These computer-generated flame lengths are listed in individual rows of the table. The greater of the flame lengths was used in the defensible space calculations, as a safety measure wherever a variance existed. In the directions column for Direction #4, #5, and #6, there are two flame length entries (lines 11, 12, 14). The top flame length in each cell, is the calculated flame length for the recovery wind. The flame length, below the recovery wind flame length, is the flame length calculated as a result of the greater velocity of the East Wind. The greater velocity of the East Wind produced significantly longer flame lengths than the recovery wind.

The significantly higher wind velocity of the East Wind (55 mph versus 30mph) produced longer flame lengths than the modeled recovery wind, even though the recovery wind was aligned with a steeper uphill slope (110% versus 65%). The physics behind this phenomenon is explained by the relationship that a five-mile per hour wind will impact the rate of spread in the same way as a 50% slope (Tele 2005). Subsequently, the flame lengths of the East Wind are used in the defensible space calculations.

The fire threat distances are the defensible space dimensions that correspond to a particular fire threat direction location. As an example, the length for Direction #1 is 476 feet. The 476-foot distance is applied along Direction #1, and becomes a defensible space boundary point. This method of defensible point determination is repeated for the remaining hazard direction locations. The defensible space boundary points are connected and become the outline of the Structure Safety Zone. The boundary lines of the Safety Zone are the thicker red lines in Figure 6.4. The Structure Safety Zone, illustrated in Figure 6.4, is shown in Figure 6.1 with the Safety Zone boundary superimposed on it.

6.1.5 DISCUSSION

The Case Study Three example illustrates the principle of adequate defensible space, as defined by the Structure Safety Zone concept, which may not be feasible in areas where extreme fire threats exist. The defensible space requirement to the east of the example extends beyond property limits of Case Study Three by nearly 200 feet. The layout of the adequate defensible space distances are sufficient if measured on the slope, because the flames are carried along the slope of the terrain when steep slopes and wind-driven fires combine. This was the occurrence for Case Study Three during the Green Meadows Fire (Figures 4.11 and H.11). To the west side of the structures, the defensible space calculations are 181 feet. On the west side of the example, this amount of space is available on site, and can be maintained by the property owner. However, on the east side of the example mitigating measures, such as Structure Fire Shields are needed to provide sufficient protection to the structures.

This was the experience with Case Study Three during the Green Meadows Fire, where a naturally formed inclined fire shield protected the structure. Even with that the terrain formed fire shield, Case Study Three structures would not have survived the Green Meadows Fire, if it were not for the presence and actions of the Santa Barbara County Firefighters.

CHAPTER SEVEN

7.1 STRUCTURAL FIRE AND EMBER SHIELDS

7.1.1 INTRODUCTION

External fire shields offer the potential of significantly increasing the fire resiliency of new construction and retrofitted structures in WUI areas and other locations threatened by wildfire. The working concept of an external fire shield is to limit flame contact to structures and reduce the impact of embers on structures. This is achieved by constructing external fire resistive obstacles to wind flow and its corresponding flame travel. Figure 7.1 depicts a model of a convex external fire and ember shield placed in an upstream airflow position from a model structure during wind tunnel examinations of their aerodynamic properties. The use of arrows, which have been added to the photos of the wind tunnel trials to accentuate the airflows observed is explained later in this chapter.

*Figure 7.1: Tea Fire Scale Rebuild Model. A convex 10 ft High Fire Shield Lifts Airflow Up and Towards the Outside Edges of Wall.
(MesKimen Thesis Collection)*

The term “external fire shield” will suffice for the description of external fire and ember shields. The current design of external fire and ember shields protects from flames better than from ember intrusion, because of the greater challenge of subduing the fluidity and lofting capabilities of embers. Additionally the author’s firefighting experience and intuitive thinking suggest that superior ember protection can be provided through the modification of external fire barriers by erecting fire resistive screening above them.

7.1.2 EMBER CATCHERS

It is hypothesized that ember catchers will capture a greater amount of embers by creating greater air pressure on the windward side of external fire shields. The suggested fire resistive mesh screening would have approximating $\frac{1}{4}$ -inch to $\frac{1}{2}$ -inch spacing.

Figure 7.2: Five Foot Scale Concave Fire and Ember Shield. Mean Distance 7.5 ft from 14 ft Structure Height. Air Movement is Concentrated in Center of Arch, With Increased Turbulence. (MesKimen Thesis Collection)

The opening size of the mesh correlates to a ¼-inch vent mesh opening size required in the *International Wildland-Urban Interface Code* for vent openings (International Code Council 2009-B). The height of the enhanced ember protection will depend on further analysis of ember producing fuels, wind velocity and direction, and wind turbulence. Conceivably a 90-degree arch facing the fire spread origin could entrap embers from the wind thereby reducing the ember and brand flow downstream. See Section 7.10.1, Followup Studies and Findings for further discussion.

There have been reports of flame and ember barriers being provided by noncombustible solid walls as minimal as five feet tall. In a video for firefighter safety in WUI operational areas, Harris referred to a researcher, who claimed five-foot tall walls were successful flame barriers. This reference has no indication of flame length, exposure time, energy release amount, or position relative to structures (Harris and Simmons 2008). In the same video, a homeowner whose home survived a WUI fire, indicated that clear polymer panels placed on top of iron fencing protected his home from flames and embers, in addition to having more than 100 feet of defensible space surrounding his home. The author could not determine if the fence was effective, or if the increased defensible space was the main reason the house survived a devastating WUI fire. The author experienced the effectiveness of an external fire and ember barrier against 100 to 150 feet flames during the Green Meadows Fire in Ventura County. This incident is discussed in the case studies section of Chapter Four. Figure 7.6 depicts an incline-type external fire barrier, replicating the terrain configuration that protected the Green Meadows Fire case study structures.

7.1.2 STRUCTURE FIRE SHIELDS

The installation of external fire shields is intended to compliment or increase the fire protection required by existing codes and building regulations in WUI areas, rather than substituting for them. External fire barrier installation could satisfy the mitigating factors needed whenever the assessment of a fire threat exceeds the existing protection required by code and development requirements. The installation of external fire shields offers protection options beyond increasing the defensible space.

Once constructed, external fire shields need minimal maintenance and have no energy requirements for operation. They would be a standalone installation, not subject to failure due to power outages, or automatic and manual startup failures. External fire shields and ember catchers are passive in operation and would therefore need no power to operate, or human or mechanical intervention for functioning. The ongoing maintenance of external fire and ember barriers, once properly constructed, is minimal and typically limited to fuel buildup from vegetation and debris.

The overriding principle for the increased fire resiliency of structures in WUI areas is the reduction of turbulent air flow by aerodynamic shaping of the building envelope. A reduction of obstructions to the air movement over a structure is achieved by preventing the entrapment of wind driven embers in reentry corners, and by eliminating wind entrapping design features (Ramsay and Rudolph 2006). The shape of the roof is the prime determinant of the degree of airflow obstruction. An airflow-obstructing roof can be compensated for by lowering the wind profile of the structure. This can be achieved by decreasing the relative exposed height of the roof through fire shields, lowering the height of the roof above the fire shield, and aerodynamic shaping the the roof relative to the predominantly high velocity wind. The most effective wildland fire resistant design feature is provided by this windward sub-grade construction. As a result the building envelope would be rendered relatively impervious to flame impingement and ember wash penetration, caused by design issues. Construction methods, practices, and material choice may still pose potential fire intrusion problems. In addition, the thermal mass provided by the surrounding earth and massive building materials would provide superior cooling for the structure and occupants.

The structural fire shield concept of disrupting the wind flow carrying embers and directing flames was tested in wind tunnel experiments conducted in a wind tunnel at California Polytechnic State University, San Luis Obispo (Cal Poly). The wind tunnel experiments were conducted during three days in January, 2010. The considerations that led to the use of the wind tunnel to validate the effectiveness of external fire barriers are twofold. First, existing development and building code requirements, and defensible space offer sufficient resistance to ignition of structural components in the absence of wind-driven fires.

Figure 7.3: Gable Model with Convex Fire Shield. Wall Mean Distance 7.5 ft from 14 ft Structure. Convex Fire Barrier Reduces Airflow Towards Structure to Outside of Arch (MesKimen Thesis Collection)

Second, flames and embers are carried by and generate their own convected air currents. Given the unavailability of additional fuel surrounding a structure, disrupting the airflow would limit flame travel, and potentially block flame contact with the structure. Actual fire tests would provide more conclusive proof of fire resiliency, but are not a feasible part of this thesis. The author believes that the use of wind tunnel experiments will provide sufficient evidence of the possibility of increased fire protection of structures by external fire and ember safety shields. Researching the combustibility of building materials and construction methods is considered beyond the scope of this thesis. Much literature is available of research being conducted in this area by building material manufacturers, building trade associations, insurance associations, and government agencies.

7.2 STRUCTURE FIRE SHIELD DESCRIPTIONS

The conclusions drawn from the windtunnel experiments relating to the performance of structural fire and ember shields are supported by the author's personal experience and anecdotal information. A description of five types of structural fire shields is presented below. A discussion of the air flow characteristics of the windtunnel tests, using different configurations of external fire barriers, is discussed in greater detail in subsequent sections of this chapter. A discussion of the wind tunnel tests of the five different configurations of structural fire shields is provided in Section 7.8 Fire Shield Performance. All the configurations of external fire and ember shields should be made of noncombustible material, so that the walls do not increase the combustible loading and do not conduct fire to the building structure itself. The minimum effective wall height should be five feet because fire barriers with a scaled height under five feet did not appear to have a significant effect on airflow modification. This minimum height is based upon the observations of the author, research, and the windtunnel tests. The greatest fire resiliency for structures in the WUI is offered by a fire shield style that deflects turbulent ember-carrying airflow above the roof.

7.2.1 CONCAVE FIRE SHIELDS

A Concave Fire Shield is a noncombustible wall with the apex of the arch in a downstream position relative to the fire spread. Visually, the crescent of the arch is positioned to accept wind flow and flames. A minimum arch of 90° is suggested as being effective for airflow modification. The airflow during the wind tunnel tests tended to concentrate the airflow to the center of the arch, away from the extremities of the wall. Even with reduced airflow, there were vortices at the ends of the barrier. A depiction of a concave shaped fire shield is shown in Figure 7.2 and a schematic diagram in Figure 7.9. The suitable utilization of a Concave Fire Shield would be to direct flames and embers away from structures into terrain features such as a chimney or chute.

7.2.2 CONVEX FIRE SHIELDS

The Convex Fire Shield is an arched fire obstacle with the apex of the arch in a windward, or fire origin, position. With this shape of fire shield, the airflow tends to be towards the outside or ends of the wall. Immediately behind the center of the convex wall is a vastly reduced airflow in comparison to the Concave Fire Shield. At the end of the wall vortices are created, which exhibit greater tuft swirling than concave walls. The suitable location of a structure would be behind the Convex Fire Shield, with the center of the structure aligned with the apex of the arch. A Convex Shield tends to focus air movement to the ends of the wall. A minimum arch of 90° , on the windward side, is suggested as being effective for airflow modification; greater curvatures will increase structural protection. An example of a 10 feet scaled external fire shield, downhill in the direction of oncoming fire, is shown in Figures 7.1, 7.3, 7.7, and a schematic diagram is shown in Figure 7.9.

Figure 7.4: High Profile Linear Fire Shield with Low Profile Structure. 6.5 ft Wall Protecting a 4 ft Roof Height. Note, Near Absence of Smoke Behind Barrier with Smoke Over Top (MesKimen Thesis Collection)

7.2.3 LINEAR FIRE SHIELDS

The Linear Fire Shield provides adequate protection uniformly along the surface area of the wall. The air movement tends to go up and over and then down, with relative moderate lofting downstream of the wall, as compared with the air flow characteristics of the other structural fire shields. The ends of the linear fire shields require additional consideration due to the creation of vortices. During the wind tunnel trials there was consistently more turbulence at the ends of the linear wall than the concave walls. Either the ends of the wall need to be extended several feet beyond the protected structure, or slanted downwind to reduce turbulence. The Linear Fire Shield is perhaps the most practical installation of a flame and ember obstacle due to the simplified construction requirements. Figure 7.4 depicts the typical airflow of a High Profile Linear Fire Shield during the wind tunnel tests. There is greater turbulence created on the upwind sides of the wall, with moderate lifting of air and slight diminishing of the lofting effect downwind. The air movement over the top of the wall is of greater uniformity than for either the convex or concave shields, but less than what was observed in the case of the Incline Fire Shield. The lofting effect of Linear Fire Shields is also seen in Figures 7.10, and the schematic diagram in Figure 7.11.

9.2.4 INCLINED FIRE SHIELDS

An Inclined Fire Shield tends to loft the airflow higher and at a further distance than any of the other fire barriers, having a vertical configuration on the face of the wall. This is probably the best configuration for mobile home structure protection. An Inclined Fire Shield is illustrated in Figure 7.5. The inclined wall has a scaled height of 12 feet, placed at a scaled distance of 20 feet from the modular homes with a scaled height of 12 feet. Figure 7.6 is an illustration of a High Profile Inclined Fire Shield. High Profile Fire Shields of any wall configuration offer considerably greater fire protection.

*Figure 7.5: Mobile Home Park Model with Inclined Fire Shield. 12 ft Wall Protecting Structure with 12 ft High Roofs. Note, Lofting of Air Up-and Over the Modular Home Models.
(MesKimen Thesis Collection)*

Inclined shields are the optimal fire obstacle design to take advantage of terrain features. The sloping upwind side of the Inclined Fire Shield should be under a constructed slope of 100%. At a steeper than 100% slope, the Inclined Fire Shield takes on the air flow characteristics of a linear wall. Inclined Fire Shields should be spaced no further than their vertical measurement from structures. As an example, a 12 feet high protection barrier should be no further than 12 feet from a structure. The lofting air currents are diminished by the prevailing airflow to an elevation that may allow some ember impact on the building envelope. Inclined fire shields can be created in linear, convex, and high profile configurations for greater fire resiliency. An inclined concave fire shield would probably have negligible, if any, improved results for structure protection due to the airflow being directed behind the arch apex.

7.2.5 HIGH PROFILE FIRE SHIELDS

High Profile Fire Shields offer the greatest protection of any of the fire shield configurations. In the case of a High Profile Fire Shield the height of the fire protection barrier equals, or exceeds the height of the building behind it.

A High Profile Fire Shield has a higher wind engaging profile than the structure it protects. The term “high” describes a wall with a high impact on airflow and does not necessarily refer directly to the physical height of the barrier (i.e., shield may be at grade level or slightly above grade). Figure 7.4 demonstrates the wind tunnel activity of a High Profile Linear External Fire Shield. Any of the different configurations of fire shields can be transformed into high profile shields, by increasing the relative height of the shield to the building structure. No precise measurements of height differentials were obtained during the windtunnel tests, however, the precautionary dimensions of conventional parapet walls may be used as a guide. A 30 inch height differential between the fire shields and the protected structure should provide adequate protection in WUI areas. This height is similar to the 30 inches extension of a parapet wall above the roof, as required for four hour rated parapet walls (International Code Council 2007). The possible additional protection afforded by High Profile Fire Shield walls was tested during the windtunnel trials. The configurations of these fire shields (i.e., Linear, Inclined, and Convex) in the high profile design produced results with reduced airflow on the structures downstream. This suggests that the impact of flames and ember washes are significantly reduced with High Profile Fire Shields. A schematic diagram of a High Profile Inclined Fire Shield is shown in Figure 7.11.

The author experienced the effectiveness of High Profile Fire Shields while on the Green Meadow Fire, where 100 to 150 feet flame lengths and accompanying embers were lofted above an ordinary constructed structure by a terrain feature that performed as an Inclined Fire Shield. The protection provided by the sloping terrain allowed the structure to withstand the impact of the flames and embers for approximately 40 minutes (Chapter Four, Case Study Three). As evidenced in this experience and confirmed by the superior performance of the Inclined Fire Shield during several windtunnel tests, the Inclined High Profile Fire Shield would offer the most protection for structures, including modular homes. The Concave fire shield in the high profile design had more obscured results than the others tested. Figure 7.8 illustrates the Concave Fire Shield in a high profile configuration, which had a concentration of turbulent air at the apex, as well as above and behind the apex. The increased benefit of the height of the barrier was offset by the increase in turbulence.

It is the opinion of the author that Concave Fire Shields are counter indicated for use as High Profile Fire Shields. Other illustrations of High Profile Fire Shields can be seen in Figures 7.6 and 7.7.

Figure 7.6: High Profile Inclined Fire Shield in Combination With a Low Profile Structure. 10.5 ft Scalde Inclinde Wall, 10 ft From 8 ft Height Structure (MesKimen Thesis Collection)

7.3 WINDTUNNEL EQUIPMENT

The windtunnel at Cal Poly has the capability of producing wind speeds from five miles per hour to 70 miles per hour. The air is drawn into the tunnel by a reverse flow from a large fan at the end of the tunnel. The air is drawn through some 25,000 straws, like flow straighteners, which produce a laminar airflow movement. With this straightening, the airstream approaches a laminar flow in the center of the test section of the windtunnel. The dimension of the windtunnel test section is approximately three feet high and four feet wide. The model size was limited by a 14 inches by 21 inches access hatch for the insertion of models.

7.3.1 TUFTS

On each component of the external fire shield models, tufts were placed to show the direction and relative strength of airflow by bending in the direction of the airflow. Tufts have been successfully used in scale model windtunnel tests as a visual gauge of air movement (Crowder 1983; Yang 2001). As portrayed in all the windtunnel models, the tufts used here were 1 inch to 1 ½ inches pieces of red knitting yarn attached to model components with small drops of cyanoacrylate. Suitable tuft material can be thin nylon, knitting yarn, nylon twine, knitted sheathing, sewing thread or nylon monofilament nylon (Crowder 1983). The tuft tips, when experiencing a whipping action, indicate turbulent flow. Without such whipping action a laminar flow is indicated (Crowder 1983). When combined with smoke and used on models of relatively small and irregular shape the tufts give valid indications of air movement approaching that of pressure sensing transducers (Yang 2001). Throughout the windtunnel tests, red knitting yarn was utilized as tufts on all model fire shields and structures. During the tests certain factors, such as model size, windtunnel use, and budget restraints mandated the use of tufts and smoke for flow visualization in lieu of equipment such as digitally recorded pressure transducers and laser sensors.

7.3.2 SMOKE

Smoke was used during the windtunnel tests for enhanced viewing of the aerodynamic properties of external fire and ember shields, structures, and the interrelationships between terrain, structures and fire shields. A smoke stream greatly increases visibility of air movement and is used extensively in windtunnel testing (Mueller 2007). The advantage of using smoke is the dynamic depiction of air movement, beyond a stationary positioning of the tufts. The smoke wand that produced the smoke was fabricated at Cal Poly. The smoke fluid was mixed from a commercially available peanut oil base. The tip of the wand was placed at a distance that varied for purposes of achieving the most effective results from 4 inches to 6 inches from the upstream edge of the models, and from 2 inches to 4 inches in elevation from the bottom of the windtunnel compartment. The distance from the opening from which the wand was inserted was approximately 18 inches from the leading edge of the fire barrier models. Improved visualization of smoke patterns would have been able to be obtained using a laser beam through a cylindrical lens with the axis of symmetry parallel to the ground and perpendicular to the flow direction (Stanislaus 2007). The result would have been an illumination of smoke in the area of question, with an accompanying resolution of flow details (Stanislaus 2007). Such laser-heightened imaging was beyond the time, equipment, and financial restraints of this thesis work.

7.4 OPERATIONAL DESCRIPTION

7.4.1 PHYSICAL LIMITATIONS

Physical limitations were placed upon the maximum dimension of the models. The cross-sectional area of the models was limited from 5% to 10% of the area of the windtunnel's test area, due to the blockage effect (Tso 2009). The blockage effect threshold should not be exceeded due to the potential invalidation of the test results. Essentially excessive suction would be induced behind the model from the windtunnel fan drive. Within these constraints, the largest cross-sectional area of the model was limited to a maximum of 1.25 square feet. A second limitation on the size of the model was the bottom access door for model insertion into the windtunnel. The access slot measured 14 inches by 21 inches and thus would limit the size of the model base to be inserted into the windtunnel. The access door was used as an anchoring point by the insertion of threaded rods through the model and model base, into a bottom plate that exceeded the size of the windtunnel access opening. The models were securely fastened in a stationary position so that no debris would enter the windtunnel exhaust fan and damage it. Both the blockage effect, and the initial perceived ingress restraint limited the scale of the model to 1:96 (i.e., $\frac{1}{8}$ inch = 1 foot) for all models, except 1:192 for the Tea Fire Rebuild model. With greater model size placement capability into the wind tunnel, the size of the models would have been solely limited by the blockage effect (simple mass models could have had a scale as large as 1 inch = 1 foot). The only model that approached the lower limit of 5% of the cross-section area was the Tea Fire Rebuild, with terrain features, see Figure 7.1.

7.4.2 RECORDING RESULTS

The results of the experimental tests were recorded with photographic equipment, and recording of personal observations. Video recordings of the windtunnel trials, even though they would have portrayed actual movement, were ruled out because of the difficulty of inclusion into the written thesis. The windtunnel tests were discussed with assisting personnel, giving the author additional points of perspective and increased operational knowledge.

Photographs were taken on the side opposite to the smoke wand portal of the wind tunnel. Under certain circumstances there was an illusion of greater smoke behind the external fire shield than observed, because smoke was between the models and the camera. This occurrence was a factor indicating the importance in the use of arrows. The Figures accompanying this writeup are photographs of scale models taken during wind tunnel tests. The depictions are from trials using smoke for increased visual reference. Black arrows were added to accentuate the depiction of the smoke-enhanced air movement. Care was taken for the visual enhancement to accurately portray airflows that were visible to the observers.

A total of 85 wind tunnel tests were performed for a mean run period of two minutes each. Some initial periods of constant wind tunnel speeds lasted up to five minutes or more without significant variation in tuft or smoke movement. The mean time of two minutes was sufficient for taking photographs, and because the direction and force of the airflow did not noticeably vary. A wind tunnel speed of 30 mph was selected for smoke speed, because it was the highest velocity that produced the best visualization of smoke. At higher wind speeds the smoke dissipated.

7.5 MODEL FABRICATION

The models were scaled to fit through the 14 inches by 21 inches access hatch of the windtunnel. The initial step in the process was sketching and digitally designing models of stereotypical structures for use in the windtunnel. With the use of Rhinoceros software, additional digital models were constructed for compatibility with the digital fabricating equipment, and for use as shop plans for the fabrication of conventional scale models. The digital drawings were used for the conventional fabrication of the Mobile Home Park and Gable Roof models. The Tea Fire Rebuild model used Rhinoceros software for three-dimensional model compatibility with the available digital fabricating equipment. A laser cutter transformed the digital three-dimensional models into physical artifacts for use in the windtunnel tests.

Proper selection of building materials was critical for the models to withstand high-speed airflows generated by the windtunnel. Solid wood and fiberboard were selected as the materials due to construction methods, availability, and cost. Simple mass models were chosen not only on the basis of construction ease, but because they were adequate for representing the required fire resilient design principles. All but the Tea Fire Rebuild model include the principles of elimination of reentry corners and ember entrapment features in respect to building envelope layout and architectural details. The fire shield construction height was to scale, but the width was determined by model strength requirements. The width of the fire shields is not to scale, but the strength requirement outweighed the possible degradation of airflow results obtained.

The simple mass models were constructed on campus at Cal Poly in the College of Architecture and Environmental Design (CAED) support shop. Scrap plywood and dimensional lumber were reused, whenever practical, from old projects to minimize cost and waste. Because there were several combinations of model fire shields and model structures required for the windtunnel tests, it was decided to utilize interchangeable model components. However, the tendency of model components to move during tests required them to be secured in some fashion.

All of the model structures, fire shields, topographical contours, and mounting boards were provided with $\frac{1}{4}$ inch holes. The holes were strategically located to facilitate interchangeability of model components. Nuts and threaded rods of $\frac{1}{4}$ inch dimension were used to bolt the scale model components to a $\frac{1}{2}$ inch plywood plate on the underside of the windtunnel. The materials, construction, fabrication, and stabilization methods proved successful to withstand air speeds in excess of 50 miles per hour.

The Tea Fire Rebuild model required special treatment, because it employed digital fabrication equipment, a laser cutter, at Cal Poly. New material for model construction was necessary to eliminate possible damage to the fabricating equipment from hard debris. The residence model was constructed by multiple passes of a laser cutter on $\frac{1}{8}$ -inch newsboard. The actual height of the topography model was beyond the practical working limits of the digital fabrication equipment. For accurate depiction of the topography, a digital image of the site plan was printed out.

Figure 7.7: High Profile Convex Fire Structure Fire Shield With Low Profile Structure. 10. 5 ft Scale Concave Wall, Mean Distance of 10 ft from 8 ft Tall Structure (MesKimen Thesis Collection)

The printed scale topography was used as a working trace sheet to cut the individual topography layers. The contour lines were traced on the plywood using an awl, and then cut with a band saw. The individually cut layers were compiled on top of one another to form the model topography. The finished digitally fabricated Tea Fire Rebuild model is shown in Figure 7.1.

7.5.1 TEA FIRE REBUILD MODEL

A model of a proposed Tea Fire Rebuild was created at a scale of 1:192, this model is depicted in Figure 7.1. The model was drawn in a Computer Aided Design (CAD) program and transferred to a computer guided laser cutter with the use of Rhinoceros software. The building model was made of plywood, and the topography of newsboard, with a plywood base. A model Convex Fire Shield, with a scale height of 10 feet, was located on the down slope of the model of a two-story residence with a gable roof. The location of the external fire shield was selected because it was in the probable spread of flames during the Tea Fire in Santa Barbara in November 2008. Many of the architectural features from the actual plans were eliminated for ease of fabrication and increased windtunnel observation capabilities. Also, eliminating these details tended to increase the fire resiliency of the building structure in WUI areas by elimination of reentry corners and air entrapping design.

7.5.2 MOBILE HOME PARK MODEL

Mobile homes and modular structures represent special concerns for fire protection in WUI areas. Modular structures because of their light-weight construction, are inherently less fire resistive than ordinary construction. An added fire safety concern is the airflow underneath these structures, because of their raised foundations. This aspect of design allows the combustible floor sheathing to be surrounded by air. Fire has the ability to start underneath the structure and burn its way into them. The close spacing of the modular homes in mobile home parks represents a severe fire exposure threat. The spacing of modular homes in mobile home parks is frequently less than the 132 feet, which is considered sufficient for the protection of structures from radiant heat of burning vegetation (Cohen and Butler 1998).

Mobile homes, because of their ease of ignition and high rate of energy release when burning can represent a greater exposure hazard than vegetation. The preceding issues are the basis for the mobile home park model being included in the windtunnel research.

The scale of the Mobile Home Park model was selected to simulate the spacing and layout in a mobile home park. The scale of the models was $\frac{1}{8}'' = 1'0''$ with both the modular home and the different configurations of structural fire shields. The models were made of solid wood and secured on a $\frac{1}{2}$ inch plywood base, using $\frac{1}{4}$ inch threaded rods and bolts. The modular home height was selected at 12 feet, with a typical doublewide layout of 28 feet and standard length of 42 to 50 feet long. The structural fire shields were set at a scaled distance of 25 feet from the closest mobile home. The basic shape of the modular home closest to the fire protecting barrier resembles that of a simple massing structure. The wind tunnel test results of the mobile home, closest to the structural fire shield, are comparable to a flat-roofed conventionally residential structure. The Mobile Home Park model is shown with different types of fire shields in Figures 9.5 and 9.10.

7.5.3 GABLE ROOF MODEL

A simple mass structure design, without wind entrapping shape was the design selected for the gable roof model. The scale of the model structure is 1:48. The resulting dimensions were a structure 14 feet wide, 50 feet long with a gable roof ridgepole at 14 feet. The model was constructed out of solid wood, and bolted onto a plywood base. The longitudinal axis of the house was set perpendicular to the air flow, so that a greater surface area existed to interact with the airflow. A much more protected house configuration would be to locate the long axis of the house parallel to the wind flow. The exposed portion of the house would be one-third of the testing alignment configuration. Reduction of fire exposure is directly related to the length-width proportions exposed to oncoming embers and flames. However, a fire protection drawback exists when placing the longitudinal axis of the structure parallel to wind direction alignment, since the vertical gable portion of the roof would have more opposing surface exposed to air movement than the inclined slopes. The greater obstruction of airflow would create substantial additional opportunity for flame and ember intrusion.

A simple remedy to this potential problem would be to redesign the roof from a gable to a hip roof, or flat roof. This small design change would allow reduced surface exposed to wind, and be inclined with the wind direction. The Gable Roof model is shown in Figures 7.2 and 7.3.

7.5.4 LOW PROFILE FIRE SHIELD MODEL

The High Profile Fire Shield is a concept in which the upwind or exposed fire front of the structure is substantially lower than the fire shield. The profile of the structure, which is lower than the external fire protecting barrier, situates the structure substantially below the wind level. The high profile fire shields were the same models used throughout the windtunnel tests. The high profile fire shield effect was created by proportionately decreasing the height of the building model, and in some cases moving the fire protecting barrier closer to the low profile building model. A model scale of 1:96 was selected to allow a 30 inches scaled height differential between the height of the flat roofed Low Profile structure model and the high profile fire shields. The 30 inches height difference was selected to correlate with a four-hour rated fire-resistive parapet wall as codified in the *2007 International Building Code*. (International Code Council 2007). The closer the structure is to the fire shield, the greater the protection. Should the structure be buried on the windward or fire-origin side, near total protection would result. Not only would the structure be sheltered from wind-driven flames and ember wash, but would be insulated by the thermal earth mass. High Profile Fire Shields, using the Low Profile Model are shown in Figures 7.4, 7.6, 7.7, 7.8.

7.6 AIR MOVEMENT RELATIONSHIPS

The validity of windtunnel testing is based upon the assumption that the air movement characteristics generated inside the windtunnel, with the use of models, correlates with the wind flows existing in the real world. A Reynolds number is the expression of the relationship that matches scale model airflow properties to the properties of airflow around a full-scale object. There are many possible criteria, besides the Reynolds number to match for accurate results of airflows of scale models in windtunnels. According to the literature, for external fire barrier and structure models it is necessary to match the Reynolds number of the windtunnel flows to the real airflows. The Reynolds number is applicable, because instead of measuring aerodynamic forces only a visually similar flow was created (Frank 2007). In short, the Reynolds number provides a measure of the degree of turbulence of the airflow (i.e., a high Reynolds number indicates greater turbulence). For small-scale models, turbulent airflows in windtunnels replicate the turbulent airflows on Earth when air flows over the ground. The Reynolds number (Re) is given by the formula below: where ρ is the density of air; v is the air velocity; l is the width of the model in feet; and, ν is the viscosity of air.

$$Re = \frac{\rho al}{\nu}$$

When the windtunnel airflow and an environmental airflow equation are compared, a significantly greater speed is generated for the model. The scale of velocity required in the tunnel is the reciprocal of the model's scale. As an example, a $1/10$ scale model of a building that undergoes winds of 100 miles per hour would need a wind speed of 1,000 miles per hour. Clearly this is not possible, but fortunately there are some airflow properties that compensate for the apparent problem in matching Reynolds numbers for small scale models.

Significant turbulence is the important compensating consideration for reducing the desired high velocity airflow in windtunnels when using small-scale models. Although a higher Reynolds number indicates greater turbulence, there is an upper limit of turbulence.

Sufficient turbulence exists when a model experiences turbulence characteristics equal to the turbulence characteristics of the full-scale object. A Reynolds number greater than 1×10^5 results in airflow characteristics of scale models of buildings being equivalent to airflow characteristics of full-scale buildings (Frank 2007). The consequence of this relationship is that full-scale objects will experience insignificant differences, as compared to models of airflow behavior when exposed to a small breeze, or 100 miles per hour winds. The flow certainly moves with greater amplitude, but it will move in the same manner, whether it be air movement around a full-scale object or a scale model in a windtunnel (Lam et al. 2008; Frank 2007).

When the Reynolds number equation is solved for a model home that is only 3 ½-inch wide, the resulting minimum wind tunnel speed is in the range of 16 to 38 miles per hour for air flow characteristics to simulate those of full-scale objects (Lam 2008). Using a scale model of a structural fire shield creates significantly greater turbulence and reduces the minimum air velocity further. The resulting minimum air speed can be reduced by a factor of two to five times. The resulting velocity differential was an insignificant factor during the windtunnel tests due to the relatively small spatial parameters, and compensating factors involved. A conservative minimum air speed of 20 miles per hour was used during the windtunnel tests. The use of smoke was selected at 30 miles per hour, which is well within the air velocity range for windtunnel testing of models to validly resemble winds acting upon structures.

7.7 WINDTUNNEL TESTS

In the initial windtunnel runs, the speed selected ranged from 12 to 14 miles per hour for a period of four minutes. The Tea Fire Rebuild model was the selected trial run model. Notation was made of the direction, bending and whipping of tufts on the model and the fire barrier. The speed was increased to 24 to 26 miles per hour for a period of four to five minutes, and the movement and positioning of the tufts were again recorded. In the process of accelerating the wind velocity, the participants conducting the test, noticed that at 34 miles per hour the tuft tips whipped more, indicating increased turbulence. The reason behind this phenomenon is not understood. The air movement was again raised to 50 to 55 miles per hour, and careful observations were made of the tuft movement and positioning. No distinction from the previous windtunnel run was observed with increased air velocities and the tuft movement in a given direction. As the velocity increased, the tufts tended to increase bending toward the horizontal position but the direction of the tuft movement was the same for the different air velocities. As the air movement exceeded 50 miles per hour the bending and whipping of the tuft tips increased. Nonetheless, there was no noticeable change in tuft direction.

Proportionally, the same compression and turbulence of air at varying velocities were applied to each combination of fire shield and building model. The air speeds selected for each of the combinations were run in the sequence of 20 miles per hour, 30 miles per hour, and 40 miles per hour. After the sequence of increasing velocity, the wind tunnel air speed was reduced to 30 miles per hour with smoke injected. For each given combination of fire shield and building model with varying wind speeds, there was no significant variation of tuft direction. There was increased horizontal bending of the tufts that appeared to be proportional to the increased air velocity. The smoke injection speed of 30 miles per hour was selected because the smoke visibility was greater, and tuft movement was typical to that of higher velocities. At higher velocities, the increased air movement tended to dissipate the smoke faster and consequently decrease its visibility.

Figure 7.8 Concave Fire Shield in High Profile Configuration. 10.5 ft Scaled Wall, Mean Distance of 10 ft From 8 ft Tall Structure. Note, Smoke Concentration in Apex of Arch and Turbulence Between Barrier and Structure. (MesKimen Thesis Collection)

7.8 FIRE SHIELD PERFORMANCE

The concave and convex external fire shields were the same model wall mounted into the same base holes in a reverse position. The position of the concave and convex fire barriers was centered on a perpendicular midline from each building model. The Concave Structural Fire Shield was rotated 180° on the longitudinal axis from the position of the Convex Structural Fire Shield. The arch of the shield, at a scale of 1:96, had a radius of 30 feet. The length of the arch extended for a minimum of five feet, depending on the scale of the building model, beyond the ends of the building models. This proportionate amount of arch (90°) relative to the length of the building models ensured desirable aerodynamic results during the windtunnel tests. A minimum arch of 90° produced acceptable fire resiliency effects, but increasing the size of the arch and circumference would have produced greater benefits. A complete circling of a structure by a Convex Fire Shield will result in the optimum divergence of airflow away from the protected structure. The fire shield will offer protection from any direction of fire threat. The height and positioning of the fire shield could vary corresponding to the flame length and wind speeds at specific areas.

7.8.1 CONCAVE FIRE SHIELD

Concave Structural Fire Shields were used for each of the scale model structures, excluding the Tea Fire Rebuild model. The flow characteristics of the concave fire shield were similar for each of the structure models. The scaled height of this external fire protecting barrier was either five feet or 10 feet depending on the model used. The airflow characteristics were duplicated for both heights during windtunnel runs. The concave shape tended to move air inward from the extremities of the arch with increased airflow towards the center of the arch. This occurred in much the same manner as a parabolic reflector concentrates light rays in the center of a dish. A Concave Structure Fire Shield would tend to move fire and embers away from the peripheries of the arch towards the midpoint of the arch. Figure 9.2 depicts a five feet scale model Concave Structural Fire Shield placed at an average distance of 10 feet from a model residence with a maximum height of 14 feet.

In Figure 7.8 a High Profile Concave Fire Shield with a 10 feet scaled height is positioned a mean distance of 10 feet from a low profile model structure with an eight foot roof height. The fire resiliency of structures will increase with the use of a concave external fire barrier directing fire away from the structure. The positioning of a building should be towards the outer limits of the fire protecting barrier arch, away from the apex. Figure 7.9 is a schematic of Concave and Convex Structure Fire Shields, with simplified airflow vectors, indicated with arrows.

*Figure 7.9: Concave and Convex Structural Fire Shields Schematic,
Airflow Vectors Indicated By Arrows
(MesKimen Thesis Collection)*

During the windtunnel tests of the Concave Structural Fire Shield a consistent concentration of turbulent air occurred behind the apex of the arch. An example of this air movement is depicted in Figure 7.3.

With similar airflow increases, a proportionally greater increase in turbulence immediately behind the arch apex occurred. As the air movement velocity increased, the center vortex became more turbulent, obtained greater elevation, and settled further downstream. Placing a structure in this position relative to the concave fire shield is counter indicated. The increased wind flow and increased turbulence significantly escalates the probability of ember intrusion into the structure. A beneficial installation of a Concave Structural Fire Shield would channel flames and wind-driven embers away from structures into terrain features such a chimney, chute, or ridge saddle. This type of fire shield, along with the other types, exhibited vortices (swirling air turbulence) at the end of the walls. The airflow wash, or turbulence, appeared to occur at a minimum scaled distance of approximately five feet, or equal to the height of the wall. To safely compensate for this type of wind reaction, the structural fire shields would need extensions of five to ten feet from structures, or other combustibles. Another possible compensation for this vortex phenomenon would be a gradual tapering of the wall height, extending at least five to ten feet. This tapering down of the structure fire shields was not tested during the windtunnel trials.

7.8.2 CONVEX FIRE SHIELD

The Convex Structure Fire Shield holds the greatest potential for mitigating severe fire threats to existing structures in WUI areas. The convex-shaped wall is positioned in the same configuration as the concave wall, except an 180° rotation in the opposite direction of the concave wall in respect to the building protected (i.e., with the apex of the arch towards the direction of fire origin, and away from the structure). During windtunnel tests, the air movement was consistently away from the center of the arch towards the ends. Also, this airflow characteristic occurred with varying wind speeds. As is the case with every external fire shield, a swirling turbulence existed at the end of the wall. This turbulence requires compensation in the design of the fire barrier. A Convex Structure Fire Shield is shown in Figure 7.1 (i.e., a 10 feet scaled height barrier on a Tea Fire Rebuild model positioned in the direction of the oncoming fire, down slope of the home).

Figure 7.3 shows a gable roof residence with a five feet high Convex Fire Shield affecting air movement impact on the structure. Figure 7.9 is a schematic of Concave and Convex Structure Fire Shields, with simplified airflow vectors. Figure 7.7 shows a High Profile Convex Fire Shield in the upstream position, sheltering a low profile residence model from airflow. The scaled height of the house is eight feet, and the fire shield is 12 feet, with a mean distance of 10 feet from wall to structure. This fire shield configuration offers the greatest potential for fire resiliency of any of the vertically walled fire shields.

Wildfire inhibiting features can exist along with fire hazards in the environment. A naturally formed rock terrain feature can mimic the airflow characteristics of a convex fire shield is shown in Figure 7.10. The rock arrangement on the outcropping of a point roughly takes on the alignment of a Convex Fire Shield. Note the burned vegetation on the outside or ends of the natural arch (indicated by red arrows), and the unburned trees near the center of the arch (indicated by green arrows). This non-combustible inorganic composition disallowed significant vegetation growth, thereby reducing fire loading. An architect or designer can take either advantage of terrain features for greater fire resiliency; or unnecessarily expose structures to greater hazards. Chapter Two, Section 2.4 discusses terrain features and their effect on wildland fire behavior in further detail.

7.8.3 LINEAR FIRE SHIELD

As the name implies, the Linear Structure Fire Shield is a straight wall constructed with fire resistive and noncombustible materials, such as masonry products, including cement masonry units (CMU), and plastics. Linear Fire Shields should have a minimum height of five feet and extend a minimum of five to ten feet past the structure protected. During the windtunnel tests a swirling air movement was observed at the ends of the wall, within a scaled distance of five to ten feet. A uniform distribution of air movement over the top of the wall, with reduced turbulence also occurred. From these observations, the author concludes that the linear configuration focuses smoke and air movement vertically and uniformly up and over the entire wall length. The linear style of wall was tested with all of the model structures, except the Tea Fire Rebuild.

*Figure 7.10 Environmental Example of Convex Fire Shield
(firenist.gov/bfrlpubs/fire09/PDF/f09028.pdf)*

The air movement was similar with each model, and the air turbulence void was estimated at a distance of one to one and one-half the height of the wall. The relative amount of smoke behind the Linear Fire Shield was significantly less than the concave wall, but was more than the convex, inclined, and high profile walls. A Linear Fire Shield is shown in Figure 9.11, a High Profile Linear Fire Shield in Figure 9.4, and a schematic diagram in Figure 9.12.

7.8.4 INCLINED FIRE SHIELD

Inclined Structural Fire Shields performed uniformly throughout the windtunnel trials with all of the structure models, and with scaled height variations. There was a uniform movement of air along the length of the wall with reduced air turbulence behind the wall. The air movement tended to uplift and stay at a higher elevation than any of the wall types. The smoke tended to descend slower than with the other wall configurations.

*Figure 7.11: Linear Structure Fire Shield with Scaled Height of 12 ft, 20 ft from Mobile Homes with Height of 12 ft.
(MesKimen Thesis Collection)*

The turbulence was consistently and significantly reduced behind the ramps-type wall. During the windtunnel tests of modular home models, the inclined fire protecting barrier produced less tuft movement. The height of the modular home models was a scaled 12 feet, placed 25 feet from the Inclined Structural Fire Shield, with a height of 12 feet. For increased ember protection, a wire mesh extending the height of 20 feet could be installed. At the ends of the Inclined Structure Fire Shield, there was less turbulence than with any other type of fire shield tested. Even with the Gable Roof model with a scaled height of 14 feet, the Inclined Structural Fire Shield lifted air to a significantly greater height and consistent amount than all of the other fire shields. There was a near void of air turbulence between the inclined face of the wall and the wall surface of the models, indicating the effectiveness of the lifted airflow. With the low profile structural model there was even less tuft movement and smoke-indicated air turbulence than with any other model. Figure 7.12 is a schematic of the airflow around a Linear Structural Fire Shield and a High Profile Inclined Structural Fire Shield with the airflow vectors indicated by arrows.

7.8.5 HIGH PROFILE FIRE SHIELD

The High Profile Structural Fire Shield describes a fire protecting barrier that extends above the top of the roof. With all but the Inclined Structural Fire Shield, the high profile wall should extend above the top of the roof by a minimum of 30 inches. An inclined fire shield provides additional lift, and another 30 inches of height may not be necessary. This height correlates with the 30 inches extension above a roof required for a fire resistive parapet wall, as specified in the *International Building Code* (International Code Council 2007). A lower height may prove sufficient, but the code requirements have been tested and rated for building code satisfaction. The High Profile Structural Fire Shield offers the greatest fire protection of any of the fire shield configurations, with a significantly greater assurance of fire resiliency from flame impingement and ember wash. If the high profile wall were to be integrated into the building envelope, a four-hour fire rated construction would be required. Any openings, including doors and windows, would require a minimum three-hour fire rating as specified by the *International Building Code* (International Code Council 2007).

For the windtunnel testing, five-foot and 10-foot scaled distances from the external fire protecting wall to the building model were selected. These distances allowed more than adequate ingress and egress space. The 10-foot distance allows landscaping of the entryway. When placed at a five feet scaled distance from the building model, insignificant tuft and smoke movement was observed between the High Profile Structural Fire Shield and the building model. Even though smoke appeared in the upper half of the low profile structural model at a separation of 10 feet, there was no noticeable tuft movement. The closer the structure is to the fire shield, the greater the protection afforded by the flame and ember barrier. Should the structure be buried on the windward and/or fire origin side, optimum fire protection would occur. Not only would the structure be sheltered from wind-driven flames and ember wash, but it would be insulated by the thermal mass of the earth.

Figure 7.12 Airflow Schematic of Linear Structural Fire Shield and High Profile Inclined Structural Fire Shield With Arrows Depicting Airflow (MesKimen Thesis Collection)

7.8.6 STRUCTURE FIRE SHIELD RETROFIT

Linear Structure Fire Shields and Convex Structure Fire Shields are projected to be the most promising types of fire protecting barriers for retrofit. In a comparison of linear and convex fire shields, convex fire shields displace greater airflow from their midpoint than do linear fire shields, and therefore would offer greater fire protection to buildings. However, the linear fire shield should be the preferable retrofit. The reason for this is simplicity of installation. The linear style has a straightforward design compared to arching walls. Inclined fire shields, although more effective, would require significantly more earth moving and structural reinforcing than linear fire shields, and as such are speculated as a more limited retrofit option.

Concave fire shields are effective fire protecting barriers, but their appropriate installation is for significantly limited applications. If concave fire shields are inappropriately placed, they can increase fire spread into a building.

7.9 MODEL PERFORMANCE

All structural models, being simple mass structures, reflect sound WUI area fire resiliency principles of eliminating reentry points and entrapping corners. These structural design principles reduce significant airflow turbulence and allow reduced airflow entrapment. Similarly, all the structural model shapes, excluding the Tea Fire Rebuild, have flat or simple gable roofs and simple massing shapes. The shapes of the roofs and structures introduce a minimal amount of airflow obstruction, thus reducing turbulence. The less turbulent airflow should result in reduced flame and ember intrusion into structures located in WUI areas. The Tea Fire Rebuild Model plot plan can be seen in Figure 7.12; and Figure 7.13 displays the Rhinoceros converted layout plans. Plan views and elevations of the remaining structural models and fire shield diagrams are located in Appendix D.

7.9.1 TEA FIRE REBUILD

The Tea Fire Rebuild is a unique model in that the house is elevated on the existing actual scaled slope. The model scale is 1:192 with a 10-foot scaled Convex Structural Fire Shield established on the downslope of the hillside, so that the top of the wall is at building site grade level. This location and height of wall was chosen to allow a view from the house, and because a terraced hillside provides fire protection for structures on or behind them. The principle of terraced hillsides providing fire protection for structures is based on anecdotal information. These are the reasons why the placement of the external fire shield was downslope on the hillside, and not at building site grade level. Fires are considered improbable to residents, but views are an everyday enjoyable feature of living in the foothills.

For this particular model a Convex Structural Fire Shield was constructed and was the only external fire shield used with the model. Attachment of other forms of fire shields onto this model required extensive modification to the terrain modeling, and would have resulted in fabrication problems. The architectural plans called for a continuous second story floor, but due to digital fabrication difficulties the midsection was eliminated. The result was a two tower second floor in appearance.

The northwest tower is identified as “A” and the southeast tower as “B” (see Figure 7.13). The slope of the terrain was approximately 60%, and acted similar to an inclined fire shield in relation to lofting air. The convex wall tended to lift the air movement up and over the “A” tower in closest proximity to the wall.

There was significant tuft movement and smoke air turbulence visible between towers “A” and “B”. This correlates with disrupted air movement in enclosures shaped to entrap wind. The trapping of embers and wind by enclosures, and reentrant corners is a significant design feature, contributing to structural fire loss in WUI areas (Ramsay and Rudolph 2003). Behind tower “B”, significantly reduced air movement indicated that the shape of the building envelope was acting as an airflow obstruction. The arch of the Convex Structural Fire Shield tended to move more air to the outside of the wall. The northwest end of the convex fire shield would be the ideal location for a Concave Structural Fire Shield.

Figure 7.13 Tea Fire Rebuild Plot Plan
(MesKimen Thesis Collection)

In this actual location is a chute/chimney-shaped terrain feature, which would direct airflow and subsequent flames and embers away from the structure up into the chute. This is an example of a proper installation within the limited number of appropriate options for concave fire shield applications.

*Figure 7.14 Tea Fire Rebuild Rhinoceros Generated Plans
(MesKimen Thesis Collection)*

The Tea Fire Rebuild model was the first model structure and fire shield tested during the windtunnel experiments.

The first windtunnel run was tested at speeds of 24 to 34 miles per hour, causing noticeable turbulent movement in the tufts. The wind speed was increased to 45 miles per hour in the second run. During this test the tuft tips pointed to the outside of the wall, which indicated a deflection of air movement from the apex of the arch to the outside. During the third run, the speed was increased to 52 miles per hour and the tuft movement and smoke indicated airflow in the same direction. However, the increased wind velocity caused greater whipping of tuft tips, indicating an increase of air velocity.

The actual structure that the Tea Fire Rebuild model was patterned after is being rebuilt on the same footprint of the WUI fire destroyed residence. The building approval process is being “fast-tracked” because of rebuilding on the footprint. Fast tracking allows the approval process to proceed at a much faster pace than other projects. All parties concerned (i.e., owners, architects, contractors, politicians, approving and planning agencies, and taxing authorities) have a vested interest in returning to normal quickly after a devastating fire. However, rebuilding on the same footprint may not be sound fire protection. The same terrain, fuel and weather conditions that combined for the first devastating fire will occur again. Unless fire problem mitigation measures are instituted the rebuilt structure will probably fall victim to another devastating WUI area fire.

7.9.2 MOBILE HOME PARK MODEL

The mobile home cluster model consists of simple massing shapes without reentry corners. The scaled size of each model home is within the typical range of dimensions of doublewide mobile homes (i.e., 28 feet wide and 42 to 50 feet long). The spacing between the mobile home models is a scaled distance of 40 feet. The model closest to the fire shield is a scaled 25 feet away from it. The models were placed with the length of the models opposing the airflow, with the position of the longitudinal axis opposing the apparent wind direction so that greater surface area could be viewed. Lower exposure to wind-driven firestorms would result with the width of the mobile homes, or any other structure, positioned towards the airflow direction.

The smaller surface area exposed to prevailing air movement, the lower impact flames and ember wash will have on the structure.

The Mobile Home Park model was used with all models of fire shields (i.e., linear; convex; concave, and inclined). The windward-positioned mobile home model was provided greater airflow protection than any of the mobile homes in the park layout. With the Inclined Fire Shield there was less air movement impact on this model, as evidenced by tuft movement and smoke positioning. This observation promises that WUI fire loss may be reduced significantly, as most loss occurs on the windward side. This relationship of air movement directing the most destruction on the windward leading edge, second row of windward direction, and flanks of development was found to be critical in the after-action study of the Witch Creek WUI fire in “Mega Fires: The Case for Mitigation” (Institute for Business & Home Safety, 2008). The Witch Creek Fire study also suggests that flank protection of mobile homes needs to be provided. An Inclined Fire Shield with an ember catcher encircling the park would provide the greatest protection.

7.9.3 GABLE ROOF MODEL

The gable roof model has scaled dimensions of 40 feet long by 14 feet wide and 14 feet tall. This model, with its simple mass design and gable roof, was selected for the windtunnel tests due to its greater wall and roof height. The Gable Roof model was used with all basic types of fire shields (i.e., linear; convex; concave, and inclined). The model length was positioned facing the wind for greater exposure to airflow. For greater fire resiliency, a structure would limit its wind obstructing profile by positioning the width towards the windward side. The windtunnel airflow had the greatest impact on this roofline due to its shape. The inclined portion of the gable roof uplifted airflow higher than any other models. This phenomenon did not exist with the other structural models, as they were flat roofed, and had no tendency of uplifting airflow aside from the walls.

The photographs of the gable roof model may be misleading, because the immediate ground tufts were attached in a forward bending position and did not move from this position. This indicated that there was insufficient airflow to bend the tufts in an opposite direction.

7.9.4 LOW PROFILE MODEL

The Low Profile model was fabricated with a roof lower than the fire shield protecting it. Although the same fire shield models were used in all of the windtunnel runs, the low profile model due to its relatively low roofline, transformed the fire shield models into high profile fire shields. The low profile model had a scaled height of eight feet, while the fire shields that were used with it had a scaled height of 10.5 feet. The scaled height differential is 2.5 feet, which is the same 30 inches minimum height required for a parapet four-hour fire rated exterior wall to extend above the roof (International Code Council 2007). The low profile model tests validated the relatively greater airflow divergence away from structures, provided by High Profile Structural Fire Shields.

7.10 FOLLOW-UP STUDIES

7.10.1 STRUCTURE FIRE SHIELDS

There are several significant areas of further study that were identified during the windtunnel test of structural fire shields. Principal among the areas needing further study is the efficacy of external fire shields for increased fire protection in WUI areas. The promising results of the windtunnel trials performed are an innovative concept of mitigating wildfire caused structure loss. The author encourages further research into the concept of increased fire resiliency using enhanced windtunnel tests, fire tunnel tests of models, wind modeling programs, or actual field testing. Wind modeling programs offer a significant potential for use in determining the aerodynamic properties of structures and airflow dynamics created from variations in terrain-modifying wind direction and speed.

7.10.2 EMBER CATCHERS

Another concept needing further validation involves ember-catching mechanisms attached atop external fire shields. These offer increased fire resiliency as compared to structural fire shields, because ember washes account for the greatest amount of wildfire-related fire loss. The potential for significant reduction in home loss in WUI fires is staggering, as indicated in the study of the Witch Fire in San Diego, California, “Mega Fires: The Case for Mitigation”: “There were few, if any, reports of homes burned as a result of direct contact with flames.” (Institute for Business & Home Safety 2008, 9). Follow-up studies in specially-equipped windtunnels, fire tunnels or through empirical field research would provide additional validation.

7.11 FINDINGS

7.11.1 MODEL SIZING

Greater accuracy and result definition would occur if the scale of the models were to be increased. Visibility would also increase with larger models, allowing greater detail of airflow. At the Cal Poly windtunnel facility there existed two limitations: entering the model into the windtunnel through a 14 inches by 21 inches access plate and the Blockage Effect. The access of models into the windtunnel was the limiting factor in determining the actual size of the models and their corresponding construction scale. The other limitation, the Blockage Effect, limited the size of the models to a cross-sectional dimension of 5 to 10% of the cross-sectional area of the windtunnel.

7.11.2 SMOKE USE

Additionally, changes to the tools used would enhance the windtunnel trials. A smoke wand with a greater smoke-emitting capacity would be needed to correspond with increased model size.

7.11.3 LASER ILLUMINATION

The use of a laser for mid-smoke illumination would greatly increase the viewing of air movement inside the tunnel. A bright laser would make the smoke more visible and facilitate viewing the smoke movement in the middle of the smoke layer, instead of on the periphery. This would be possible with a vertical laser aimed at a mid-barrier position above a stipulated vertical plane. The observation of highlighted the mid-section smoke was not feasible during the windtunnel tests, which would have resulted in recording and observing airflow with greater accuracy.

7.11.4 PRESSURE TRANSDUCERS

Pressure transducers were not used during the windtunnel tests, because there were working problems with their use on structural and terrain models. Pressure transducers could possibly provide air speed and pressure readings at designated points.

A relative pressure differential would distinguish greater pressure from lower, indicating a change in airflow velocity. Pressure transducers used for structural models airflow recordings would only obtain the velocity of airflow off the surface of the model. The pressure transducers would have to be placed in the airflow and not on the surface of the model. Calculations are necessary to correlate the changes in air movement from increased or decreased pressure readings provided by pressure transducers. Pressure transducer measurements of the airflow off the model surface could result in a better understanding of the aerodynamics of fire shields and ember catchers.

7.11.5 TUFT ACTIVITY

The tufts became saturated with smoke fluid and experienced a decreased ability to move with air movement, during multiple two-to three-minute runs with the same fire barrier model or structural model. There was a tendency for the tufts to be weighted down with smoke fluid, if the smoke was used for more than five minutes on the same model. The saturation time was lowered if the smoke wand was placed within six inches of the model. Careful placement of tuft fibers in a vertical position on horizontal surfaces is required for the accurate depiction of airflow. Under varying conditions, a few tufts were mounted on models in a position that gave false indications of airflow. With both saturation and misleading placement of the tufts, the air velocity and turbulent flow exhibited by some tuft movement was significantly reduced.

7.11.6 FIRE SHIELD VORTICES

All fire shield models during the windtunnel tests had swirling turbulence or vortices at the ends of the walls. This is one feature that needs to be planned into the design of structural fire shields when the ends of the walls are within 10 feet of the building.

7.11.7 AIRFLOW INTRUSION

Caulking the bottom of fire barrier would prevent wind intrusion at the bottom of external fire barriers if the excessively large gaping conjunctions of the wall required it. During the windtunnel tests smoke that was observed to enter behind the Linear External Fire Shield was difficult to differentiate from the smoke moving above and around the ends of the model shield.

7.11.8 ENLARGED PHOTOGRAPHIC IMAGES

A close-up lens would provide greater detail of smoke and tuft movement around structural and fire shield models. The greater detail would increase the accuracy of the tuft and smoke movement recording.

7.11.9 VIDEO RECORDING

A URL link to a video site such as UTube or Facebook could provide video coverage of windtunnel trials. Video, instead of still photography could have provided moving results. Graphically showing tuft movement, especially the whipping tips, would enhance the understanding of airflow around structures and fire shield aerodynamics.

CHAPTER EIGHT

8.1 CONCLUSION

8.1.1 INTRODUCTION

The conclusion of this thesis will be presented in descending order of importance and depth of coverage of the material, beginning with the objectives, and ending with individual items of structure fire resiliency. The objectives of this thesis are twofold. First is to assess the fire threats posed to individual structures, and to entire developed areas within WUI regions. Second, to propose enhanced fire mitigation measures for structures at risk of burning during interface fires. The author believes that these measures will improve structure fire resilience beyond existing design, construction and defensible space guidelines. This conclusion is based on the author's fire service experience, literature searches, and experimental research conducted at Cal Poly, San Luis Obispo. The credibility of this statement is validated by the results of wind tunnel tests, case studies, interviews, and literature research. The greatest potential for improving the fire resiliency of structures located in WUI fire-prone areas is recognizing the impact that airflow has on fire spread, flame length development and ember carrying ability. Airflow is a combination of prevailing wind, thermal currents, orthographic currents, convected heat and turbulence. Further, on a micro-level, airflow has been identified as a prime determinant of flame length variance, increased burning intensity, and direction of fire spread beyond the standard models of fire behavior that rely largely on factors such as of fuel, weather and terrain.

The research and background of the author combined to produce several aspects of assessing and improving fire resiliency. A significant portion of Chapter Five, the Fire Profile Index, Developers Guide, and Fire Assessment Guide, contains several fire threat mitigating features of design, construction, and landscaping. The Structure Fire Shields of Chapter Seven offer design options of noncombustible walls, which channel airflow as a mitigation measure when sufficient defensible space is not an option, or when increased fire resiliency is warranted.

Several configurations of flame and ember shields are presented in the form of differing arrangements of walls placed between structures and the projected direction of the oncoming severe to extreme fire spread. The concept of Structure Safety Zones, discussed in Chapter Six, determines the extent of sufficient defensible space, and defensible space criteria. Further mitigating measures are discussed in this chapter. These include berms and plantings as additional ways of increasing fire resiliency for structures and occupant safety beyond the requirements of building codes and fire codes. Finally, the concept of faux subterranean construction and, its application under the most extreme fire threats conditions is discussed at the end of this chapter.

8.1.2 INCREASING WUI FIRE PROBLEM

There are a number of factors that in combination can exacerbate the worldwide WUI fire problem, in Southern California, in particular. Increased population, forests with highly flammable fuels, forests and chaparral areas with greater amounts of dead fuels, and long, dry, hot summers abound in this locale. People are building and living in areas where fire is part of the natural lifecycle of the vegetation. The fire losses will grow as development continues to encroach into wildland areas. Fully one-third of homes in the United States are now located in what fire safety officials call the WUI, or Wildland-Urban Interface (Institute for Business and Home Safety 2008). There are over 5 million homes in the WUI areas of California alone, and nationwide over 60 % of new development is located within or adjoining to WUI areas (Institute for Business and Home Safety 2008). The importance of WUI fires is not only due to increasing losses in terms of dollars, injuries and lives, but because of the potential impact on society as a whole. As an example, during the Southern California Fire Storms of 2003 and 2007, approximately 7,000 structures were destroyed in High to Extreme Fire Threat Zones in WUI areas (Mission-Centered Solutions and Guidance Group 2003; Office of the State Fire Marshall 2010). The growing fire loss in WUI areas is the result of both natural factors and anthropogenic factors. Anthropogenic factors arise from a combination of population growth, development, and both governmental and private policy decisions.

In addition to the migration of the Wildland-Urban Interface into fire-prone areas since World War II, a chief factor exacerbating the fire problem has been the “fire exclusion” policy adopted by most governmental agencies. This policy, driven by increased population and air pollution reduction controls, has greatly interfered with the natural cycle of forest rejuvenation. Regulations, plus fire suppression and fire prevention activities have virtually eliminated frequent low-intensity burning in WUI areas. As fire was prohibited from being used as a tool to increase the health of forests including chaparral, the health of the forests has declined. This diminution of forest health has produced an even greater fire risk for Southern California, by causing a significant accumulation of dead vegetation. In some cases, chaparral and woodlands have completely invaded and supplanted grassland biomes (Barbour 2001). Since Fire Exclusion Policy came into being, the fires that do occur burn with greater intensity and tend to spread to much larger areas (Ritter 2004). While it may be argued that the Fire Exclusion Policy has been successful throughout much of the nation, it tends to increase the wildfire threat in high risk WUI areas such as Southern California. Here, chaparral fires are driven by Santa Ana winds, and are not usually controlled within any one burn period (Keeley 2006).

8.1.3 INTERNATIONAL IMPLICATIONS

The WUI fire problem is a complex and unique worldwide threat. The development in fire prone areas has been driven, in large part, by the phenomenon of people moving to areas of high natural amenities, sometimes called “Amenity Migration.” This phenomenon, besides being widespread in the United States is occurring in many other parts of the world, including the European Alps, Norway, Philippines, Czech Republic, and New Zealand. The population living in WUI areas has increased from 25 million to 140 million from 1960 to 2000 (Bailey 2007). The worldwide WUI fire problem is significantly more severe in the five Mediterranean climate areas of the world, which includes Southern California.

A number of other factors contribute to the significance of the WUI fire problem in Mediterranean climate areas: increased population; forests with highly flammable fuels; forest areas with greater amounts of dead and drought stressed fuels; and extreme fire weather conditions.

Southern California epitomizes the most severe WUI fire problem anywhere on earth (Stephens 2006). Figure 8.1 shows the five Mediterranean climate areas from a global perspective.

Figure 8.1: Mediterranean Climate Areas
<http://www.grabovrat.com/mapsViews/mapsViewsFig/mapsViews800.gif>

The Mediterranean forests, woodlands, and shrub biomes are closely associated with their climate conditions. The wet winter and dry summer seasonality of precipitation is the defining characteristic. The summer drought places a great deal of stress on the local vegetation, but plant structures have evolved and adapted to the climate and fire. Another driving force are the foehn winds that occur frequently in the late fall and winter in the mountain states of the western United States, Europe, and Mediterranean climate areas of the world (Fovell 2008).

Chaparral and its Mediterranean climate equivalents are generally considered medium to heavy fuels (Scott and Burgan 2005). The coastal mountain ranges are forested with chaparral vegetation. Chaparral plants are adapted to dry hot summers thus, drought tolerant. These plants can survive without significant rainfall for upwards of six months. Because of the drought tolerance, the chaparral forests have unusually high flammable oil content and a significant percentage of accumulated dead growth (Fovell 2008).

These plants are known in California woodlands as chaparral, in Chile as matorral, in Australia and New Zealand as mallee scrub or kwongan, and in the Cape Province of South Africa as fynbos (Ford 2008-A). For explanatory purposes in this thesis, California chaparral will serve as the principal example of sclerophyllous plants. The similarities of soft-type sclerophyll plants from Mediterranean Climate biomes are shown in Chapter Two, Figures 2.21 through 2.23, and Appendix A.

Foehn winds not only exist in Southern California, but in all Mediterranean Climate areas. Worldwide examples of foehn include: Skysweeper over Majorca, Spain; the Aspre wind over the Garonne plain of France; Bergwind over the southern cape of South Africa; and Föhn or Southcoast wind over Australia. The airflow and compressive heating characteristics are similar for all these foehn winds. As an example, the direction of the Bergwind, much like the Santa Ana, is locally changed due to barriers posed by the position and forms of mountain ridges on the windward side of forests. The airflow is then channelled through valleys and canyons running from the mountains (Aerographer/Meteorology 2008). The combination of climate, weather and fuels produce a severe environment for fire worldwide. When development occurs in these areas prone to fire, a dangerous and explosive situation results.

8.1.4 SIGNIFICANCE OF AIRFLOW

Every large-loss WUI fire in Southern California has occurred during a foehn wind event. As an example, the 1961 Bel Air Fire in Los Angeles, California burned during an intense Santa Ana episode. Firebrands were carried over a mile in advance of the main flame front by the wind (Fovell 2008). The Freeway Complex Fires in Los Angeles County and Orange County, and the Sayre Fire in Los Angeles, all occurred within a few days of the Tea Fire in the Santa Barbara region during November 2008. These all occurred during foehn wind events (Fovell 2008). The winds occur as far north as Ventura County, and frequently occur in Los Angeles County, Orange County, Riverside County, San Bernardino County and south into San Diego County (Fovell 2008). Terrain affects airflow by increasing or decreasing velocity and redirecting it (Fovell 2008). The concept of the terrain shape modifying wind is examined in the preceding discussion of Foehn Winds in Chapter Two, Section 3.3.2, and Fire Behavior Analysis of Chapter Four, Section 4.5.2.

The overriding principle for the increased fire resiliency of structures in WUI areas is the reduction of turbulent airflow by aerodynamic shaping of the building envelope, adequate defensible space as determined by Structure Safety Zones, and airflow diverting mechanisms, such as Structure Fire Shields.

8.2 FIRE ASSESSMENT CONTRIBUTIONS

8.2.2 FIRE PROFILE INDEX

The Fire Profile Index is the content of Chapter Five, and is the principal innovative concept presented in this thesis. It was created from a review of literature, interviews, and the professional background of the author. The Fire Profile Index is a catalogue of over 250 factors that aid in assessing the fire potential for increased resident and first responder fire safety, and improved fire resiliency of structures in WUI areas. The Fire Profile Index is intended for use by fire professionals, planners, developers, and policy makers concerned with those living and working in WUI areas. It is intended to be a WUI fire potential assessment tool for knowledgeable individuals to determine the relative fire threat present and for possible need of mitigating measures. Two other contributions for improved fire assessment in WUI areas result directly from the Fire Profile Index. The first of these two derivatives is the Fire Assessment Guide, intended to estimate the potential fire behavior of a given property or area. The second derivative is the Developers Guide, which is essentially a compilation of design and construction factors that affect the WUI fire resiliency of a structure.

The Fire Profile Index is intended to be used by persons with knowledge of the WUI fire problem, but significantly less than that of an interface fire behavior expert. The Fire Profile Index is located in Appendix I as Table I.1. The accompanying strategy codes, explaining possible mitigating strategies are shown in Chapter Five as Figure 5.2 and in Appendix I, Figure I.2. The Fire Profile Index is in a spreadsheet format that includes point ranges, or stated points, for each of the fire threat or fire remedy attributes. The spreadsheet format facilitates an accounting of the fire resiliency factors affecting a structure. The cumulative value of the Fire Profile Index can exceed 1,000 points. A total value below 500 points groups the structure in Category I, indicating that the fire resiliency will likely be maintained throughout a severe firestorm. A point total of between 500 and 750 indicates that the structure is likely to survive a severe interface firestorm with the aid of trained and adequately equipped personnel, and is a Category II classification. A total point value of over 750 indicates that the structure is unlikely to survive a severe fire storm, even with the aid of trained firefighting personnel. This point total indicates a structure located in a Category III fire threat environment.

A Category III assessment is an indication that the structure will be a likely to be “write-off” in a structure triage situation (Section 2.1 of Chapter 2) performed by fire service personnel. The Fire Profile Index categories are general and flexible; however, the use of this index is intended to be employed with discretion.

8.2.3 DEVELOPERS GUIDE

The Developers Guide is a compilation of 100 design and construction factors essential in determining the fire resiliency of structures. It is a subset of the Fire Profile Index composed of individual design, construction, and building features that are known to enhance fire-resistivity. Also included in the Developers Guide are the characteristics that contribute to the burning potential of a structure. The intended users of the Developers Guide are designers, contractors, developers and planners. In addition, firefighters can gain insight into the flammability of structures in WUI areas by using the Developers Guide as a training aid, or during pre-action assessments. The intent of the Developers Guide is to be a fire safety building and design reference for the establishment of increased fire safety in WUI areas.

8.2.4 FIRE ASSESSMENT GUIDE

The Fire Assessment Guide is another derivative of the Fire Profile Index. It is a compilation of 38 categories of items assessing the fire potential in terms of flame length, burning intensity, and spread. The incorporation of fire and wind modeling programs, found best suited in the Fire Modeling Programs in Chapter Three, was used to validate the fire potential characteristic composing the Fire Assessment Guide. The intended users of the Fire Assessment Guide are firefighters and those concerned with fire behavior on structures during firestorms. Design and development professionals could benefit from this guide for determining the fire threat for a particular development. The Fire Assessment Guide, as compared to the Fire Profile Index, is most useful after a fundamental understanding of wildland fire behavior has taken place.

8.2.5 FIRE MODELING PROGRAMS

The objective of examining several different wind-modeling and fire-modeling programs was to arrive at a micro-level fire simulation model that can be applied to individual structures or entire developments. No wildland fire modeling program was found that has a sufficiently small enough resolution for this purpose. Nonetheless, several computer modeling programs were reviewed and two were selected for validating the fire behavior predictions made by the Fire Profile Index and through the analysis of case studies. The programs provided the foundation for the Assessment Guide and case studies, and were incorporated within the Fire Profile Index for the purpose of enhancing its accuracy. To confirm validity, the fire behavior projected by the Assessment Guide was compared to historic fire behavior. The BehavePlus and Wildland Tool Kit software packages were used for determining worst case fire behavior by entering data that duplicates the terrain, fuel and weather variables for a particular location. Refer to Chapter Four, Section 4.5.2, Fire Behavior Analysis for details.

8.3 CONTRIBUTIONS MADE BY MITIGATING MEASURES

8.3.1 STRUCTURE SAFETY ZONES

Structure Safety Zones are a method of determining whether the code required defensible space is adequate. The Structure Safety Zones concept is a site-specific determination of adequate defensible space that should allow a WUI model code-compliant structure to survive a severe interface firestorm, without the intervention of trained firefighters. With the use of the Assessment Guide and computer modeling, flame lengths are determined for a particular location, by assuming worst-case fire conditions. If adequate defensible space is not present, additional mitigating design or ignition-resistant construction features are indicated, such as Structure Fire Shields for reasonable fire resiliency. Properties with greater fire hazards, such as heavier fuel loading, steep slopes and chimneys may require more than 200 feet of defensible space, recommended by the Los Angeles County Fire and National Fire Protection Association (Los Angeles County Fire Department 2010; National Fire Protection Association 2008-A). Structure Safety Zones can determine what is sufficient defensible space, and thereby increase structure survivability. Also, Structure Safety Zones will help increase occupant and firefighter safety by allowing firefighters to protect structures, without facing unacceptable risk to their lives (State Board of Forestry and Fire Protection 2006).

The adequate defensible space determined by Structure Safety Zones calculations initially involve an evaluation of the fire threat posed to the concerned structures. The Structure Safety Zones defensible space distances are calculated by the greatest flame length posed on each dissimilar fire hazard side of the structure, and then adding 100 feet to that distance. If the calculated flame length exceeds 100 feet, then the flame length is doubled. The calculation of flame length includes several fire behavior factors. The influences of the variations in topography, airflow, relative wind direction to uphill slope, and fuel conditions exist in differing combinations and effect on fire behavior surrounding structures. The entered fire behavior factors are selected from historical worst-case scenarios of unfavorable fire danger conditions; for example, weather conditions that include temperature, relative humidity, wind gust speed and direction. The topography inputs include slope percentage, aspect, and presence of special terrain influences of chimneys and saddles.

The special terrain factors are identified in Chapter Two, Sections 2.4.3 and 2.4.4, and flame length conversion factors determined in Chapter Four, Section 4.5.2 and are used to determine flame lengths in Section 6.1.4 of Chapter Six.

8.3.2 STRUCTURE FIRE SHIELDS

The overriding principle for the increased fire resiliency of structures in WUI areas is the reduction of turbulent airflow by the aerodynamic shaping of the building envelope. Structure Fire Shields offer the potential of significantly increasing the fire resiliency of new construction and retrofitted structures. The concept of an external fire shield is to limit the flame contact to structures and reduce the impact of embers on structures. This is achieved by constructing external fire-resistive obstacles to airflow and its accompanying flame and ember travel. All structural models used in the wind tunnel tests were simple mass structures. This shape reflects the sound WUI area fire resiliency principles of eliminating reentry points and entrapping corners. Such structural design principles reduce airflow turbulence and reduced airflow entrapment. Similarly, all the structural model shapes, excluding the Tea Fire Rebuild, have flat or simple gable roofs and simple massing shapes. The Tea Fire Rebuild Model can be seen in Figure 8.2.

*Figure 8.2: Tea Fire Scale Rebuild Model
(MesKimen Thesis Collection)*

The shapes of the roofs and structures introduce a minimal amount of airflow obstruction, thus reducing turbulence. The decreased airflow turbulence results in reduced flame and ember intrusion into structures.

The actual structure that the Tea Fire Rebuild model was patterned on is being rebuilt on the same footprint as the WUI fire-destroyed residence. The building approval process is being “fast-tracked” because of rebuilding on the footprint. Fast tracking allows the approval process to proceed at a much faster pace than other projects. All parties concerned (i.e., building owners, architects, contractors, politicians, approving and planning agencies, and taxing authorities) have a vested interest in returning to normality as soon as possible after a devastating fire. However, rebuilding on the same footprint may be problematic. The same terrain, fuel and weather conditions that combined for the original devastating fire can easily occur again in the future. Unless fire problem mitigation measures are instituted, the rebuilt structure is likely to be destroyed again when another interface fire occurs under similar conditions.

The wind tunnel test of external fire shields included several configurations of Structure Fire Shields. The conclusions from the observations of the wind tunnel tests for each of the configurations are included here. Concave Structural Fire Shields were used for each of the scale model structures, excluding the Tea Fire Rebuild model. The flow characteristics of the concave fire shield were similar for each of the structure models. The scaled height of this external fire protecting barrier was either five feet or 10 feet depending on the model used. The airflow characteristics were duplicated for both heights during windtunnel runs. The concave shape tended to move air inward from the extremities of the arch with increased airflow towards the center of the arch. This occurred in much the same manner as a parabolic reflector concentrates light rays in the center of a dish. A concave fire shield will tend to move fire and embers away from the peripheries of the arch towards the midpoint of the arch. The positioning of a building should be towards the outer limits of the fire protecting barrier arch, away from the apex. The positioning of a concave fire shield between the projected fire spread and a structure is counter-indicated, because embers and flames would be channeled onto the structure. Figure 8.3 is a schematic of concave and convex fire shields, with simplified airflow vectors, indicated by arrows.

Inclined structure fire shields produced a uniform movement of air along the length of the wall with reduced air turbulence behind the wall. The air movement tended to uplift and stay at a higher elevation than any of the wall types. The turbulence was consistently and significantly reduced behind the ramp-type wall. For increased ember protection, a wire mesh extending the height of 20 feet could be installed. At the ends of the inclined fire shield, there was less turbulence than with any other type of external fire shield that was tested. Even with the Gable Roof model with a scaled height of 14 feet, the inclined fire shield lifted air to a significantly greater height than all of the other fire shields. There was a near void of air turbulence between the inclined face of the wall and the wall surface of the models, indicating the effectiveness of the lifted airflow. With the low profile structural model there was even less tuft movement and smoke-indicated air turbulence than with any other model. Figure 8.4 is a schematic of the airflow around a Linear Structural Fire Shield and a High Profile Inclined Structural Fire Shield, with the airflow vectors indicated by arrows.

The Linear Structure Fire Shield is a straight wall constructed with fire resistive and noncombustible materials, such as masonry products, including cement masonry units. Linear fire shields should have a minimum height of five feet above grade, and extend a minimum of five to 10 feet past the protected structure. During the windtunnel tests, a swirling air movement was observed at the ends of the wall, within a scaled distance of five to 10 feet. A uniform distribution of air movement over the top of the wall with reduced turbulence was also observed. From these observations, the author concludes that the linear configuration focuses smoke and air movement vertically and uniformly up and over the entire wall length. The linear style of wall was tested with all of the model structures, except the Tea Fire Rebuild. The air movement was similar with each model, and the air turbulence void was estimated at a distance of one to one and one-half the height of the wall. The relative amount of smoke behind the Linear Fire Shield was significantly less than the concave wall, but was more than the convex, inclined, and high profile walls. A schematic of a Linear Fire Shield is shown in Figure 8.4.

*Figure 8.3: Concave and Convex Structural Fire Shields Schematic,
Airflow Vectors Indicated By Arrows
(MesKimen Thesis Collection)*

The Convex Structure Fire Shield holds the greatest potential for mitigating severe fire threats to existing structures in WUI areas. During the windtunnel tests, the air movement was consistently away from the center of the arch towards the ends. This airflow characteristic occurred with varying wind speeds. As is the case with every external fire shield, a swirling turbulence existed at the ends of the wall. This turbulence requires compensation in the design of the fire barrier. Figure 8.3 is a schematic of Concave and Convex Structure Fire Shields, with simplified airflow vectors. Figure 8.5 is a photograph of a naturally formed convex fire shield. This fire shield configuration offers the greatest potential for fire resiliency of any of the vertically walled fire shields. The proportionate amount of arch (90°) relative to the length of the building models ensured desirable aerodynamic results during the windtunnel tests.

A minimum arch of 90° produced acceptable fire resiliency effects, but increasing the size of the arch and circumference would have produced greater benefits. A complete circling of a structure by a Convex Fire Shield will result in the optimum divergence of airflow away from the protected structure. The fire shield will offer protection from any direction of fire threat. The height and positioning of the fire shield could vary corresponding to the flame length and wind speeds at specific areas.

Figure 8.4 Airflow Schematic of Linear Structural Fire Shield and High Profile Inclined Structural Fire Shield With Arrows Depicting Airflow (MesKimen Thesis Collection)

The High Profile Structural Fire Shield describes an external fire shield that extends above the top of the roof. A high profile wall should extend above the top of the roof by a minimum of 30 inches. An inclined fire shield provides additional lift, and another 30-inch of height may not be necessary.

*Figure 8.5 Environmental Example of Convex Fire Shield
(firenist.gov/bfrlpubs/fire09/PDF/f09028.pdf)*

This height correlates with the 30-inch extension above a roof required for a fire resistive parapet wall, as specified in the *International Building Code* (International Code Council 2007). A lower height may prove sufficient, but the code requirements have been tested and rated for building code satisfaction. The High Profile Structural Fire Shield offers the greatest fire protection of any of the fire shield configurations, with a significantly greater assurance of fire resiliency from flame impingement and ember wash. If the high profile wall were to be integrated into the building envelope, a four-hour fire rated construction would be required. Any openings, including doors and windows, would require a minimum three-hour fire rating as specified by the *International Building Code* (International Code Council 2007). An equivalent of a high profile external fire shield is shown in Figure 8.6 for the faux subterranean structure.

Wildfire inhibiting features can exist along with fire hazards in the environment. A naturally formed rock terrain feature can mimic the airflow a characteristic of a convex external fire shield is shown in Figure 8.5.

The rock arrangement on the outcropping of a point approximates the alignment of a convex fire shield. Note the burned vegetation on the outside or ends of the natural arch (indicated by red arrows), and the unburned trees near the center of the arch (indicated by green arrows). This noncombustible inorganic composition disallowed significant vegetation growth, thereby reducing fire loading. An architect or designer can take either advantage of terrain features for greater fire resiliency; or unnecessarily expose structures to greater hazards.

Linear Structure Fire Shields and Convex Structure Fire Shields are projected to be the most promising types of fire protecting barriers for retrofit. In a comparison of linear and convex fire shields, convex fire shields displace greater airflow from their midpoint than do linear fire shields, and therefore will offer greater fire protection to buildings. However, the linear fire shield should be the preferable retrofit. The reason for this is simplicity of installation. The linear style has a straightforward design compared to arching walls. Inclined fire shields, although more effective, will require significantly more earth moving and structural reinforcing than linear fire shields, and as such represent a more limited retrofit option. Concave fire shields are effective fire protecting barriers, but their appropriate installation is for significantly limited applications. If concave fire shields are inappropriately placed, they can increase the possibility of fire spread into a building.

8.3.3 FIRE SHIELD EQUIVALENTS

The author's firefighting experience and intuitive thinking suggests that superior ember protection can be provided through the modification of external fire barriers by erecting steel screening above them. Wind tunnel experiments were conducted on scale-model structures and mobile homes to simulate ember and flame flow against fire mitigating measures. Through this process, the author gained invaluable knowledge used to substantiate his thesis theories. Landscaping features, including plantings, are additional forms of fire shielding affects. Certain terrain features can be taken advantage of to increase fire resiliency, such as shown in Figure 8.5.

Further, subterranean construction and minimal height profile designs of building envelopes offer the greatest protection against the most severe fire threats. Such structures are seen in Figure 8.6 and 8.8. This type of construction is a faux subterranean structure (i.e., it is not completely buried and has one or more sides exposed).

Figure 8.6: Faux Subterranean House Under Construction, Survived the Tea Fire
(<http://blkswanstudios.com/teafirearea1/set2/>)

Roof options, offering greater fire resistance than conventional Class A-rated roofs, consist of various configurations of flat roofs. Concrete roofs, pool roofs, sod, and green roofs are recommended as improved fire resilient designs over conventional Class A-rated pitched roofs. The structure, pictured in Figures 8.6, 8.7 is a sod and concrete roofed house, and the structure in Figure 8.8 is a pool roofed house. The structure in Figure 8.6 was under construction at the time of the Tea Fire in the Santa Barbara region of California. Figure 8.7 is a rendering of the structure, indicating that the backside of the structure is excavated into the hillside. The faux subterranean structure was insulated by the terrain, and the fire went over the top of the roof with minimal impact and turbulence.

Figure 8.7: Rendering of House Under Construction
(<http://aiasb.com/events/aawHome/aawHomeTours/radtkey.html>)

Figure 8.8: Faux Subterranean House with Pool Roof
(<http://www.aiasb.com/events/ArchitecTours2010/myers.htm>)

The author visited the house on a tour in September 2009, and verified the positioning of the structure, and the spread direction of the Tea Fire towards it. Also, excavated into the hillside are the pool roofed structures of Figure 8.8. The pool roofs have the dual purpose of reflecting ponds and fire resiliency enhancements. The water in the pools provides additional noncombustible insulation.

Both of properties shown in Figures 8.5, 8.6 and 8.7 are located in the Santa Barbara area. The extreme fire threat is from Sundowner Winds (Chapter Two, Section 2.3.2) that blow downhill towards the Pacific Ocean. The positioning of the structures coincidentally enhances their fire resiliency, because the excavated backsides of the structures are positioned towards the principal fire spread. Due to the thermal mass of the hillside, plus its wind buffering effect, these structures have the significant fire resiliency of subterranean structures. However, this mitigating terrain condition does not apply to most severe WUI interface situations, and therefore skillful fire resilient design is the alternative for enhanced structure and life safety.

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APPENDIX A

PLANT LISTINGS &
ILLUSTRATIONS OF HARD CHAPARRAL
(*Hard Chaparral, # Soft Chaparral)

COMMON NAME	BINOMIAL NAME	SECTION	PAGE
Bitterbrush	<i>Purshia tridentata</i>	1.2.2	page 5
Blackberry	<i>Rubus fruticosus</i>		
Black sage#	<i>Salvia mellifers</i>		
Buckwheat#	<i>Eriogonum fasciculatum</i>		
Bunchgrass	<i>Festuca idahoensis</i>	1.2.3	page 2
Buckeye#	<i>Aesculus californica</i>		
California lilac#	<i>Ceanothus</i> spp.		
California sagebrush#	<i>Artemisia californica</i>		
California sunflower#	<i>Encelia californica</i>		
Canyon sunflower#	<i>Venegasia carpesioides</i>		
Ceanothus, bigpod*	<i>Ceanothus megacarpus</i> var.	1.2.2	page 7
Ceanothus, snowbrush*	<i>Ceanothus velutinus</i>	1.2.2	page 5
Chamise*	<i>Adenostoma fasciculatum</i>	1.2.2	page 3
Cherry*	<i>Prunus</i> spp.		
Choke cherry*	<i>Prunus virginiana</i> var.		
Christmas berry*	<i>Heteromeles arbutifolia</i>		
Coffeberry*	<i>Ramnus californica</i>		
Corydalis	<i>Corydalis semprevirens</i>	1.2.2	page 5
Coyote bush#	<i>Baccharis pilularis</i>		
Cypress	<i>Cupressus</i> spp.	1.2.2	page 7
Cypress, MacNab	<i>Cupressus macnabiana</i>	1.2.2	page 5
Cypress, Monterey	<i>Cupressus macrocarpa</i>	1.2.3	page 3
Cypress, Sargent	<i>Cupressus sargentii</i>	1.2.2	page 5
Deer grass	<i>Muhlenbergia rigens</i>	1.2.3	page 3
Deer weed#	<i>Lotus scoparius</i>	1.2.3	page 5
Fir, Big-cone Douglas	<i>Pseudotsuga macrocarpa</i>	1.2.2	page 6
Flannelbush*	<i>Fremontodendrum</i> spp.		
Elderberry	<i>Sambucus</i> spp.	1.2.3	page 2
Geranium	<i>Geranium bicknellii</i>	1.2.2	page 5
Gooseberry	<i>Ribes</i> spp.	1.2.3	page 2
Grape, Oregon	<i>Berberis</i> spp.	1.2.2	page 6
Grape, wild	<i>Vitus californica</i>	1.2.3	page 2
Hazelnut	<i>Corylus cornuta</i>	1.2.3	page 2

Laurel sumac#	Malosma laurina		
Lily, mariposa	Calochortus spp.	1.2.2	page 6
Lupines#	Lupines spp.		
Manzanita*	Artostaphylos spp.	1.2.2	page 3
Maple, bigleaf	Acer macrophyllum	1.2.3	pg 2, 6
Monkey flower bush#	Mimulus aurantiacus		
Mountain mahogany*	Cercocarpus betuloides		
Mountain misery	Chamaebatia foliolosa	1.2.2	page 6
Oaks	Quercus spp.	1.2.3	page 2
Oak, black*	Quercus kelloggii	1.2.2	page 6
Oak, blue*	Quercus douglasii	1.2.3	page 5
Oak, coastal live*	Quercus agrifolia		
Oak, interior live*	Quercus wislizenii		
Oak, valley*	Quercus lobata	1.2.3	page 5
Pine, bishop	Pinus muricata	1.2.2	page 6
Pine, foothill*	Pinus sabiniana	1.2.2	page 5
Pine, knobcone	Pinus attenuata	1.2.2	page 5
Pine, ponderosa	Pinus ponderosa	1.2.3	page 2
Pine, lodgepole	Pinus contorta	1.2.2	page 5
Pine, gray	Pinus sabiniana	1.2.2	page 5
Poison oak	Toxicodendron diversilobum		
Prickly pear#	Opuntia littoralis		
Raspberry	Rubus idaeus	1.2.2	page 5
Red berry*	Ramnus crocea		
Red shank*	Adenostoma sparsifolium		
Sages#	Salvia spp.		
Sage, purple#	Salvia leucophylla		
Sage, white#	Salvia apiana		
Scrub oak*	Quercus agrifolia		
Scrub oak*	Quercus berberidifolia		
Scrub oak*	Quercus ilicifolia		
Sequoia, giant	Sequoiadendron giganteum	1.2.2	page 6
Spiraea	Spiraea spp.	1.2.2	page 6
Strawberry, wild	Fragaria vesca	1.2.3	page 2
Sugarbush*	Rhus spp.		
Sumac*	Rhus spp.		
Whispering bells	Emmenanthe penduliflora	1.2.2	page 5
Willow	Salix spp.

Chilean Mattoral Hard Scrub, 7,000 Acre Wildfire December 2009
([Http://www.frakanai_linve.paces.ch](http://www.frakanai.linve.paces.ch))

Mallee Hard Scrub in Australia
(<http://www.malleeactiveplants.com.au/mallee-scrub/>)

Greece Maquis Hard Scrub

(http://www.ee_sunysb.edu/_serge/ArW-4/PHOTOS/ZASLAVSKY/List.html)

Chilean Matorral Hard Scrub

(http://frikinai_spaces.live.com/defald.aspx?_c111_BlogPart_pagedir=Next&_c11F03)

South African Fynbos Hard Scrub
(http://www.fire.uni-freiburg.de/iffn/country/za/za_14_2b.jpg)

California Hard Chaparral

(<http://www.calpoly.edu/~bio/FacultyStaff/Faculty/Holland/Polycnyn/chaprl.htm>)

California Hard Chaparral
(<http://www.biosbcc.net/b100plant/htm/hard.htm>)

APPENDIX B

FEMA DISASTER DECLARATIONS

TOTALS

MAJOR DISASTERS + EMERGENCY DECLARATIONS + DECLARED FIRE
DISASTERS

	TOTAL	129 Fire Related
Incidents		

MAJOR DISASTERS:	15 Fire Related
EMERGENCY DECLARATIONS	3 Fires (1 duplicate)
DECLARED FIRE DISASTERS	<u>111 Fires</u>
TOTAL	129 Fires & Fire Related

CATEGORIES OF DISASTER DECLARATIONS

MAJOR DISASTERS:	15 Fire Related
1810 11/18/2008	Wildfires
1731 10/24/2007	Wildfires
1498 10/27/2003	Wildfires
1005 10/28/1993*	Fire, Mud & Landslides
0958 08/29/1992*	Old Gulch, Fountain Fires
0942 05/05/1992*	Fire During Civil Unrest
0919 10/22/1991*	Oakland Hills Fire
0872 06/30/1990*	Fires
0815 09/29/1988	Wildfires
0739 07/18/1985*	Grass, Wildland, Forest Fires
0657 04/24/1982*	Urban Fire
0635 11/27/1980*	Brush, Timber Fires
0295 09/29/1970*	Forest, Brush Fires
0119 11/16/1961*	Fire (Los Angeles County)
0065 12/29/1956	Forest Fire

EMERGENCY DECLARATIONS:	4 Fires
1810 11/18/2008*	Wildfires
3279 10/23/2007*	Wildfires
3140 09/01/1999	Extreme Fire Hazards
3120 10/23/1996*	Severe Fires

DECLARED FIRE DISASTERS

111 Fires

LISTINGS BY YEAR & TYPE

2009

MAJOR DISASTER DECLARATIONS none

EMERGENCY DECLARATIONS none

FIRE MANAGEMENT ASSISTANCE DECLARATIONS 9

2841	10/04/09*	Sheep Fire
2839	09/22/09*	Guiberson Fire
2836	09/01/09*	Pendelton Fire
2833	08/31/09*	Oak Glen Fire
2833	08/31/09*	49er Fire
2830	08/28/09*	Station Fire
2828	08/28/09*	PV Fire
2825	08/15/09*	Yuba Fire
2824	08/13/09*	Lockheed Fire
2817	05/06/09*	Jesusita Fire

2008

MAJOR DISASTER DECLARATION 1

1810 11/18 Wildfires

EMERGENCY DECLARATIONS 1

3287 06/28 Wildfires

FIRE MANAGEMENT ASSISTANCE DECLARATIONS 16

2792	11/15*	Freeway Complex
2791	11/15*	Sayre Fire
2790	11/14*	Tea Fire
2789	10/13*	Senson Fire
2788	10/12*	Mareck Fire
2786	09/02*	Gladding Fire
2782	07/08*	Camp Fire
2781	07/04*	Basin Fire Complex
2780	07/04*	Gap Fire
2776	06/22*	Wild Fire
2775	06/20*	Trabing Fire
2772	06/11*	Martin Fire
2771	06/11*	Humboldt Fire
2770	06/10*	Ophir Fire
2766	05/22 *	Summit Fire

2763	04/27*	Santa Anita Fire	
2007	MAJOR DISASTER DECLARATION		1
1731	10/24	Wildfires	
	EMERGENCY DECLARATIONS		1
3279	10/23	Wildfires	
	FIRE MANAGEMENT ASSISTANCE DECLARATIONS		16
2739	10/22*	Rice Fire	
2738	10/22*	Grass Valley Fire	
2737	10/22*	Santiago Fire	
2736	10/22*	Ranch Fire	
2735	10/21*	Harris Fire	
2734	10/21*	Witch Fire	
2733	10/21*	Buckweed Fire	
2732	10/21*	Canyon Fire	
2728	09/15*	Butler 2 Fire	
2708	07/08*	Canyon Fire	
2706	07/07*	Inyo Fire Complex	
2702	06/29*	Creek Fire	
2700	06/25*	Angora Fire	
2694	05/10*	Island Fire	
2691	05/09*	Griffith Park Fire	
2683	03/11	241 Fire	
2006			
	MAJOR DISASTER DECLARATIONS		none
	EMERGENCY DECLARATIONS		none
	FIRE MANAGEMENT ASSISTANCE DECLARATIONS		8
2681	12/03	Shekell Fire	
2678	10/26	Esperanza Fire	
2677	09/26	Day Fire	
2676	09/17	Orchard Fire	
2662	07/30	Junction Fire	
2656	07/24	Horse Fire	
2653	07/12	Sawtooth Fire Complex	
2630	02/06	Sierra Fire	
2005			
	MAJOR DISASTER DECLARATIONS		none
	EMERGENCY DECLARATIONS		none
	FIRE MANAGEMENT ASSISTANCE DECLARATIONS		7
2586	11/18	School Fire	
2585	10/06*	Border 50 Fire	

2584	10/06*	Woodhouse Fire	
2583	09/28*	Topanga Fire	
2582	09/05	Sundevil Fire	
2580	08/26*	Manton Fire	
2571	07/25	Quartz Fire	
2004			
MAJOR DISASTER DECLARATIONS			none
EMERGENCY DECLARATIONS			none
FIRE MANAGEMENT ASSISTANCE DECLARATIONS			22
2555	09/13*	Old Highway Fire	
2554	09/04	Geyers Fire	
2553	09/03	Pattison Fire	
2552	09/02	Bear Fire	
2548	08/14	Lake Fire	
2547	08/14	French Fire	
2545	08/11	Oregon Fire	
2544	08/11	Bear Fire	
2541	08/08	Stevens Fire	
2540	08/07	Calaveras Fire Complex	
2535	07/21	Crown Fire	
2534	07/18*	Foothill Fire	
2533	07/18*	Melton Fire	
2532	07/14	Hollow Fire	
2530	07/14	Lakeview Fire	
2529	07/14	Mataguay Fire	
2528	07/14	Pine Fire	
2519	06/05*	Gaviota Fire	
2517	05/04	Cerritos Fire	
2516	05/04	Eagle Fire	
2515	04/26	Pleasure Fire	
2003			
MAJOR DISASTER DECLARATIONS			1
1498	10/27	Wildfires	
EMERGENCY DECLARATIONS			none
FIRE MANAGEMENT ASSISTANCE DECLARATIONS			16
2508	10/28	Whitmore Fire	
2507	10/26	Mountain Fire	
2506	10/26	Paradise Fire	
2505	10/26	Cedar Fire	
2504	10/26	Simi Fire	
2503	10/26	Old Fire	

2502	10/25	Verdale Fire	
2501	10/23	Grand Prix Fire	
2500	10/21	Pass Fire	
2497	09/06	Bridge Fire	
2491	08/19	Locust Fire	
2487	07/25	Wedge Fire	
2475	07/03	Railroad Fire	
2474	06/29	Tejon Fire	
2473	06/28	Sawmill Fire	
2466	01/07*	Pacific Fire	
2002			
MAJOR DISASTER DECLARATIONS			none
EMERGENCY DECLARATIONS			none
FIRE MANAGEMENT ASSISTANCE DECLARATIONS			12
2465	09/25	Croy Fire	
2464	09/24	Williams Fire	
2463	09/19	Sierra Fire	
2462	09/04	Leona Fire	
2461	09/04*	Squirrel Fire	
2456	07/30	Pines Fire	
2450	07/22	Deer Fire	
2425	06/17	Blue Cut Fire	
2417	06/06	Copper Fire	
2405	05/14	Antonio Fire	
2396	02/11	Gavilan Fire	
2001			
MAJOR DISASTER DECLARATIONS			none
EMERGENCY DECLARATIONS			none
FIRE MANAGEMENT ASSISTANCE DECLARATIONS			none
2000 MAJOR DISASTER DECLARATIONS			none
EMERGENCY DECLARATIONS			none
FIRE SUPPRESSION AUTHORIZATIONS			none
1999			
MAJOR DISASTER DECLARATIONS			none
EMERGENCY DECLARATIONS			1
3140	09/01*	Extreme Fire Hazard	
FIRE SUPPRESSION AUTHORIZATIONS			none
1998 MAJOR DISASTER DECLARATIONS			none

EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1997 MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE MANAGEMENT ASSISTANCE DECLARATIONS	none
1996	
MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	1
3120 10/23* Severe Fires	
FIRE SUPPRESSION AUTHORIZATIONS	none
1995 MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1994	
MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1993	
MAJOR DISASTER DECLARATIONS	1
1005 10/28* Fires, Mud & Landslides	
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1992	
MAJOR DISASTER DECLARATIONS	2
0958 08/29* Old Gulch, Fountain Fires	
0942 05/02* Fire During a Period of Civil Unrest	
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1991	
MAJOR DISASTER DECLARATIONS	1
0919 10/22* Oakland Hills Fire	
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none

1990		
MAJOR DISASTER DECLARATIONS		1
0872 06/30* Fires		
EMERGENCY DECLARATIONS		none
FIRE SUPPRESSION AUTHORIZATIONS		none
1989		
MAJOR DISASTER DECLARATIONS		none
EMERGENCY DECLARATIONS		none
FIRE SUPPRESSION AUTHORIZATIONS		none
1988		
MAJOR DISASTER DECLARATIONS		1
0815 09/29 Wildfires		
EMERGENCY DECLARATIONS		none
FIRE SUPPRESSION AUTHORIZATIONS		1
2071 09/13* Forty Niner Fire		
1987		
MAJOR DISASTER DECLARATIONS		none
EMERGENCY DECLARATIONS		none
FIRE SUPPRESSION AUTHORIZATIONS		1
2065 09/02* Stanislaus Complex		
1986		
MAJOR DISASTER DECLARATIONS		none
EMERGENCY DECLARATIONS		none
FIRE SUPPRESSION AUTHORIZATIONS		none
1985		
MAJOR DISASTER DECLARATIONS		1
0739 07/18* Grass, Wildlands, Forest Fires		
EMERGENCY DECLARATIONS		none
FIRE SUPPRESSION AUTHORIZATIONS		2
2055 07/11* Hidden Valley Lake Fire		
2054 07/11* Lexington Fire		
1984		
MAJOR DISASTER DECLARATIONS		none
EMERGENCY DECLARATIONS		none
FIRE SUPPRESSION AUTHORIZATIONS		none

1983	
MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1982	
MAJOR DISASTER DECLARATIONS	1
0657 04/24* Urban Fire	
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATION	none
1981	
MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1980	
MAJOR DISASTER DECLARATIONS	1
0635 11/27* Brush, Timber Fires	
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	
1979	
MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1978	
MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1977	
MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	1
2028 08/07* Scarface Fire	
1976	
MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none

1975	
MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1974	
MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1973	
MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1972	
MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1971	
MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1970	
MAJOR DISASTER DECLARATIONS	1
0295 09/29* Forest, Brush Fires	
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATION	none
1969	
MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1968	
MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none

1967	
MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1966	
MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1965	
MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1964	
MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1963	
MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1962	
MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1961	
MAJOR DISASTER DECLARATIONS	1
0119 11/16* Fires (Los Angeles County)	
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1960	
MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1959	
MAJOR DISASTER DECLARATIONS	none

EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1958	
MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1957	
MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1956	
MAJOR DISASTER DECLARATIONS	1
0065 12/29 Forest Fire	
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1954	
MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none
1953	
MAJOR DISASTER DECLARATIONS	none
EMERGENCY DECLARATIONS	none
FIRE SUPPRESSION AUTHORIZATIONS	none

RESULTS FOUND ON SEARCH AT FEMA SITE

* Indicates Incident Emergency Declaration Found on FEMA Web Site Search	
MAJOR DISASTER DECLARATIONS:	10
EMERGENCY DECLARATIONS	3
DECLARED FIRE DISASTERS:	71

Results of Survey Obtained at:

FEMA FEDERAL DISASTER DECLARATIONS

(http://www.fema.gov/news/disaster_totals_annual.fema)

ADDITIONAL INFORMATION:

SINCE 1953 THE PRESIDENT HAS DECLARED 13 WUI FIRE EMERGENCY
DECLARATIONS AND 74 FIRE DISASTERS IN CALIFORNIA

SINCE 2000

532 Major Disasters	3 CA WUI fires	8 other CA WUI fires
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Management Assistance		
107 CA	371 Other	total 478

APPENDIX C

SELECTED HAZARD SEVERITY ZONES OF CALIFORNIA

Figure C.1: Santa Barbara County Very High Fire Hazard Severity Zones in Local Responsibility Areas

Figure C.2: San Luis Obispo County Very High Fire Hazard Severity Zones in Local Responsibility Areas

APPENDIX D

RHINOCEROS GENERATED MODEL PLANS

Figure D.1: Tea Fire Rebuild Model

Rhinoceros Generated Model
Scale: 1:192

Figure D.2: Gable Roof Model

Rhinoceros Generated Model with
Convex, Concave, Linear Structural Fire Shields
Scale: 1:96

Figure D.3: Mobile Home Park Model

Rhinoceros Generated Model with
Inclined Structural Fire Shield
Scale: 1:96

APPENDIX E

TEA FIRE WEATHER DATA

Figure E.1: Tea Fire Weather Data

MONTECITO RAWs: November 13, 00:00 hours to November 15, 00:00 hours

SOURCE OF DATA: "California Data Exchange" (Department of Water Resources 2010)

Figure E.1: Continued

Figure E.1: Continued

Figure E.1: Continued

Figure E.1: Continued

Figure E.1: Continued

APPENDIX F

CASE STUDY ONE ACCOMPANYING INFORMATION

GREEN BUILDING & FIRE RESISTANCE ARTICLE

SANTA BARBARA NEWS PRESS 12/14/08
AFTER REBUILDING TEA FIRE SEMINAR 12/13/08
MARCI WORMSER, NEWS-PRESS CORRESPONDENT
December 14, 2008 7:09 AM

Santa Barbara resident Dave Berry knows firsthand about the value of building a fire-resistant "green" home while living in an area that's a potential wildfire hazard.

Mr. Berry, 56, lives on West Mountain Drive with his wife, Marlene Berry, also 56. During the Tea Fire, the homes of the couple's neighbors burned down all around them, while their only damage was to their landscaping. But it wasn't just luck that helped sustain the Berrys' home. Knowing that their home is located in a potential fire zone, the couple used fire-resistant materials to build their residence.

Those included a metal roof, concrete floors, metal eaves, foam insulation, stucco walls, hardscaping around the home and even a concrete driveway. Insulation in the walls helped prevent the interior from heating up too much, and the couple continuously clear brush around their home.

"We were very conscious about fire when we built it," said Mrs. Berry.

Mr. Berry shared his story with about 250 architects, contractors and residents who attended a "From Ashes to Opportunity: Rebuilding and Retrofitting After the Tea Fire" forum at the Montecito Covenant Church on Saturday morning. The forum was hosted by the Community Environmental Council.

The forum was held to educate Tea Fire victims about how they can rebuild using fire-resistant construction strategies that will also make their homes more environmentally friendly.

Victims can use last month's tragedy to help the environment and to improve their quality of life, local architects said.

Diane Black, who works with the Santa Barbara County Planning and Development Department, told forum attendees that new building codes will somewhat restrict how victims can rebuild. To date, 20 county residents have pulled permits allowing them to live in temporary trailers on their property while they rebuild.

"You probably can't rebuild exactly as it was because we have new codes you have to comply with," she said.

According to Santa Barbara architect Lori Kari, a relatively new state building code has turned some of the materials that builders can use into more fire-resistant ones. But, architects say, even more can be done to fire proof a home.

One of the best ways to fire proof a home, according to Steve Oaks, who works at the Santa Barbara County Fire Department, is to build a home without vents. Embers can enter through a home through any opening, setting the house ablaze. Vents, he said, are a primary source of "ember intrusion."

"If you're building a fire-safe area, you need to stay away from vents," said local general contractor Dennis Allen.

Many houses, said Steve Oaks, burn from the top down and start with embers entering the attic through vents. It's also important to have fire-resistant decks around homes, as well as fire-resistant landscaping, outbuildings and fencing.

It's also important, said Don Oaks, Steve Oaks' father and a retired fire marshal, to make sure there is an adequate water source around a home. Firemen look for a nearby water source around a structure when responding to the scene of a wildfire. If a structure doesn't have an adequate water supply, the fireman may choose to save another structure.

Architect Dennis Thompson told residents that building with "green" materials can help cut down on energy and water bills. Glass windows should be on the south side of a home to let the sun in. Tankless water heaters take up less space and use less energy. Using a whole-house fan provides cross-ventilation, and using appliances with a gold star energy rating can reduce a home's energy load. There are more home-insulation options today than ever before, he said.

Spray and foam insulation are also recommended. "Green" homes can reduce energy consumption by more than 30 percent. Water usage using water-conservation products can be cut by 20 percent to 80 percent, according to local landscape architect Leland Walmsley. A "green" roof is 15 to 20 times less likely to burn, he said.

There are five major components to building a fire-resistant "green" home, said Mr. Allen. They include fire-resistance, durability, low maintenance, moisture protection and recycled content. If any of these aspects of the building process is missing, he said, the building will not be protected from a fire. "The weakest link on any of these is where you're going to have 90 percent of the problem," said Mr. Allen.

Other fire-resistant materials include house wraps, which deflect heat and give a structure a moisture-protectant barrier; non-combustible materials for the outside shell of the home; plaster; insulated concrete; fiber cement roofs; and metal, stone, plaster or wrought iron railings. Mr. Allen also advised people to avoid having vents between the skirting on their home and the ground.

Mr. Walmsley also advised residents to create a defensible space around their property, to eliminate dense brush around their home and to use fire-resistant trees. Sidewalks can be built with non-combustible stone to make them fire-resistant. Swimming pools, he said, are good for more than just recreation. Firemen can use them when responding to a house fire when they don't have adequate water pressure.

"They're also good for putting out spot fires," he said.

Using mulch is another way to help make landscape more fire-resistant, he said. Mulch can slow the growth of invasive weeds, add moisture and help slow the erosion of top soil after a fire.

Meanwhile, high wind gusts in the area Saturday left residents concerned about potential fires and also about hazards from dust in areas that were hit by the Tea Fire. West-northwest winds blowing up to 26 miles per hour prompted a high wind warning for the area. And it wasn't just winds that raised red flags. Possible rainfall today and Monday in the county has many residents worried about potential land- and mudslides. To that end, building officials warned residents against removing the foundation at their fire-affected properties.

If residents do wish to remove their existing foundation, they should wait until the end of the rainy season.

In a recent written statement about rebuilding after the Tea Fire, Santa Barbara County staff members advised residents to not cut down non-burnt vegetation and to not remove root systems from dead vegetation until they're ready to be replaced. That will help keep the soil stabilized.

According to the statement, "Depending on the steepness of your property, installing erosion control measures once the debris has been cleared can be a very important and time sensitive issue, given that we are now in our normal rainy season. Measures such as slope drains, hydraulic mulch, geo-textiles and mats, fiber rolls, straw bale barriers and silt fences are among the list of measures that can be used to help control and prevent erosion."

The county also recommends that residents interested in obtaining the services of local architects, designers or contractors contact the local chapter of the American Institute of Architects at 966-4198 or the Santa Barbara Contractors Association at 884-1100.

*Figure F.1: Roofs of Case Study One and Site of Case Study Two
(Berry Family Collection of Photographs)*

*Figure F.2: Case Study One Residence, Studio and Garage with Jesusita Fire in Background
(Berry Family Fire Collection of Photographs)*

*Figure F.3: Water Tank at Top of Chimney on West Side of Property
(Berry Family Fire Collection of Photographs)*

*Figure F.4: Coyote Canyon Ridgeline Protection of Case Study One Structures
(Berry Family Fire Collection of Photographs)*

*Figure F.5: Scorched Eaves on East Side of Main Residence
(Berry Family Fire Collection of Photographs)*

APPENDIX G

CASE STUDY TWO ACCOMPANYING INFORMATION

Tempered by Fire

Santa Barbara News Press, November 28, 2008

By Peter LeVay

Our house and all our possessions were burned to a crisp in the Santa Barbara Tea Fire. My fiancée, Mary, and I heard fire engines which I had told her were emanating from the television that I had just turned on.

Shortly after, my best friend called and said there was a fire in our area and I should go outside and check it out. We went outside and could clearly see what was already a raging forest fire two ridges away. The Santa Ana winds were blowing the fire down those canyons at a constant 35 miles per hour with gusts up to 50. I said “there is no way the fire will be able to advance into this wind” (I’m an engineer) and decided to do a leisurely evacuation. I was in denial.

At the sight of white hot flames 50 feet tall blending into an iridescent orange and grey plume of smoke shooting hundreds of feet into the night sky, Mary wisely decided the time to evacuate was now or sooner. We quickly loaded a few clothes, the backup to the computer, some documents, and her valued jewelry into her car. She drove to her mother's house where, if needed, I would meet her later.

I was still in denial. I remained behind and at a strangely slow pace, almost as if drugged, prepared for what I was sure was not to happen, the complete destruction of our home. I moved my 1950 and 2001 Chevy, my motorcycle, and

Rino (a recreational, two seated, off road vehicle) out of the garage and into the driveway away from any structures which might burn. Giving them what I thought was their best chance of survival. All the while glancing back at the fire which had crossed another ridge and was unbelievably advancing toward our home. I was still in denial.

I went back into the house and looked around. If the house was actually going to burn I would grab the picture off the wall of my two sons, and some clothes. I went to the car, put on my bicycle rack and loaded onto it my favorite bicycle. Why I didn't load some other bicycles I don't know, maybe denial still. I went to look at the fire again to see it one canyon away, about 600 yards, crossing the last ridge necessary to reach our home. The radiant heat from those white flames was hot on my skin.

The noise had the distant rumble of a far away train added to the high frequencies of glass shattering and wood splintering, dotted with the occasional explosion of a propane tank. It was clearly time to run for my life. It is one of the most bizarre physiological switches of my life. Denial, denial, denial; run for your life.

I drove with what was left of my worldly possessions about a quarter of a mile down the road along with the last of the evacuees, stopping at the last vantage point for seeing our house.

A lone, brave policeman, in his car with light flashing, was going down the road, house to house, ensuring that everyone had evacuated. I could clearly see on a hillside to our north what the fire had become. It was a very clear view of about 100 acres of burning mountainside only slightly distorted by a curtains of heat waves. Through this curtain was a surreal alien Martian landscape. The mountain floor was brightly lit, as if by overhead spot lights, by bright white three-foot mounds of coal, the remains of mountain chaparral spaced about 30 feet apart,

burning with the same white intensity of the sun. The scorched black, ashen grey, and brown earth and been vacuumed of all debris by four or five dancing tornadoes of flame dissolving into the smoke 100 yards above. After absorbing this magnificent view of nature, like lemmings, all the evacuees decided at the same time to hop into our cars and move along.

I met Mary at her mom's house as the fire burned through the next morning. For the first few days afterward we were in a daze. Did our house really burn? I thought for certain it had, but with no concrete evidence, hope springs eternal. The next morning I went to a vantage point to see our house, but through the smoky haze it could not be seen. I could, however, see the silhouettes of the tall trees which surrounded our house. If they had survived perhaps, miracle of miracles, the house did too. We were on an emotional see-saw which wracked our stomachs more than any roller coaster. It wasn't until the next morning, when the wind had shifted, that I could get a clear view. The silhouettes of trees were their standing charred remains. Where the house stood was the water heater and the blistered remains of the vehicles which I had moved to the front driveway, all of which should have been blocked from view by the house. The emotional roller coaster was over and filled with a strangely calm depression of disbelief.

Tem 'per, --v. 2. To bring to the right condition by treating in some way (steel is tempered by heating and sudden cooling to make it hard and tough).

Throughout this ordeal we were flooded by calls from friends and family expressing their concern and sharing in our disbelief. They all said how their hearts were with us and that they were available to give us whatever they had that we might need. It was a tidal wave of emotional support unlike anything I have felt. You would think such an outpouring of love would leave you elated and emotionally high. It did, but with each call there was a sharing of the events of the fire and the grief and re-realization of the total destruction of everything we

owned. It was a crystalline example of the yin and yang of life all in one moment. The elation of love and depression of loss.

This strange yin and yang perception continued with the review of all the things that were lost. Things you took for granted became much more appreciated and things you once thought were important you realize are not. Toiletries, clean underwear, and socks became very important a few days after the fire, and now have again been reduced to the level of the unimportant commonplace. A cup that my son had given Mary from a trip to New Zealand miraculously survived the fire. It had been forgotten but was now placed on a pedestal of importance. Upon trying to clean the cup, it crumbled, losing its elevated importance as a survivor, but reliving in our hearts it's importance as a gift of love from my son. Up and down and up and down go our emotions and perceptions; which have been tempered by the fire. Old family photos and memorabilia which would trigger memories of the past have been lost, but the memories are burned in our hearts forever.

Although we have lost all our possessions, our lives are fuller than they ever have been. Your home is where your heart is. Never has it been more true. As long as Mary and I have each other, and the incredible love of our family and friends, we are home; and nothing can ever take that away from us. We are truly blessed.

*Figure G.1: Location of Case Study Two After Tea Fire.
(Berry Family Collection of Fire Photographs)*

*Figure G.2: Case Study Two Location as Viewed From Coyote Canyon.
(Berry Family Collection of Fire Photographs)*

*Figure G.3 As Built Print of Case Study Two
(LeVay Archives)*

Figure G. 4: Case Study Two Site Plan
(LeVay Archives)

*Figure G.5: Case Study Two Contour Map
(LeVay Archives)*

*Figure G.6: Panoramic View of Case Studies One and Two
(Berry Family Collection of Fire Photograph)*

APPENDIX H

CASE STUDY THREE ACCOMPANYING INFORMATION

Table H.1: Fuel Ages and Fire Severity Index
(<http://150.299.72.10/paper/WF8055.html>)

Table 3. Vegetation type, age, fire severity indices and rock cover for the 22 sites in the Old Topanga and Green Meadow fires.

Site	Pre-burn vegetation type	Pre-burn age (yrs)	Average fire severity index		Mean rock cover (%)
			1	2	
Old Topanga Fire					
Carbon Cyn	Coastal Sage	25	4.1	5.6	19
Old Topanga 1	Chaparral	31	4.9	7.2	11
Old Topanga 2	Chaparral	48	4.9	6.3	9
Old Topanga 3	Chaparral	55	4.3	7.2	10
Puerco Cyn 1	Coastal Sage	22	3.3	2.0	1
Puerco Cyn 2	Coastal Sage	21	2.5	4.5	5
Schueren Rd	Chaparral	25	7.5	4.9	18
Tuna Cyn 1	Coastal Sage	36	4.2	4.9	15
Tuna Cyn 2	Chaparral	24	4.8	4.9	5
Tuna Cyn 3	Chaparral	24	7.2	4.9	6
Green Meadow Fire					
L. Sycamore Cyn 1	Coastal Sage	19	4.4	6.7	21
L. Sycamore Cyn 2	Coastal Sage	20	4.5	5.5	4
L. Sycamore Cyn 3	Chaparral	21	3.0	5.5	14
L. Sycamore Cyn 4	Coastal Sage	3	1.2	4.0	3
L. Sycamore Cyn 5	Chaparral	17	6.4	7.8	30
U. Sycamore Cyn 1	Chaparral	26	9.2	4.9	5
U. Sycamore Cyn 2	Coastal Sage	26	6.2	4.9	28
U. Sycamore Cyn 3	Chaparral	6	2.1	4.9	9
U. Sycamore Cyn 4	Chaparral	31	3.9	4.9	14
U. Sycamore Cyn 5	Coastal Sage	20	3.9	4.9	24
Circle X 1	Chaparral	48	3.8	4.9	6
Circle X 2	Chaparral	35	4.5	4.9	8

*Figure H.2: Aerial Map of Case Study Three with Contours,
and Location of Ridgeline Peaks Indicated
(gis/library.calpoly.edu)*

*Figure H.3: Aerial Photograph of Case Study 3 with Location of Ridgeline Peak Indicated.
(GoogleEarth.com)*

*Figure H.4: View of Inside of Retaining Wall Forming Linear Fire Shield
(MesKimen Thesis Collection)*

*Figure H.5: Terrain Formed Incline Fire Shield
(MesKimen Thesis Collection)*

*Figure H.6: Flat Roof, Parapet Walls and Front Fire Shield
(MesKimen Thesis Collection)*

*Figure H.7: Fire Shield Retaining Wall at Front of Residence
(MesKimen Thesis Collection)*

*Figure H.8: Terrain Formed Incline Fire Shield
(MesKimen Thesis Collection)*

*Figure H.9: Palm Tree Trunks
(MesKimen Thesis Collection)*

*Figure H.10: Terrain Formed Inclined Fire Shield
(MesKimen Thesis Collection)*

*Figure H.11: Flames Angle of 65%, Same as Slope
(Los Angeles Times: East Ventura County Edition, Sunday October 31, 1993)*

APPENDIX I

TABLE I.1:
FIRE PROFILE INDEX

Category	Subcategory	Attribute	Strategy Code	Attribute Definition	Point Range	Value
FUELS						
	Structures	Wall Construction	①④⑤⑥⑦	Combustibility of wall materials	1-5 points	3
		Roof Construction	①④⑤⑥⑦	Combustible roof, non-rated	300 points	
		Roof Shape	①④⑤⑥⑦	Airflow turbulence generated by Shape	1-20 points	10
		Interior Fire Loading	①④	Amount and flammability of contents	1-5 points	3
		Structure Size	①④⑤⑥⑦	Aggregate volume of combustible materials	1-10 points	5
		Structures Proximity	①④⑤⑥⑦	Separation distance between structures		
		Select One Attribute Category ④⑥⑫		Under 30 feet	60 points	
				30-45 feet	10 points	
				Over 45 feet	1 point	1
		Development Proximity	①④⑫	Development within Two miles without fire spread barrier	1-5 points	3
		Combustible Decking	①⑦	Amount and quantity of decking materials	1-5 points	3
		Combustible Fencing	①⑦	Amount of fencing within 10' of Structures	1-5 points	3
	Natural Plants					
	(Native & Exotic)	Mineral Content of Leafs	②③⑪⑭	Mineral content of of leaves	1-3 points	2
		Volatile Oil Content	②③⑪⑭	Ability of oils within plants vaporizing	1-3 points	2
		Fuel Moisture	②③⑪⑭	Percent weight of a particular fuel that is composed of water	1-20 points	10
		Density of Foliage	②③⑪⑭	Mass and shape of foliage	1-3 points	2
		Canopy Density	②③⑪⑭	Closeness of leafs	1-3 points	2
		Foliage Proximity to Ground	②⑨⑪	Quantity of plant material from 18 inches to 6 feet high	1-3 points	3
		Understory	②③⑨⑪	Amount of combustible plant matter beneath trees	1-3 points	2
		Aerial Ability	③⑬⑪⑭	Proportion of plant surface area to mass	1-3 points	1
	Cultivated Plants					
	(Native & Exotic)	Mineral Content of Leafs	③⑬⑪⑭	Mineral content of of leaves	1-3 points	2
		Volatile Oil Content	③⑬⑪⑭	Ability of oils within plants vaporizing	1-3 points	2
		Density of Foliage	③⑬⑪⑭	Mass and shape of foliage	1-3 points	2
		Fuel Moisture	③⑬⑪⑭	Percent weight of a particular fuel that is composed of water	1-20 points	10

		Canopy Density	③⑬⑪⑭	Closeness of leafs	1-3 points	1
		Fuel Loading	③⑬⑪⑭	Amount of combustible material per acre	1-40 points	5
		Foliage Proximity to Ground	②⑨⑪	Quantity of plant material from 18 inches to 6 feet high	1-3 points	2
		Understory	②③⑨⑪	Amount of combustible plant matter beneath trees	1-3 points	2
		Aerial Ability	③⑬⑪⑭	Proportion of plant surface area to mass	1-3 points	2
	Brands/Embers					
		Mass and Density	①②③④⑤	Size and quantity of embers/brands	1-20 points	10
		Carry	①②③④⑤	Distance brands/embers are carried by wind	1-20 points	10
	Organic Mulch	Wooden chips	⑭	Size, quantity, and combustibility	1-3 points	2
	Fire/Fuel Generated Weather	Fuel Driven Fire	①②③④⑤	Erratic fire behavior as a result of fuel-driven fire	1-5 points	3
	Light Flashy					
		Type	②③④⑤⑥	Light fuel type:	1-5 points	3
		Fuel Moisture	②③④⑤⑥	Percent weight of a light fuel that is composed of water	1-3 points	2
		Percent Dead	②③④⑤⑥	Weight percent of a standing fuel that is dead	1-5 points	3
		Arrangement	②③④⑤⑥	Proportion of fuel type in landscape mix	1-3 points	2
		Continuity	②③④⑤⑥	Continuos coverage of fuel type	1-5 points	3
	Medium Fuels					
		Type	②③④⑤⑥⑭	Medium fuel type	1-10 points	3
		Fuel Moisture	②③④⑤⑥⑭	Percent weight of a particular fuel that is composed of water	1-5 points	3
		Percent Dead	②③④⑤⑥⑭	Weight percent of a standing fuel that is dead	1-5 points	3
		Arrangement	②③④⑤⑥⑭	Proportion of fuel type in landscape mix	1-3 points	2
		Continuity	②③④⑤⑥⑭	Continuos coverage of fuel type	1-3 points	2
	Heavy Fuels					
		Type	②③④⑤⑥⑭	Heavy fuel type	10-30 points	20
		Fuel Moisture	②③④⑤⑥⑭	Percent weight of fuel that is composed of water	1-15 points	8
		Percent Dead	②③④⑤⑥⑭	Weight percent of a standing fuel that is dead	1-20 points	13
		Arrangement	②③④⑤⑥⑭	Proportion of fuel type in landscape mix	1-15 points	8
		Continuity	②③④⑤⑥⑭	Continuos coverage of fuel type	1-20 points	10
		Fuel Load				
		Select One Attribute Category ②③④⑤⑥⑬⑭	Low under 5 tons/acre	1-10 points		
			Medium 5 to 15 tons/acre	10-20 points	15	
			Heavy over 15 tons/acre	20-40 points		

Explosive Fuels						
		Type	②③④⑤⑥⑭	Medium and heavy fuels that burn extremely fast	5-30 points	
		Arrangement	②③④⑤⑥⑬ ⑭	Proportion of fuel type in vegetation mix	1-5 points	
		Continuity	②③④⑤⑥⑬ ⑭	Continuos coverage of fuel type	1-5 points	
		Fuel Load				
		Select One Attribute Category ②③④⑤⑥⑬⑭		Low under 5 tons/acre	10-20 points	
				Medium 5 to 15 tons/acre	20-40 points	
				High over 15 tons/acre	40-60 points	
		Percent Dead	⑨⑪⑭	Aggregate quantity of dead fuel exceeding 10%	50-60 points	
	Defensible Space	Vegetation Management	②③④⑤⑥⑭	Less than 100' of defensible space around structure	200-300 points	
	Fuel Age	Fuel Bed Age	②③④⑤⑥⑬ ⑭	Medium & heavy fuel over 15 years old	1 to 10 points	5
	Fuel Moisture	Percent of Dry Weight	②③④⑤⑥⑬ ⑭	Percent weight of fuel that is composed of water	1-40 points	20
WEATHER						
	Relative Humidity	Percent moisture in air	②③④⑤⑥	Critical level below 30% RH	1-10 points	5
	Temperature	Hot fire weather	②③④⑤⑥	Temperature above 90°F critical	1-10 points	5
	Wind Velocity	Fire wind speed	②③④⑤⑥	Sustained wind speed		
		Select One Attribute Category ②③④⑤⑥⑬⑭		Moderate wind event > 20 mph	10 points	
				High wind event > 30 mph	20 points	
				Extreme wind event > 40 mph	40 points	40
	Wind Direction	Historic fire wind	①②③④⑤⑥	Significant wind event direction(s)	1 to 3 points	2
	Windward & Parallel Position	Structure orientation to airflow direction	①②③④⑤⑥	Structure creating wind turbulence to prevailing winds	1-10 points	5
	Cloud Cover	Percent of clouds in sky	⑩⑥	Historic cloud cover during fire > 20%	-1 to -6 points	-3
	Front Movement	Frontal movement during fire season	①②③④⑤⑥	Historic occurrence of weather front movement	1-10 points	5
	Drought	Seasonal drought	①②③④⑤⑥	Summer draughts (i.e. Mediterranean climate)	5-15 points	10
	Drought	Unusual annual	①②③④⑤⑥	Less than 75% normal rainfall for 2 years	5-15 points	10
	Rainfall Pattern Divergence	Heavy annual rainfall followed by low	①②③④⑤⑥	Weighted heavy rainfall year followed by below normal weighted year	15 points	
	High Burning Index	High fire weather, low fuel moistures	①②③④⑤⑥	Fire service declared events above 5 per year	10 points	10
	Red Flag	Critical fire weather events	①②③④⑤⑥	Fire service declared events above 5 per year	15 points	15
TERRAIN						

	Percent Slope	Height/Horizontal	①②⑫	Fire burning faster uphill		
		Select One Attribute Category ②③④⑤⑥		Terrain slope under 10 to 30%	5 points	
				Terrain slope between 30 to 55%	10 points	10
				Terrain slope over 55%	40 points	
	Fire Breaks					
		Natural Fire Breaks	⑩	Significant fire breaks to impede or stop fire	-10 to -40 points	
		Fuel Breaks	⑩	Constructed breaks in fuels to impede or stop fire	-40 to -80 points	
		Developments	⑩	Large expanses of irrigated area (i.e., orchards, cemeteries)	-10 to -40 points	
	Downhill Burn	Structure in low lying areas	①②③④⑤⑥	Fire spread decreases 20 times from uphill to downhill travel	-5 to -10 points	
	Saddles	Structures located within a saddle	①②③④⑤⑥ ⑫	Depressions in ridge lines	100-200 points	
	Chimneys	Structures located within a chimney	①②③④⑤⑥ ⑫	Depression between protrusions of slope	100-200 points	
	Ridge Tops	Structure located at ridge top	①②③④⑤⑥ ⑫	Steep slope setback < 30 feet	100 points	
	Leeward Side	Structures locate on leeward side of ridge	⑩	Structure on downwind side of ridge during wind-driven & terrain-driven fire	-10 to -40 points	
	Windward Side	Structures located on windward side of ridge	①②③④⑤⑥ ⑫	Increased rates of spread on upwind/fire exposed side	10-40 points	30
	Hillside Solar Aspect	Direct slope is facing	①②③	South and west slopes have greatest burning	1-3 points	2
	Thermal Belt	Structure on middle one-third of slope	①②③	Higher temperatures during day and night	1-3 points	2
SERVICES						
	Water Supply					
		Flow	⑧⑩	Adequate fire flow available during conflagration - gpm	1-5 points	3
		Pressure	⑧⑩	Adequate water pressure available during conflagration -psi	1-5 points	3
		Storage	⑧⑩	Adequate quantity of storage	1-5 points	3
	Electricity			Backup power supply available during fires	-1 to -15 points	
DEVELOPMENT						
	Structure Monetary Values	High	①②③④⑤⑥ ⑫	Homes/structures with over \$500,000 value	10 points	10
	Number of Structures	Concentration of house within fire area	①②③④⑤⑥ ⑫	Homes/structures exceed first response capability		
		Select One Attribute Category ①②③④⑤⑥⑫ High and Medium ⑤⑥Low		High > 100 per fire area	50 points	50
				Medium 25 to 100 per fire area	20 points	
				Low < 25 per fire area	5 points	
	Urban Setting	Limited road capacity	⑥⑦⑮	Increased traffic congestion and life exposure	1-5 points	3

	Wildland-Urban Interface	Encroaching development on wildland area	①②③④⑤⑥ ⑫	Structures exposed to wildland fuels	5-30 points	17
	Building Code Requirements	Structures and defensible space	②③④⑤	Does Not substantially meet model WUI code (after 2001) requirements	200 points	
	Fire Threat Zones	Identified fire threat	①②③④⑤⑫ ⑰	Defined by Authority Having Jurisdiction		
		Select One Attribute Category ①②③④⑤⑥⑫⑰		Very High	40 points	40
				High	20 points	
				Moderate	10 points	
	Zoning Requirements	Limits place on development	①②③④⑤⑥	Adequacy of local codes to provide adequate structure density & egress	1-20 points	10
	Structure Density	Structures/area	①②③④⑤⑥ ⑰	> Density increases fuel load and exposures		
		Select One Attribute Category ①②③④⑤⑥⑫⑮⑰		High > 4 structures/acre	20 points	
				Medium 2 to 4 structure/acre	5 points	5
				Low < 1 structure/acre	-15 points	
	Population Density	Population/Area within 5 miles	②⑤⑦⑫⑮	Increased ignition possibilities, traffic		
		Select One Attribute Category ⑦⑩⑮		High > 1,000 persons/square mile	20	
				Moderate 200 to 1,000 persons/square mile	10 points	10
				Low < 200 persons/square mile	5 points	
	Structures Proximity to Fuels	Structures exposure to embers, flames	①②③④⑤⑥ ⑰	Location within 1 mile of heavy fuels	10-40 points	25
CONSTRUCTION FEATURES						
	Airflow Turbulent Design	Trapped Airflow	①⑤⑥	Horizontal solid overhangs: ledges, decks	10-20 points	15
		Alcoves	①⑤⑥	Room or wall protrusions perpendicular to other walls of structure	10-20 points	15
		Windward Angular Surfaces	①⑤⑥	Walls facing windward & fire exposure sides	10-20 points	15
		Elevated Roof Profile	①⑤⑥	Gables and steep pitches on roof	10-20 points	15
		Combustible Decking	①⑤⑥	Increased turbulence under decks	10-20 points	15
		Eaves	①⑤⑥	Increased turbulence under eaves	10-20 points	15
		Wall Reliefs	①⑤⑥	Raised portions on wall surfaces	1-5 points	3
		Rough Wall Finishes	①⑤⑥	Increased surface turbulence	1-5 points	3
		Combustible Moldings	①⑤⑥	Increased surface turbulence and fire penetration possible	1-5 points	3
		Large Windows	①⑤⑥	Window over 4 square feet	10-20 points	15
		Exposed Windows	①⑤⑥	Large windows on fire exposed walls, not recessed	1-10 points	5

		Solar Shading	①⑤⑥⑦	Combustible shading such as sun screens, porches, awnings	1-10 points	5
		Porches	①⑤	Increases wind turbulence	5-10 points	7
		Raised Foundations	①⑤	Allows embers and brands under house	5-10 points	7
		Soffit Vents	①⑤	Allows ember and brands into concealed spaces	10-20 points	15
		Multistory Structures	①⑤	Increases surface area exposed to air movement	1-10 points	5
	Problem Areas	Large Floor Areas	①②③④⑤⑥	Structures with floor area over 1600 square feet	1-20 points	10
		Crawl Spaces	①⑤⑥	Accessible areas where upright walking is impossible	5-10 points	7
		Concealed Spaces	①⑤⑥	Walled-in areas not accessible	1-5 points	3
		Raingutters	①⑤⑥	Exposed raingutters, not boxed or screened	1-5 points	3
		Vents	①⑤⑥	Vents for attic, floor, and concealed spaces	1-40 points	20
		Wood Siding	⑦	Includes structural and fascia	1-20 points	10
		Windows	①②⑥	Single pane windows	40 points	
		Windows Exposure	①②⑥	Windows exposed to fuels and wind	1-10 points	5
Beneficial Construction						
		Structure Fire Shield	⑤⑥⑥	Noncombustible wall of appropriate configuration for environment	-150 points	
		High Profile Structure Fire Shield	⑤⑥⑥	Noncombustible wall of appropriate configuration, minimum of 2 1/2' above roof line	-250 points	
		Smooth Exterior Walls	⑤⑥⑥	Smooth plaster or cement or metal	-1 to -5 points	
		Automatic Fire Sprinklers	⑤⑥⑧	Installation of automatic fire sprinklers for live & fire safety	-10 to -20 points	
		Windows double pane & safety glass	⑤⑥⑥	Metal framed windows with double-pane glazing & safety glass	-10 to -20 points	-15
		Wall/Roof/Attic Insulation	⑤⑥⑥	Noncombustible insulation	-20 to -40 points	
		Sod Roofs	⑤⑥⑥	Minimum of 1 foot thick medium with irrigated grass, forbs	-20 to -40 points	
		Pool Roofs	⑤⑥⑥	Minimum of 1 foot deep water pool	-20 to -40 points	
		Flooded Roofs	⑤⑥⑥	Flat roofs that can be flooded with 1 foot of water	-20 to -40 points	
		Rainwater Collection Roofs	⑤⑥⑥	Flat roofs used for rainfall harvesting	-20 to -40 points	
		Green Roofs	⑤⑥⑥	Heavily insulated roofs made of noncombustible materials	-10 to -20 points	
		Metal Roofs with Insulated	⑤⑥⑥	Metal roofing material with adequate thermal insulation underneath	-10 to -20 points	
		Fire Rated Doors & Windows	⑤⑥⑥	Fire tested and rated assemblies that operate automatically	-10 to -20 points	
		Floors - Slab	⑤⑥⑥	Concrete footing and flooring applied on grade	-10 to -20 points	-15

		Floor Radiant Heat	⑤⑥⑩	Heating tubing in slab floors	-20 to -40 points	
		Bury House	⑤⑥⑩	House with 3 side below grade w/ flat roof, or w/ 3 feet of earth on sides	-200-400	
		Flat Roofs	⑤⑥⑩	Flat roofs without overhangs on fire exposed side(s)	-50 to -100 points	
		Roof Tie-Downs	⑤⑥⑩	Use of tie-downs of flat roofs, especially with truss rafters	-10 to -20 points	
		Eliminate Attics & Vents	⑤⑥⑩	Flat roofs or non-vented insulation	-50 to -100 points	
		Bird Stops - Tile Roofs	⑤⑥⑩	Noncombustible filling of first row of curved tile hemispheres	-10 to -20 points	
		Smaller Houses	⑤⑥⑩	House with floor plans under 1600 sq. ft.	-50 to -100 points	
		Open Floor Plans	⑤⑥⑩	Structures with minimum partitions	-20 to -40 points	-30
		Window Covering Internal	⑤⑥⑩	Living area side of windows coverings	-1 to -5 points	
		Window Covering External	⑤⑥⑩	Noncombustible shutters on external wall side	-20 to -40 points	
		Windows with Glass Block	⑤⑥⑩	Translucent hollow glass bricks, non-openable	-10 to -20 points	
		Recessed Windows	⑤⑥⑩	Windows externally recessed into thick walls	-10 to -20 points	
		Window Blinds - Vertical	⑤⑥⑩	Noncombustible vertical blinds that are closable	-10 to -20 points	
		Window Blinds - Horizontal	⑤⑥⑩	Non-combustible horizontal blinds that are closable	-10 to -20 points	
		Heavy Insulation	⑤⑥⑩	Insulating materials with an R-Value over 40	-10 to -20 points	
		Cementous Siding	⑤⑥⑩	Various forms of aggregate with cement	-40 to -80 points	
		Dome/Arch Roof	⑤⑥⑩	Arched roof without flat surfaces facing wind/fire spread	-40 to -80 points	
		In-Steel Plaster	⑤⑥⑩	Metal lath for plaster	-20 to -40 points	
		Pise De Terre Walls	⑤⑥⑩	Adobe rammed earth with 10% cement added	-40 to -80 points	
		Rammed Earth Walls	⑤⑥⑩	Earthen walls with 10% cement added	-40 to -80 points	
		Roof Radiant Barriers	⑤⑥⑩	Radiant, reflective barriers place underneath or on-top-of roofing	-20 to -40 points	
		Eliminate Vents	⑤⑥⑩	Attic vents, roof & floor crawl spaces, wall vents, HVAC vents	-40 to -80 points	
		Retractable Coverings	⑤⑥⑩	Moveable, non-combustible shading features of structures	-20 to -40 points	
		Metal Framing	⑤⑥⑩	Reduces combustible loading	-20 to -40 points	
		Reflective Surface Insulation	⑤⑥⑩	Reflective material placed on the outside of insulation	-10 to -20 points	
		Reflective Surface Roofing	⑤⑥⑩	Reflective material placed on the underside or outer roof surface	-10 to -20 points	

		Deck/Patio Covers	⑤⑥⑬⑰	Heavy timber or non-combustible materials	-10 to -20 points	
		Deck/Balconies-Enclosed	⑤⑥⑬⑰	Non-combustible enclosure underside of decks & balconies	-20 to -40 points	
		Grey/Rainwater Cistern	⑬	Combination fire water & irrigation system using grey/rainwater/potable	-20 to -40 points	
	Driveways	Model WUI Code compliant	⑦⑬	Acceptable grade, width, curves, turn-outs	-10 to -20 points	-15
LANDSCAPING FEATURES						
	Plants	Avoidable Plants	⑬⑭	Plants listed by agencies as being highly flammable	20-40 points	
	Beneficial Landscaping					
	Defensible Space	Vegetation management	②③⑥⑫⑬⑭	Minimum of 100' distance, without fuels surrounding structures	-50 points	-50
	Fire Zones	Vegetation management to > 200'	③⑫⑬⑭⑰	Distinct areas with lower amounts of flammable fuels outward from structure	-20 to -40 points	
	Terracing	Slope of Hillside terraced with > 6' walls	⑤⑥⑫⑰	Leveling of hillside in steplike fashion with the use of retaining walls	-20 to -40 points	
	Berms	Compacted mounds of earth	⑥⑫⑰	Mounding of earth to a height of roofline within 10 feet of Structure	-40 to -80 points	
	Patios	Hard surfaces on top of earth	⑥⑫⑰	Outdoor areas of hard surface applied on top of earth	-1 to -10 points	
	Walls/Fencing	Noncombustible walls or fencing	⑥⑫⑰	Non-combustible walls < 6' surrounding exterior of structure	-20 to -40 points	
	Lipped Walls	Noncombustible walls with top curved outward	①⑥⑫⑰	Non-combustible walls with rounded overhand at top	-40 to -80 points	
	Convex Structural Fire Shield	Wall with structure inside arch	①④⑤⑥⑰	> 6' Non-combustible with structure inside arch	-40 to -80 points	
	Concave Structural Fire Shield	Arching wall towards fire spread	①⑫⑰	Fire directed toward inside arch-used for terrain chimney	-1 to -10 points	
	Auxiliary Water Supply	Pools/Ponds	⑩⑰	Tanks, ponds, pools w/pump & hose	-20 to -40 points	
	Gates	Fire barrier gates	④⑥⑰	Non-combustible gates for walkways & driveways, blocks fire spread	-20 to -40 points	
	Inorganic Mulch	Rock, stones	①②⑰	Replaces organic mulch within Defensible Space. Reduces ember generation	-1 to -10 points	
	Beneficial Plantings					
		High Water Content	⑥⑰	Succulents & other plants with high water content	-20 to -40 points	
		Approved Plants	⑥⑭	Agency recommended plants for particular fire zone/defensible space	-50 points	-50
		Fire Barrier Plantings	⑥⑰	Hedges of succulents, irrigated orchards	-1 to -10 points	
	Structure Safety Zone	Defensible space determined by fire behavior	②⑥⑰	Minimum of 2X flame length distance of defensible space each side of structure	-250 points	

HUMAN FACTORS						
	Human Presence					
		Residents Present	②⑩⑮⑯	Resident present, safe and capable of at least protecting themselves	-1 to -10 points	
		Firefighters Present	②⑩⑮	Firefighters w/ engine & water available	-40 to -80 points	
		Firefighter & Residents	②⑩⑮⑯	Firefighters w/ engine & water available, plus residents	-40 to -80 points	
	Emergency Access	Width, grade, fuel clearance, visibility	⑦	Fire, police, private agency access into and out-of fire area	1-10 points	6
	Water Supply	Access to water supply	⑧⑩	Fire agency access to adequate & supplemental water supply	1-10 points	6
	Evacuation/ Egress	Width, grade, fuel clearance, visibility	⑦	Adequacy of emergency egress under adverse conditions	1-10 points	6
	Personnel Safety	Fire Behavior, training, equipment	②⑩⑮	Emergency response personnel can safely operate in incident area	1-10 points	6
	Resident Notification	Notification methodology	②⑦⑮	Public notification by responsible agency (i.e. Reverse 911, Media)	1-10 points	6
	Resident Awareness	Resident aware of fire danger and remedies	②⑦⑮⑯	Public education performed by public & private agencies	-1 to -6 points	
	Resident Training	Resident appropriate response to WUI threat	②⑦⑮⑯	Resident training performed by public & private agencies (i.e. CERT)	-1 to -6 points	
	Shelter-In-Place	Resident fire sheltering	②⑦⑮⑯	Resident protection provided by structures during wildfire	-1 to -10 points	
	Panic Level	Resident response to WUI fire emergency	②⑦⑮	Historic or projected emotional response of residents w/o education & training	1-10 points	5
	Communications					
		Public Agency communications	⑦⑮	Ability of fire agencies and law enforcement to communicate by radio	1-20 points	3
		Public Agencies to Public	⑦⑮	Ability of public agencies to notify residents of emergency status	1-20 points	3
		Public to Public Agencies	⑦⑮	Capability of residents to notify emergency responders of changing needs	1-20 points	3
FIRE PROTECTION						
	Initial Response Time	Professional fire Agency response	②⑦⑮	Time required from notification of fire to arrival of firefighting crews	1-20 points	3
	Paid/ Volunteer Firefighters	Fire agency with volunteer component	②⑦⑮	Number of fully trained and available firefighter for response	1-10 points	3
	WUI Experience Level	Fire agency WUI fire experience	②⑦⑮	Past performance on WUI fires and on-going training of fire jurisdiction	1-40 points	5
	Red Card Qualifications	Accomplished training	②⑦⑮	National system of qualifications for firefighters	1-3 points	1

	Interagency Drills	WUI interagency fire training	②⑦⑮	Number and frequency of interagency emergency agencies training sessions	1-10 points	6
	EOC	Emergency Operation Center communications	⑦⑮⑯	Emergency Operation Center establishment & operation	-1 to -5 points	-5
	EOP	Emergency responders pre-fire planning	⑦⑮⑯	Emergency Operation Plans, advanced emergency plans for WUI fire	-1 to -5 points	-5
	Command & Control	Responding agencies command/control	⑦⑮⑯	Communications and coordination within & between responding agencies	-1 to -10 points	-5
	Hydrants & Hose	Fire & water agencies fittings compatibility	⑦⑮⑯	Compatibility of attachments to other jurisdictions' hose & hydrants	1-10 points	1
	WUI Training	State & Federal training standards	⑦⑮⑯	WUI specific training - amount & frequency	-1 to -10 points	-5
	Mutual/ Automatic Aid	Interagency cooperative response agreements	⑦⑮⑯	Prearranged emergency response agreements between agencies	-1 to -10 points	-5
	ICS/SEMS Use	Incident Command System use on incidents	⑦⑮⑯	Coordinates command, communication, control between agencies	-1 to -5 points	-5
	Engine Companies	WUI capable	⑦⑮⑯	ETA, type, number available for response	-1 to -20 points	-10
	Bulldozers	WUI capable	⑦⑮⑯	ETA, type, number available for response	-1 to -10 points	
	Aircraft	Fixed Wing	⑦⑮⑯	ETA, type, number available for response	-1 to -20 points	
	Aircraft	Rotary	⑦⑮⑯	ETA, type, number available for response	-1 to -20 points	
	Handcrews	Handcrews/Hot Shots	②⑦⑮⑯	ETA, type, number available for response	-1 to -10 points	
	Water Tenders	Tanker vehicles	②⑧⑩⑮⑯	ETA, type, number available for response	-1 to -5 points	
	Escape Zones	Emergency survival areas	②⑦⑮⑯	Safe areas for residents & firefighter during WUI fires	-1 to -5 points	
	Structure Coverings					
		Foam	①②⑧⑩⑮⑯	Application of foam fire barrier on structure exterior	-40 to -80 points	
		Reflective	①②⑦⑩⑮⑯	Application of reflective foil on structure exterior	-40 to -80 points	
		Insulation	①②⑦⑩⑮⑯	Application of insulating non-combustible material on structure exterior	-40 to -80 points	
	Fire Flow	Fire service & extinguishment systems	②⑧⑩⑯	Quantity and flow of water necessary during emergency operations	-1 to -20 points	
	Water/Foam Application	Water foam mix	②⑧⑩⑯	Ability of fire agencies to apply water & foam for extinguishment	-1 to -5 points	
	Fire Sprinklers	Residential automatic fire sprinklers	⑧⑩⑯	Automatic fire sprinklers approved for residences	-1 to -5 points	

	Flame/Fire Detectors	Flame/fire detectors with power supply	②⑩⑮⑯	Detection of fire and flame with independent power supply	-1 to -5 points	
	CAF Systems	Compressed air foam system	②⑧⑩⑯	High expansion foam system used for protection of structures	-1 to -5 points	
	Fuel Modification	Fuel modification outside development	②③⑥⑯	Public agency managed reduction of highly flammable WUI vegetation	-40 to -80 points	
	Stored Water	Stored water for structure protection	⑧⑩⑯	Fire agency approved storage of fire water, minimum of 500 gallons	-1 to -5 points	
FIRE BEHAVIOR						
	Flame Impingement	Flame contact on structures	①②③④⑤⑫⑰	Interface flames contacting structures	1-20 points	10
	Ember Problems	Ember Wash	①②③④⑫⑰	Embers & brands swirling before/after main body of fire passes	1-20 points	10
	Ember Problems	Ember extent of travel	①②③④⑫⑰	Distance of embers carried by convected wind currents	1-10 points	5
	Smoldering/Hidden Fire	Embers smoldering inside structures	①②③④⑤⑫⑰	Smoldering areas of hidden fire within structures	1-10 points	5
	Rekindle	Structure re-ignition	①②⑤⑫⑰	Re-ignition of structure after initial fire extinguished	1-10 points	5
	Area Ignition/Blowups	Fire in ravine or valley igniting within minutes	①②③④⑤⑫⑰	Near simultaneous area ignition within a matter of minutes	1-10 points	5
	Spotting	Embers igniting fires ahead of main fire	①②③④⑤⑫⑰	Small areas ahead of main body of fire ignited by embers.	1-10 points	5
	Rate-of-Spread	Rapid rate of spread	①②③④⑤⑫⑰	The rate of progress of the main body of fire exceeding normal	1-20 points	
	Last Burn	Previous interface burn	①②⑤⑫	> 15 year interval since last burn	20-40 points	
SPECIAL HAZARDS						
	High Value Structures	Public buildings, churches, hospitals, historic, museums	①②⑤⑫⑮	Structures, within 5 miles of projected, whose loss would affect functioning of community	1-10 points	
	High Life Value Structures	Schools, hospitals, churches, theaters	①②⑤⑫⑮	Structures, within 5 miles of projected, where large numbers of people congregate	1-10 points	
	Cultural Assets	Museums, gardens, theaters	①②⑤⑫⑮	Locations, within 5 miles of projected that are valued by community for cultural benefit	1-10 points	
	Hazardous Materials	Oil refineries, nuclear plants, chemical manufacture.	①②⑤⑫⑮	Unusually highly toxic, reactive, flammable materials within 5 miles	1-10 points	
	High Tension Wires	Above ground high voltage lines	①②⑤⑫⑮	Lines & towers representing electrocution & aircraft hazard within immediate fire area	1-10 points	5
	Utilities	Transmission lines of utilities	①②⑤⑫⑮	Natural gas lines, electrical lines, oil & gas pipelines within projected fire area	1-10 points	
	Railroads	Trains & tracks	①②⑤⑫⑮	Railroad trains and tracks within projected fire area	1-5 points	

TOTAL VALUE						674

STRATEGY CODES	
①	Limit Ember Intrusion
②	Structure Safety Zone
③	Fuel Modification/Defensible Space
④	Provide Structural Fire Shields
⑤	Lower Wind Turbulence of Building Envelope
⑥	Lower Fire Profile Index Value
⑦	Establish Adequate Egress
⑧	Adequate Water Supply
⑨	Cleanup Litter/Leafs
⑩	Independent Fire Water Supply
⑪	Limb-up Trees/Bushes
⑫	Provide Adequate Separation
⑬	Remove Plants
⑭	Reduce Quantity
⑮	Shelter-In-Place
⑯	Take Advantage of Benefit
⑰	Noncombustible/Fire Resistive Construction

Figure I.2: Fire Profile Index Strategy Code

APPENDIX J

TABLE J.1
FIRE ASSESSMENT GUIDE

Category	Sub Category	Attribute	Subcategory/Attribute Definition	+	-	--
Development						
Development	WUI Code	Non-Code Compliant	Area not subject to provisions of WUI building code & ordinances			--
		Compliant	Area subject to provision of WUI code before 2003		-	
		Compliant	Area subject to provision of 2003, or newer WUI code or newer	+		
	Structure Separation	< 30' Separation	Structures with < 30' separation from other structures & other heavy fuels			--
		30' to 45' Separation	Structures with 30' to 45' separation from other structures & other heavy fuels		-	
		> 45' Separation	Structures with > 45' separation from other structures & other heavy fuels	+		
	Structure Density	High Density	> 100 Structures per square mile			--
		Medium Density	20 to 100 Structure per square mile		-	
		Low Density	< 20 Structures per square mile	+		
Fuels						
	Natural Plants	Fuel Type	Predominate most severe type of fuel		-	
		Heavy Fuel Load	> 40 Tons per acre			--
		Medium Fuel Load	10 to 40 Tons per acre		-	

Category	Sub Category	Attribute	Subcategory/Attribute Definition	+	-	--
Fuels	Natural Plants	Light Fuel Load	< 10 Tons per acre			
		Continuity	Continuous Medium fuel type distribution		-	
		Continuity	Continuous Heavy fuel type distribution			--
		High Fuel Moisture	Live High fuel moisture as a percentage of weight	+		
		Moderate Fuel Moist	Live Medium fuel moisture as a percentage of weight		-	
		Low Fuel Moisture	Live Low fuel moisture as a percentage of weight			--
		High % Dead	High Percent of dead vegetation			--
		Moderate % Dead	Average Percent of dead vegetation		-	
		Low % Dead	Low Percent of dead vegetation	+		
		Fuel Age	Assume 25 year age class			--
		Fuel Ladder	Light fuel to aerial fuel continuity to structure locations			--
		Fuel Modification	Fire agency supervised reduction of natural vegetation in vicinity of development			
	Cultivated Plants	Fuel Type	Predominate most severe type		-	
		Heavy Fuel Load	> 40 Tons per acre			--
		Medium Fuel Load	10 to 40 Tons per acre		-	
		Light Fuel Load	< 10 Tons per acre	+		
		High % Dead	High percentage amount of dead vegetation			--
		Moderate % Dead	Average percentage amount of dead vegetation		-	
		Low % Dead	Low percentage amount of dead vegetation	+		
		Low Fuel Moisture	Low Live fuel moisture as a percentage of weight			--
		Moderate Moisture	Medium Live fuel moisture as percentage of weight		-	
		High Fuel Moisture	Low Live fuel moisture as a percentage of weight	+		
		Fuel Ladder	Low to medium fuel moisture in ground to aerial fuel to structure continuity			--
		Fire Barriers	Irrigated > 200 feet, irrigated, low combustibility	+		
		Continuity	Predominate fuel types proportionate distribution			
Weather						

Category	Sub Category	Attribute	Subcategory/Attribute Definition	+	-	--
Fuels	Relative Humidity	Low	< 15 percent relative humidity			--
		Medium	15 to 30 percent relative humidity		-	
		High	> 30 percent relative humidity	+		
	Temperature	High Temp.	> 90° F dry bulb temperature			--
		Moderate Temp.	75° to 90° F dry bulb temperature		-	
		Lower Temp.	< 75° F dry bulb temperature	+		
	Wind Velocity	High Velocity	> 20 mph sustained winds			--
		Moderate Velocity	5 to 20 mph sustained winds		-	
	Cloud Cover	Beneficial	> 30 percent cloud cover	+		
	Front Movement		Historic occurrence of weather front movement			
	Drought	Annual	Summer draughts (i.e. Mediterranean climate)		-	
		Unusual	Historic probable worst case			--
	Rainfall Pattern	Divergent Pattern	Heavy rainfall year followed by below normal year			--
	Structure/ Wind Position	Downwind	Structure downwind in path of fire			--
Terrain						
Terrain	Percent Slope	Steep	> 50 percent slope			--
		Moderate	30 to 50 percent slope		-	
		Mild	< 30 percent slope	+		
	Fire/Slope	Alignment	Predominate fire wind pushing fire uphill towards structures			--
	Fire Breaks	Natural	Significant breaks in fuels to impede/ stop fire (i.e. rock outcroppings, rivers)	+		
		Manmade	Significant breaks in fuels to impede/ stop fire (i.e. freeways, parking lots, orchards)	+		
	Saddles	Moderate	Mild depression in ridge lines located in fire's path		-	
		Steep	Well defined depression in ridge lines located in fire's path			--
	Chimneys	Moderate	Mild vertical depression between protrusions of slope located in fire's path		-	
		Steep	Well defined steep vertical depression between protrusions of slope located in fire's path			--

Category	Sub Category	Attribute	Subcategory/Attribute Definition	+	-	--
Terrain	Ridge Lines	Moderate Slope	Structures located in vicinity of ridgelines< 50 percent slope		-	
Terrain		Steep Slope	Structures located in vicinity of ridgelines >50 percent slope			--
	Solar Aspect	South & West	Structures located on west & south facing slopes			--
		East	Structures located on east facing slopes		-	
		North	Structures located on north facing slopes	+		
	Slope Setback	Steep Slope	< 30 Feet setback from a slope of > 50 percent slope			--
	Slope Setback	Mild Slope	< 30 Feet setback from a slope of 30 to 50 percent slope		-	
	Midslope Location	Thermal Belt	Structures located on middle 1/3 of slope		-	
	Structure Location	Perimeter Location	Structures located on perimeter of development			--
Mitigating Measures						
	Mitigating Measures	Structure Safety Zone	Increased defensible space > 2X flame length of worst case scenario	+ 10		
	Mitigating Measures	Structure Fire Shield	Low Profile Structure Fire Shield appropriately installed	+ 5		
		High Profile Structure Fire Shield	High Profile Structure Fire Shield appropriately installed	+ 10		
		Other	Fire Agency Approved systems (i.e. Foam Systems, Reflective Material, Deluge)	+ 5		
Totals						

APPENDIX K

*TABLE K.1:
DEVELOPERS GUIDE*

Category	Subcategory	Attribute	Subcategory/Attribute Definition
Construction Features	Problems Areas		
	Building Envelope		
☐		Trapped Airflow	Overhangs on flat surfaces
☐		Alcoves	Room or wall protrusions from axis of structure
☐		Combustible Decking	Increases turbulence below decking, increases ignition possibility & increases fuel loading
☐		Second Story Decking	Increases turbulence below decking, increases ignition possibility of adjacent portion of structure
☐		Solar Shading	Combustible shading (i.e.sun screens, porches, awnings)
☐		Windward Angular Surfaces	Wall facing windward/fire exposed side increases wind pressure & turbulence
☐		Large Floor Areas	Structures with floor area over 1600 square feet
☐		Crawl Spaces	Accessible areas where upright walking is impossible
☐		Concealed Spaces	Walled-in areas not accessible
☐		Porches	Increases wind turbulence
☐		Raised Foundations	Allows embers and brands under house
☐		Venting	Unprotected vents for attic, floor, & concealed spaces allow ember intrusion
☐		Soffit Vents	Allows embers into confined spaces
☐		Multistory Structures	Increases surface area exposed to air movement & greater wind pressures

Category	Subcategory	Attribute	Subcategory/Attribute Definition
	Roofs		
☐		Elevated Roof Profile	Vertical gables and steep pitches on roof increases wind pressure & turbulence
☐		Angular Roof Lines	Gables and steep pitches on roof increases wind pressure & turbulence
☐		Combustible Sheathing	Non-rated roofs contribute to low fire resiliency
☐		Eaves	Increased turbulence under eaves
☐			
	Walls		
☐		Wall Reliefs	Raised portions on wall surfaces
☐		Rough Wall Finishes	Increased surface turbulence
☐		Combustible Moldings	Increased surface turbulence & fire penetration possible
☐		Wood Siding	Includes structural and fascia increases ignitability
☐			
	Windows		
☐		Large Windows	> 4 square feet on fire side(s) & unprotected
☐		Exposed Windows	Large windows on fire exposed walls, not recessed
☐		Raingutters	Open without screens, not covered allows combustible debris buildup
☐			
	Structure Positioning		
☐		South & West Aspect	Structures located on slopes facing south & west have greater fire danger
☐		Slope	> 20 percent slope increases fire danger
☐		Slope Setback	< 30' setback from slopes
☐		Ridgeline	Ridgelines have 3X to 4X wind velocity than midslopes
☐		Chimneys	Chute, draws, and road in-turns have greater flame lengths and wind velocity

Category	Subcategory	Attribute	Subcategory/Attribute Definition
☐		Saddles	Depression in ridgelines have funnel effect of airflow
☐		Structure Separation	< 45' separation from structure & heavy fuels
☐		Windward Location	Structures located on slopes with fire winds blowing uphill
☐			
Landscaping Features	Problems Areas		
☐	Fencing	Combustible Fencing	Combustible fencing < 10' of structures
☐	Mulch	Organic Mulch	Organic mulch within 30' of structures
☐	Plants	Avoidable Plants	Plants listed by fire agencies as being highly flammable
☐	Plants	Combustible	Plants that contribute fuel to spread of fire
☐	Defensible Space	Minimal	< 100' of fire authority approved defensible space
☐	Defensible Space	Inadequate	> 100' of fire authority approved defensible space that is inadequate due to terrain, weather or fuel conditions
Beneficial Construction			
	Building Envelope		
☐		Wall/Roof/Attic Insulation	> R 40 insulation that reduces rates of heat transfer
☐		Deck/Patio Covers	Heavy timber or noncombustible construction
☐		Deck/Balconies Enclosed	Enclosed underside of decks & balconies
☐		Slab Floors	Concrete footing and flooring applied on grade
☐		Floor Radiant Heat	Heating tubing in slab floors eliminates ducting, concealed spaces, fire & ember travel
☐		Buried Houses	House with 3 side below grade, or with 3 feet of earth on sides
☐		Smaller Houses	House with floor plans under 1600 square feet

Category	Subcategory	Attribute	Subcategory/Attribute Definition
☐		Open Floor Plans	Structures with minimum of partitions
☐		Eliminate Vents	Attic vents, roof & floor crawl spaces, wall vents, HVAC vents
☐		Retractable Coverings	Moveable, noncombustible shading features of structures
☐		Reflective Surfaces on Insulation	Reflective material placed on the outside of insulation
☐			
	Roofs		
☐		Flat Roofs	Flat roofs reduce airflow turbulence & pressure
☐		Sod Roofs	Minimum of 1 foot thick earth with irrigated grass
☐		Pool Roofs	Minimum of 1 foot deep water pool
☐		Flooded Roofs	Flat roofs that can be flooded with 1 foot of water
☐		Rainwater Collection Roofs	Flat roofs used for rainfall harvesting
☐		Insulated Metal Roofs	Metal roofing material with adequate thermal insulation underneath
☐		Green Roofs	Heavily insulated roofs made of noncombustible materials
☐		Roof Tie-Downs	Use of tie-downs of flat roofs, especially with truss rafters
☐		Bird Stops - Tile Roofs	Noncombustible filling of first row of curved tile hemispheres
☐		Eliminate Attics & Vents	Ceiling applied to underside of roof rafters, or use of insulation that requires no venting
☐		Dome/Arch Roof	Arched roof without flat surfaces facing wind/fire spread
☐		Roof Radiant Heat Barriers	Radiant, reflective barriers place underneath or on-top-of roofing
☐		Metal Framing	Reduces combustible loading
☐		Reflective Surfaces Roofing	Reflective material placed on the underside or outer roof surface

Category	Subcategory	Attribute	Subcategory/Attribute Definition
☐			
	Walls		
☐		Smooth Exterior Walls	Smooth plaster or cement or metal
☐		Fire Rated Doors	Fire tested and rated assemblies that operate automatically
☐		Cementous Siding	Various forms of aggregate with cement
☐		In-Steel Plaster	Metal lath for plaster
☐		Pise De Terre Walls	Adobe rammed earth with 10% cement added
☐		Rammed Earth Walls	Earthen walls with 10% cement added
☐			
	Windows		
☐		Windows Metal, 2X Pane	Metal framed windows with double-pane glazing
☐		Fire Rated Windows	Fire tested and rated assemblies that operate automatically
☐		Window Covering Inside	Living area side of windows coverings reduces radiant heat transfer to structure contents
☐		Window Covering External	Non-combustible shutters on external wall side
☐		Windows - Glass Blocks	Translucent hollow glass bricks, non-openable
☐		Windows - Recessed	Windows externally recessed into thick walls
☐		Window Vertical Blinds	Non-combustible vertical blinds that are closable
☐		Window Horizontal Blinds	Non-combustible horizontal blinds that are closable
☐			
Beneficial Landscaping			
☐	Defensible Space	2005 Code Compliant	Minimum of 100' distance, without fuels surrounding structures

Category	Subcategory	Attribute	Subcategory/Attribute Definition
☐	Altered Terrain	Terracing	Leveling of hillside in steplike fashion with the use of retaining walls
☐	Altered Terrain	Berms	Mounding of earth to a height of roofline within 10 feet of Structure
☐	Hardscapes	Patios	Increases defensible space
☐	Walls/Fencing	Noncombustible	Noncombustible walls surrounding exterior of structure
☐	Gates	Protective Gates	Noncombustible gates for walkways & driveways
☐	Gates	Staggered	Gates staggered with noncombustible walls to block fire travel
☐	Mulch	Inorganic Mulch	Use of rock, sand, pebbles as ground covering within 30' of structures
☐	Plants	High Water Content	Succulents & other plants with high water content
☐	Plants	Approved Plants	Fire agency recommended plants for particular fire zone
☐	Plants	Fire Barrier Plantings	Hedges of succulents, irrigated orchards
☐	Irrigation/ Firefighting Water	Grey/Rainwater Cistern	Combination fire water & irrigation system using grey and/or rainwater
☐			
Mitigating Measures			
☐	Defensible Space	Structure Safety Zone	Minimum of 2X flame length distance of defensible space each side
☐	Fire Spread Inhibitors	Structure Fire Shield	Noncombustible walls/berms effectively placed to protect structures
☐	Ember/Fire Inhibitors	Lipped Walls	Noncombustible walls with outward-facing rounded overhand at top
☐	Shelter-In-Place	Occupant Fire Shelters	Safe fire resistant areas with adequate ventilation, lighting, power
☐	Structure Coverings	Foam	Application of foam fire barrier on structure exterior

Category	Subcategory	Attribute	Subcategory/Attribute Definition
☐	Structure Coverings	Reflective	Application of reflective foil on structure exterior
☐	Structure Coverings	Insulation	Application of insulating noncombustible material on structure exterior
☐	Fire Extinguishment	Fire Sprinklers	Automatic fire sprinklers for interior & exterior application
☐	Fire Extinguishment	CAF Systems	Compress Air Foam systems that are applied to exterior of structures
☐	Fire Extinguishment	Water Application	Ability of fire agencies & occupants to apply water from stored supply
☐	Fire Extinguishment	Extinguishment System	Stored water with pump, independent power supply & equipment for application
☐	Fire Detectors	Flame/Fire Detectors	Flame and fire detector with independent power supply
☐			
☐			
☐			