Urban Wildfire Exposure Modeling in the Municipality of Anchorage, Alaska

Principal Author:
Charlie Barnwell
GIS/Data Resources Manager
Information Technology Department
Municipality of Anchorage, Alaska
barnwellce@muni.org

Cooperating Authors:
Sue Rodman
Forester
Fire Department
Municipality of Anchorage, Alaska

John Koltun
Director GIS Services
Geographic Resource Solutions
Anchorage, Alaska

CONTENTS

Abstract

The Anchorage Wildfire Exposure Model (AFEM) is the result of a phased Municipality Anchorage, Alaska (MOA) four-year wildfire risk assessment modeling process. The AFEM and associated projects arose out of a multi-agency effort to mitigate and respond to wildfire threats in the Anchorage area. The AFEM stresses the input of a multi-disciplinary and agency Fire Science Team, and generates a fire exposure map that reflects the potential threat of wildfire throughout the MOA wildland/urban interface area. The AFEM is a GIS-based model that automates the analyses of MOA GIS data for the calculation of the exposure components: potential fire intensity, values at risk, suppression constraints, and ignition risk. The AFEM conceptual design leveraged previous modeling efforts in Phase 1 using ERDAS Imagine. In Phase 2, AFEM was initially implemented and refined using ArcGIS Model Builder. This allowed the fire scientists to visualize the process flow of GIS data through the model and evaluate the impacts of the weights and parameters on the calculation of the exposure components. After implementation in Model Builder, AFEM was converted to an ArcObjects extension with a custom interface and extended processing options. AFEM is currently being used to guide mitigation efforts and evaluate what-if scenarios for urban development options. A Phase 3 project will refine the AFEM, and supporting land cover and fire fuel types categorization. The AFEM also serves the MOA as a strategic ArcGIS modeling prototype for other potential uses in the city.

Setting

In the last 10 years, over 3.2 million acres in Alaska have been infested by the spruce bark beetle (Dendroctonus rufipennis) leaving entire stands of white spruce (Picea glauca) dead or dying. Anchorage, Alaska's largest city at a population of 250,000 and area of 2,000 square miles, contains a large wildland urban interface (see Figure 1). Within the Municipality of Anchorage, over 88,000 acres of spruce forest have been affected. In response, the Municipality has implemented an aggressive program to assess and mitigate the potential of extreme wildfire activity.

Since 2000, the Municipality of Anchorage has partnered with local, state, and federal agencies to develop strategies to address the risk of wildfire. The Firewise program at first provided the umbrella under which this program developed. With funding assistance appropriated through Congress, the Municipality has received the resources to approach this challenge directly. In 2002, the MOA received $5 million and in 2003 Congress appropriated an additional $4.1 million to continue these efforts. The Municipality has additional funding of $400,000 from FEMA and been a partner to $710,000 from a State Fire Assistance Grant.

These funds have used towards the following mitigation strategies:

- Public education through television, radio, etc.
- Direct homeowner education with SCA Fire Education Corps volunteers
- Hazardous fuels removal in MOA parks with the Mat Su Fire Crew & others
- Providing wood lots and brush pick-up to homeowners
- Training line personnel at the Anchorage Fire Department and the Anchorage Police Department on wildfire suppression tactics & risks
- Supporting AFD with additional wildfire suppression capabilities such as brush trucks, portable pumps, contract helicopters, and maintaining our mutual aid agreements.
- Working to support forest health through management and reforestation
- Assessing wildfire risk through risk mapping and fuel type modeling

In support of risk assessment and mapping for mitigation and response planning, the MOA together with private contractors developed the Anchorage Fire Exposure Model (AFEM) Decision Support System.

Project Background

In 2000, the Municipality of Anchorage GIS began working with the Firewise program, government agencies, and the Anchorage Fire Department to utilize geographic information systems (GIS) for wildfire mitigation and response. In 2001, a contract was let for Phase 1 of the Wildfire GIS/Mapping Support program, and an intensive risk assessment and modeling effort ensued (Abeyta, 2001).

In 2003, the Municipality of Anchorage (MOA) released the Wildfire Mitigation and GIS Mapping Services Contract directing the development of a wildfire hazard Decision Support System (DSS). Lessons learned from the GIS modeling and mapping project contributed to a strategy focused on the DSS in conjunction with a Fire Science Team. This DSS would leverage previous wildfire risk assessment modeling, and enable the interactive analysis of key wildfire influences and then report the relative danger posed by wildfire to cultural and resource values across the Municipality. The DSS would allow users full control over the input themes and weight of wildfire factors. In this manner, various scenarios involving the impacts of mitigation and planning on wildfire events could be analyzed.

The resulting Anchorage Fire Exposure Model (AFEM) DSS is an interactive tool that allows public safety professions, fire scientists, foresters, and others to assess the effects of fire mitigation and prevention measures such as vegetation enhancement, FireWise home protection, building developments, and suppression improvements. The AFEM DSS interface was built within the ArcMap (ESRI, Redlands, CA) environment. A fire professional with limited GIS experience can define the model's input layers and exposure weights through user-friendly dialogs. The results of an analysis can be viewed immediately in the interactive map environment.

The completed AFEM DSS was initially run to calculate a baseline fire exposure map to define the threat of wildfire exposure through the MOA study area. This exposure map was based on current MOA GIS data including the vegetation/fuels map that was also developed in this project. The parameters and weights used in this baseline analysis were selected by the Fire Science Team to represent a worst-case fire scenario.

AFEM is implemented within the ArcGIS (ESRI, Redlands, CA) ArcMap environment. Initially the AFEM component models were designed and prototyped using ArcGIS ModelBuilder environment. After the model was designed and tested, the components were combined into a single VBA application - AFEM. The AFEM DSS was developed in the ArcGIS VBA development environment so that any experienced GIS analysts and programmers at MOA can modify the structure and algorithms of the model itself without additional development tools.

Fire “Hazard” Modeling

The components that contribute to fire exposure are categorized into the following components:

- Hazard,
- Risk,
- Values, and
- Suppression.

Hazard is the intensity at which the natural fuels burn; risk is the probability of ignition based on both the ignitability and the presence of ignition sources; values are the cultural and resource values being exposed (or in danger) during a wildfire event; and suppression is speed and ease of suppression of a wildfire based on location and intensity.

Each of these components, Hazard, Risk, Values and Suppression, are calculated from the environmental factors and cultural conditions that contribute to each. Vegetation, habitation, buildings, land-use, terrain, weather, and fire history are among the environmental and cultural conditions that contribute to fire exposure. Exposure is calculated as the combination of the components that occur at each location across the landscape. Exposure modeling is the process of combining these factors and components to calculate or predict the threat posed by wildfire.

The AFEM incorporates model inputs, calculates the weights for each component and combines these components weights into an exposure rating.

The exposure rating calculated in AFEM is a relative ranking of the threat of wildfire to cultural resources. The AFEM reports and map products can be used for the following purposes:

- Mitigation design and prioritization,
- Emergency response planning,
- Homeowner awareness,
- Community planning, and
- Risk assessment.

Model Design

The initial wildfire model structure and design process began in April 2003, and as mentioned above leveraged prior modeling efforts in Phase 1 (Abeyta, 2001). A lesson learned in Phase 1 is that a critical factor for successful modeling is to maintain an interactive dialogue with subject matter experts. The MOA invited fire science professionals familiar with Alaska fire issues to form a Fire Science Team (FST). The FST was comprised of representatives from Anchorage Fire Department, Anchorage IT/GIS Department, US Forest Service, Alaska Department of Natural Resources, National Park Service, Anchorage Soil and Water Conservation District (ASWCD), Soil Conservation Service, and Bureau of Land Management. The purpose of the FST was to serve an advisory role and provided assistance in the model development and the definition of model parameters.

In a series of meetings, GRS, MOA, and the FST established the modeling factors and weighting system that would be used in the fire exposure assessment. The FST identified the key concepts that should be addressed by the fire exposure model for Anchorage:

- The Values component of the model should be weighted highest reflecting the focus of this project on the preservation of life and property.
- Fuels Hazard should be quantified in a manner that is consistent with established fire behavior models Behave, FARSITE, and FlamMap.
- Fuels hazard weights should be calculated for each fuel type based on fire intensity as expressed by flame-length.
- The model should be based on standard fuel type descriptions from Anderson (1982) and the fuels/vegetation study done by Cheyette (2003).
- Slope and Aspect hazard weights should be calculated using BEHAVE and FlamMap runs with categorized slope and aspect values.

- Slope and Aspect weights should be multiplicative relative to the fuels. This more accurately reflects the relationship of the slope and aspect on overall intensity.
- The parameters in the Suppression category should be developed and weighted based on actual equipment specifications and estimated suppression times.
- The Risk category should incorporate fine fuels as a qualifier to account for flammability of location. It also incorporates parameters that reflect probability of fire ignition based on current studies of ignition causes.
- Fire behavior would be calculated based on a worst-case scenario for weather and fuel moisture conditions Cohen (2003).

As part of the design process, GRS and MOA researched existing wildfire threat models used in other communities throughout the world. These included models from McGregor Forest, BC (Hawkes, 1997); New Zealand, (Leathwick, 2001; Majorhazi, 2002); California (Radke, 1995); Idaho (Harkins, unknown); and Colorado (Johnson, 2001). Based on this research, GRS selected a suite of factors that contribute to overall exposure to fire within the urban-wildland fire interface. These factors were then categorized in to the four major components contributing to exposure:

- Fuels Hazard
- Ignition Risk
- Values at Risk
- Suppression

Table 1 contains a selection of the factors used in other wildfire threat models that were considered by the FST.

Table 1

Hazard (fire behavior)	Units of Measure
Elevation	feet
Slope	percent
Aspect	category/degrees
Canopy Cover	category/percent
Fuel type	Anderson & Local
Wind	mph
Humidity	percent
Temperature	degrees
FARSITE Themes	
Tree/Stand Height	feet/meters
Crown Base Height	feet/meters
Crown Bulk Density	lbs/ft3; kg/m3
Course Wood Debris	Course Woody Profile
Duff	mg/ha; tons/acre
Risk Inputs (ignition)	
Roads	feet/meters
Trails	feet/meters
Structures	feet/meters
Recreation	feet/meters
Fire History	years between fires
Land Use	category
Lightning Ignitions	strikes /year
Values of Concern	
Population Density	Occupants/acre
Structure Density	Homes/acre
Public Facilities	feet/meters
Utilities	feet/meters
Recreation Use	feet/meters
Natural Resources	
Wildlife Habitat	
Suppression Issues	
Response Time	HH:MM
Equipment Availability	
Proximity to Roads	
Proximity to Trails	
Distance from hydrant	feet/meters
Distance from draftable water	feet/meters

These factors served as the foundation for the design of the Anchorage Fire Exposure Model (AFEM). The FST narrowed this list of factors to those that were appropriate for Anchorage and South Central Alaska. The FST also considered that some of the factors did not have a significant effect while others could be incorporated into the calculation of intermediate factors. For example, temperature, elevation, humidity, wind, vegetation, and tree canopy, are combined in the calculation of flame length. Table 2 reflects the distilled factors for each component that were selected for the AFEM.

Table 2

Hazard (fire behavior)	Units of Measure	Factor Weight
Fuel type	Anderson & Cheyette	Flame Length (FL)
Slope	percent	FL multiplier
Aspect	category/degrees	FL multiplier
Risk Inputs (ignition)		
Roads	feet/meters	Road class
Trails	feet/meters	Trails class
Fuel type	Anderson & Cheyette	Fuels Ignition class
Land Use	category	LU Ignition class
Values of Concern		
Improvements	Improvements code	Improvement class
Parcel Size	acres	Improvement multiplier
Land Use	Land Use code	Land Use class
Suppression Issues		
Response Time	minutes	Response Time
Proximity to Roads	feet	Road class
Proximity to Trails	feet	Trail class
Distance from hydrant	feet	Water class
Distance from draftable water	feet	Water class

Once these factors were selected, GRS and the FST defined categories within these factors and developed relative weights for each class.

Model Components

The factors that contribute to the Anchorage Fire Exposure Model are grouped into four major components:

- Fire Hazard,
- Ignition Risk,
- Values at Risk, and
- Suppression.

In the following sections, these components are defined along with the individual data factors that contribute to the component weight.

Fire Hazard

Fire Hazard is sometime used as a term seemingly equivalent to fire exposure. In fire science terminology, *fire hazard* is the term used to describe the potential intensity of the fire. It is a complex and significant factor contributing to fire exposure. Yet in and of itself fire hazard does not necessarily equate to danger to life or property. Wildfire behavior models such as FARSITE (Finney, 1998), Behave

(Burgan and Rothermel, 1986), and FlamMap (Finney, 2001) provide methods to calculate and assess fire hazard based on a number of environmental factors. GRS, MOA, and the FST chose to leverage these established fire behavior models for the fire hazard component within the AFEM model.

Flame length was chosen as the hazard weight factor as it is directly related to the Burning Index (BI), defined as "A number relating to the potential amount of effort needed to contain a single fire in a particular fuel type within a rating area." In the National Fire Danger Rating System (NFDRS), the BI combines fire intensity and rate of spread as a function of Flame Length (FL). Flame Length is a function of the Energy Release Component (ERC) (BTU/sq. ft.) of a fire front, and the Spread Component (SC) (ft/minute). The BI is calculated by multiplying the FL by a constant factor (10) (Gross, 1998). In this model, it was decided to use flame length directly and skip the conversion to BI.

Fuels

The fire-fuels map was derived from the MOA vegetation map that was also created during this project. Members of the Fire Science Team defined the vegetation components of each fuel type. These vegetation descriptions were then converted to a hierarchical classification (Table 3). This classification was then implemented by using a series of queries and updates to classify the MOA vegetation map into fuels classes based on the vegetation components stored in the database.

Table 3

MOA Vegetation to Fuels Classification

Description	Decision Rules	Fuels Class Code	FST Anderson Class
Barren	1000 Bar_cover + Oth_cover > 50		**99**
Vegetated	2000 Bar_cover + Oth_cover <= 50		
NON-TREE	2100 Tree_cov < 60 % of total cover		
Herbaceous	2110 Forb_cover > Shr_cover And Forb_cover > Gram_cover		
	All	2110	**1**
Graminoid (Grass)	2120 Gram_cover >= Forb_cover And Gram_cover > Shr_cover		
Non-Tree	Tree_cov < 25 % total cover	2121	**1**
Graminoid Timber	Tree_cov >= 25% (and < 60%) of total cover	2122	**2**
Graminoid Dead Spruce	Dead_cover > 15%	2123	**12**
Shrub	(Tsh+Lsh+Dsh) >= Forb_cover And (Tsh+Lsh+Dsh) >= gram_cover		
Dwarf Shrub	Dsh_cover >= Lsh_cover And >= Tsh_Cover	2131	**1**
Low Shrub	2132 Lsh_cov > Dsh_cov And >= Tsh_cov		
Low Shrub	Tree_cover < 20%	21321	**1**
Low Shrub Timber	Tree_cover >= 20%	21322	**5**
Low Shrub Tundra	Tree_cover < 25% And Dsh > 1	21323	**1**
Tall Shrub	Tsh_cov > Dsh_cov And > Lsh_cov	2133	**9**
TREE	2200 Tree_cover >= 60% of total cover		
Conifer	2210 Conf_cover > 75 % of Tree_cover		
Black Spruce	Pr_Comp = "Black Spruce"	2211	**6**
Sitka/Hemlock	Pr_Comp = "White Spruce" or Pr_Comp = "West Hemlock"	2212	**10**
Dead White Spruce	Dead_cover > 15%	2213	**12**
Other Conifer	Other	2214	**8**
Hardwood	2220 Hdwd_cover > 75 of Tree_Cover		
	All	2220	**9**
Conifer/Hardwood Mix	2230 Conf_cover <= 75 And Hdwd_cover <=75% of Tree Cover		
Mixed w/ Dead	Dead_cover > 15%	2231	**12**
Mixed	Other	2232	**9**

Modifications made to the reclass database table:

1) Shr_cover was previously defined (Tsh_cover + Lsh_cover). It is now all shrub (Tsh_cover+Lsh_cover+Dsh_cover)

2) A new column was created that represents Forb_cover that is equal to (Hrb_cover - Gram_cover) since Hrb_cover includes Gram_cover)

3) A new column was created that represents Dead Spruce Cover (Dead_cover) Dead spruce types are now defined by the value in this column

Weather

In the standard scenario used to develop the MOA fire exposure maps, the fire behavior models were run using a worst-case weather and moisture scenario defined by the FST. The fuels moisture and live fuel moisture were set at 5, 8, 12, 100, and 100 (1hr, 10hr, 100hr, Herb, Woody) for all fuel types. Winds were held constant at 5-mph uphill. Elevation was held constant at 500 feet since the affects of elevation are nominal within the study area.

Hazard Calculation Options

Although it is desirable to use the established fire behavior models to calculate hazard inputs, these models are complex and take training and experience to run properly. It was anticipated that in many instances the precision of the fire behavior models would not be necessary to evaluate some scenarios. Therefore, the AFEM was designed so that the hazard can be calculated in one of two ways:

1. The output from map-based fire behavior models such as FlamMap and FARSITE can serve as direct hazard inputs into the Exposure Model, or
2. AFEM can calculate the hazard based on pre-calculated categorical weights that were developed by modeling fire behavior over a range of scenarios.

The first option for calculating the flame length is to run the FlamMap model using the MOA fuels map with the associated topography and standardized weather inputs. In this option, the output from the FlamMap run is used directly in the model without modification. The process for running FlamMap is well documented in the FlamMap User's Guide; therefore, it is not covered in this paper.

The second method of hazard calculation provides a straightforward alternative within the AFEM model. The hazard calculation was broken into its major components, fuels/flame-length, slope, and aspect. Each of these components was categorized and values for each category were calculated independently. Based on the assumption of a "worst-case" scenario, weather was held constant. AFEM calculates a hazard value based on the pre-defined fuels weight adjusted for local slope and aspect.

Each fuel type was pre-assigned a flame length calculated using the BehavePlus software and appropriate environmental parameters. The flame length values at each location are then adjusted for slope and aspect at that location.

The predefined category weights were calculated using the Behave and FlamMap. So although they lack the precision of a FlamMap run, the calculated values are equivalent in magnitude since Behave, FARSITE, and FlamMap use the Rothermel (1972) model for calculating fire intensity.

The affects of slope and aspect were removed from the fuels weighting since these factors contribute as separate weights. Table 4 contains the standard Anderson (1982) fuel types and the flame length calculated for each type using BehavePlus.

Table 4

Fuels Models and Flame Length
Based on Anderson (1972)

Group	Model	NFDRS	Flame Length (ft)
Grass and Grass-Dominated Models			
	1 Short Grass (<2.5ft)	A,L,S	**4.8**
	2 Timber (grass and understory)	C,T	**6.5**
	3 Tall Grass (2.5+ ft)	N	**14.3**
Chaparral and Shrub Fields			
	4 Chaparral Shrubs (6+ ft)	B,O	**20.1**
	5 Brush (2 ft)	(D)	**6.1**

	6 Dormant Brush, Hardwood Slash "Alaska spruce taiga and shrub tundra"	F	**6.4**
		Q	**6.4**
	7 Southern Rough/Low Pocosin (2-6 ft) "Black spruce-shrub combinations in Alaska…"	D	**6.2**
Timber Litter			
	8 Closed Timber Litter	H,R	**1.2**
	9 Hardwood Litter	E	**3.1**
	10 Heavy Timber Litter and Understory	G	**5.3**
Slash			
	11 Light Logging Slash	K	**3.6**
	12 Medium Logging Slash	J	**8.3**
	13 Heavy Logging Slash	I	**10.9**

*Flame Length Calculated Using BehavePlus at fuel moisture regime (5,8,12,100,100) for all fuels.

Slope

The weights for each slope class were calculated in BehavePlus by calculating the flame length of each fuel type at the midpoint of each slope category. The flame lengths for each fuel and slope class were then divided back through the flame length calculated for zero slopes to get the multiplier factor for each class.

Aspect

BehavePlus does not calculate the effects of aspect. Therefore, the aspect weight was calculated by using FlamMap. In order to calculate the Aspect weights within FlamMap, grid was created with aspect values repeated throughout the grid such that each aspect class would coincide with blocks of pixels for the fuels classes. In this manner, a cell for each aspect class overlaid each fuels class. These grids were used as inputs to FlamMap to calculate the flame lengths for each combination of fuels and aspect. Elevation, weather, and slope were held constant. A multiplier factor that could be applied across all fuel types was then calculated for each aspect class.

Calculation of Hazard

Once the flame length and the multipliers for slope and aspect have been calculated, these values are used to reclassify their respective subject maps into values maps: fuels are reclassified into flame length; slope is reclassified into slope-weights; and aspect is reclassified into aspect weights. The hazard (H) at every grid location is calculated as a function of flame length (FL), slope (S), and aspect (A).

$$H = FL * S * A$$

The resulting map represents the potential flame length (fire intensity) at each location adjusted for the effects of terrain.

Ignition Risk

Ignition Risk is defined as the potential for a fire to be ignited at a particular location. A great number of cultural and natural factors influence the potential for ignition. GRS, MOA, and the FST distilled a list of likely ignition factors into fuels, accessibility, and land use. Although it is a common factor of fire exposure models, historic fire occurrence was not used in this study.

There is no comprehensive history of wildfire occurrence within the MOA study area. Fire department databases contain structure fire and response data, but no study exists that could correlate past fire events to wildland/urban fire issues within the scope of this study. Statewide fire occurrence studies were not at a level of scale or detail to include data in the Anchorage area. In addition, there is some evidence that in a dynamic environment such as the wildland/urban interface, past fire locations may not correlate to the probability of future occurrence. Factors that lead to past fires in a location may no longer exist in the current or future condition at that location (Farris, et. al., 1999)

The relative weighting for each category within each component of Ignition Risk is a subjective process. Lacking any historical information for the Anchorage area, the actual correlation between the categories and the ignition risk could not be directly calculated. Therefore, the weights were determined based on a review of other exposure models and the overall contribution to the model output.

Fuels Risk

The fuels ignition risk reflects the susceptibility of a fuel type to ignition when exposed to flame or sparks. It is based on the availability of fine fuels within a fuel type as well as the general shading that is typical of that type. A general trend in the ignitability of fuels was determined by evaluating the ignition component (IC) output of BehavePlus for each fuel model. The fuel types were grouped into 5 main categories. Each category was then assigned a relative weight with an increasing weight corresponding to an increase in ignitability.

Accessibility

Accessibility is determined by the existence of roads and trails. It has been shown that increased accessibility leads to an increased risk of ignition (Harkins, unknown). In general, this increase is related to the relative traffic volume on an access route; greater traffic increases the number of potential ignition sources. Roads and trails are categorized into five classes of ignition risk based on relative quantity of traffic and then assigned a relative weight (Table 5).

Table 5

IGNITION RISK						
Roads & Trails (adjacent*)	Class	Paved Heavy (Arterial & Freeway)	Paved Roads (Collector)	Neighborhood Roads Paved Trails	Light Use Roads Moderate Use Trails	None
	Weight	**4**	**3**	**2**	**1**	**0**
Land Use	Class	High-Risk Business Schools	Residential (24hr Use) Mod-Risk Business	Low Risk Commercial (Offices, parking, etc..)	Utilities (< Daily-use Facilities)	Infrequent Access
	Weight	**4**	**3**	**2**	**1**	**0**
Fuel type	Type	1,3,7,10	2,6	4,5	8,9,11,12,13,14	Bare Ground
(from above)	Weight	**4**	**3**	**2**	**1**	**0**

Land Use

Land use is an important factor in the assessment of risk. Related to accessibility, the type of land use indicates the nature and frequency of human access. Residential areas have human access 24 hours a day, which leads to more opportunities for accidental ignition. Commercial properties typically are limited in use to business hours, but the ignition risk is relative to the nature of the business. Low traffic businesses have a lower risk than high traffic businesses or businesses that involve exposed ignition sources such as welding, grinding, or burning. The general categories developed for land use by GRS and the MOA FST are defined based on the general land use of a location and the corresponding assumptions of activity and human traffic (Table 6).

Table 6

Land-Use Risk Category	Description & Examples	Land Use Weight
High Risk	Welding, burning, and outdoors smoking areas.	4
Moderate Risk	24-hour use: residential, camping, and some commercial.	3
Low-Risk	Less than 24-hour use. Outdoor flames sources rare.	2
Utility	Non-manned infrastructure	1
Vacant	Unimproved land and water	0

Calculating Ignition Risk

The ignition risk factor maps are reclassified into weights based on their attributes. Land use risk-weight map is generated from the land use raster layer. The accessibility risk map is created from a union of the roads risk-weight map and the trails risk-weight map. The fuels risk map is generated by reclassifying the fuels types into risk weights. The ignition risk-weight (I) is calculated as an additive function of fuels risk (Fr), land-use risk (Lr) and access risk (Ar):

$I = Fr + Lr + Ar$

Values at Risk

Values are a relative weighting of the cultural values at risk from wildfire. The destruction of property and loss of life are the most important issues in wild-land/urban interface (Cohen, 2002). Therefore the risk to life and property should be the greatest significant contributor to exposure rating. This may not be the case in rural or wildland areas where damage to resources is also a major concern. The difficulty lies not in determining the values at risk, but in quantifying them in the model. The values at risk in the AFEM are calculated based on three parameters: improvements, parcel size, and land use.

Improvements

The FST and GRS defined the primary values at risk to be based on improvements; namely private homes and other residential structures. Subordinate to this are other improvement such as private and commercial structures, public facilities, and utilities. Within the DSS Model, the location and existence of private structures is determined by parcel and land-use databases.

The term value in the AFEM is not a reflection of cash or assessed value. Values in this context are the intrinsic values of cultural improvements such as shelter, livelihood, quality of life, and the correlation of improvements to the exposure of human life. Early in the model definition process the FST agreed that the actual assessment value would not be used in determining values at risk. Although useful for insurance purposes, it would be inappropriate to equate value to cost in this context.

Initially, GRS evaluated the MOA land use database for the determination of improvements. This database contained the database attributes and the GIS content that were necessary for this study. Unfortunately, this database has not been maintained since the last update in 1998. Given that a great deal of development has occurred since 1998, much of it in the interface area, these data were not used in the final study. Instead the MOA parcels were combined with the tax assessment data to determine the existence of structures. The associated land use attributes in this database were then used to define the nature and use of these structures and their corresponding weight).

Table 7).

Table 7

Improvement Category	Description	Land Use Weight
High-Density Residential	Risk to life and home - multiple residential.	5
Single-Family Residential	Risk to life and home - single residential.	4
Non Residential & Commercial	Risk to property. No risk to habitation.	3
Utility	Risk to infrastructure	1
Unimproved	Low risk to life and improvements.	0

MOA cautioned GRS that there were many issues against using the parcel and assessment data in this manner, namely there are a number of inconsistencies in the conventions used in the attribution. Despite this, these data were the best and most appropriate available for use in this study. Even though parcel is being used in the exposure calculations, the resolution of this study is at a neighborhood level.

Parcel Size

A critical factor in city type modeling is the resolution aspect of a parcel (or lot as some know it). The parcel database (called CAMA and managed by the MOA Property Appraisal section) indicates the existence but not the location of structures (except by address). This is not an issue in areas with small parcels, but in larger parcels, the structure may occupy only a small portion of a larger area. This gives the entire parcel a higher value weight instead of the actual location of the improvement. Therefore, the improvement weights are multiplied by a parcel size factor to reflect the adjusted weight based on the relative density of structures. This has the effect of calculating a values-at-risk per unit area that is more appropriate for a model of this type.

Some consideration was given to buffering parcels containing improvements to incorporate the influence of adjacent fuels on the risk of a particular parcel. Recent research indicates that the potential for structure ignitions during wildfires principally depends on a home′s fuel characteristics and the heat sources within 100-200 feet adjacent (Cohen 1995; Cohen 2000). Since this model incorporates the entire parcel when determining values at risk, the entire parcel would need to be buffered, adjusting for an assumed building location at the center of parcel. In larger parcels (>.25 acre), a 100-foot buffer around an assumed building site falls largely or entirely within the parcel. In the absence of building footprint data layer, it was not possible to effectively implement an ignition zone buffer around structures.

In consideration of the limited ignition zone around a structure, this model would tend to overestimate the exposure for large lots where portions of the lot may be well outside the home ignition zone (>200 feet from structure). Since the intent of this model is to evaluate fire exposure on a neighborhood level, parcel-level issues should not be overstated. In addition, the overestimation of exposure may not necessarily be inappropriate in these cases.

Land Use

The third factor in determining values at risk is land use. The MOA land use GIS layer was mainly developed through extensive field surveys in 1998, but not significantly updated since then. For this modeling, the land use category is considered independent of structures and improvements. The land use takes into account the value of lands that are unoccupied or has minimal improvements. Although it may not result in a loss of human habitat or livelihood, wildfire does affect the overall natural and cultural values of the property through the changes such as aesthetics, wildlife habitat, and watershed. All damage to lands constitutes a loss of quality of life to those that use the land and loss of value to those that own it. This category is weighted by ownership and frequency of use. The land use attributes are grouped into the general categories in Table 8.

Table 8

Land Use Category	Land Use Weight
Private Land	15
Public Services	12
Improved Recreation & Unimproved Private	10
Unimproved Parks & Recreation	5
Vacant Public, Cleared Private	0

Calculating Values at Risk

The MOA parcel layer is reclassified into three separate raster layers:

- improvements,
- land-use, and
- parcel size.

The improvements weights (Iv) are multiplied by the parcel size weights (Pv) to derive an improvement density. The improvement density weight is then added to the land-use weight (Lv) to generate the values at risk weight (V).

$$V = (Iv * Pv) + Lv$$

Suppression

Suppression is the relative difficulty of putting a fire out once it has started. Suppression ranking involves the calculation of the factors that affect the responder's ability to access the fire and the availability of resources once they are on site. There are other issues that the affect the difficulty of suppression such as the intensity of the fire, weather conditions, and the availability of shared resource, just to name a few. Some of these factors are already incorporated within other components of the model. For example, the fire intensity has been already been identified as a separate component - Fire Hazard. Based on consultation with the Fire Science Team, GRS narrowed the list of factors that affect suppression to response time, proximity to access, and proximity to water sources.

Response Time

Response Time is calculated based on an estimate of time it would take for a fire-response vehicle to arrive at any location along the road network. It is the cumulative distance from any point (pixel) on the road network to the closest fire station. The time to travel to a location is calculated by using the speed limits across the route traveled.

To calculate the response time, the distance to the nearest fire station is calculated over the road net and factored by the speed limit for each segment. This is accomplished by converting the road-speed raster to a travel-time raster. The travel time raster contains, for each pixel, the time it takes to travel over one unit of measure (foot) within that pixel. This travel time raster is then used as the weighted (distance) surface to determine the cost-distance to the closest fire station. The total calculated cost is the sum of the time across the road net along the selected route; this value is the total time between that point and the fire station.

An assumption in this calculation is that an emergency vehicle can travel over a segment with an average speed equal to the speed limit considering other impedances such as traffic and intersections. As a result, this is only an approximate value that may not reflect the actual travel time to reach any location. Given that travel can be affected by many other issues such road closures, traffic volume, and road conditions, it is impractical to attempt to calculate a true value.   As a relative weight, it reasonable to assume that the magnitude of difference to arrive at any point in the road-net as compared to any other point is adequately reflected in this calculation.

The response time calculation also includes a weighted cost-distance for travel off the road network. This off-road travel is weighed based on a fast walking pace (4 mph) to reflect that the access would likely be by foot.

Proximity to Access

The proximity to access reflects not only the difficulty to getting to a fire that is off the road system, but also the limitation of equipment. The access proximity is calculated as the distance from any point on the map to the nearest vehicle access point. The access locations are based on the road network as well as major trails. The weights for the proximity are categorized based on the nature of the best and closest access point. The proximity categories for each type of access overlap. For example, the weight for a distance of 400 feet from an ATV trail is equivalent to the weight for 2500 feet from a full-access road. In the AFEM the proximity weight that is assigned to a location is based on the closest distance to the "best" access. The distance categories and weights were determined by the AFD considering the limitations of equipment, vehicular access, and foot access restrictions.

Water Sources

The water source accessibility weights consider the limitations of equipment and the time it would take to get water from a water source to the fire for a sustained suppression effort. Beyond the limits of hoses and pumpers, the water has to be transported by water trucks or other equipment. Also considered is the time it takes to establish a hose-lay and the restrictions on water volume and pressure. Calculating the distance over a cost surface incorporates the effort necessary to setup hose and equipment off road. In the model, the cost distance from water sources to an off-road location is double that for the distances along a road or trail. A maximum weight is placed on locations greater than 5000 feet from a water source. This maximum value is based on the calculation that the time it takes to get water to the remote locations (> 5000 feet) is relatively the same within the study area.

The suppression weights for response time, access, and water sources are presented in Table 9.

Table 9

SUPPRESSION						
Response Time	Class	>90 min	60-90 min	30-60 min	15-30 min	<15 min
	Weight	**4**	**4**	**3**	**2**	**1**
Proximity to Access	Class	Difficult Access	Limited Access	Access Constrained	Conditional Road Access	Fully Road Accessible
(Select lowest Weight that applies)	*Full - Access Roads*	>5000ft Full-Access	2500 - 5000ft Full-Access	1000 - 2500ft Full-Access	500 - 1000ft Full-Access	0-500ft Full-Access Rd
	Cond. Access Roads	>2500ft Conditional-Access Rd	1000-2500ft Conditional-Access Rd	500-1000ft Conditional-Access Rd	0-500ft Conditional-Access Rd	
	Trails	>500ft 4WD Trail	0-500ft 4WD Trail			
	Weight	**5**	**4**	**3**	**2**	**1**

Water Sources Class	Significant Transport >20min	> 5000 ft Hydrant	> 2500 - 5000ft Hydrant 2500-1000ft Draftable	2500-1000ft Hydrant <1000ft Draftable	<1000ft from Hydrant Hose
Weight	**5**	**4**	**2**	**1**	**0**

Calculating Suppression

The response time is calculated using a cost-distance function between all points on the road network and the closest fire station. These response times are then categorized into the response time weights. The proximity to access is determined by calculating the distance from all points in the study area to the nearest access point. The roads, and trails maps are reclassified into weights and combined such that the lowest value for a location (best access) is the value used as the weight. The water source weights are based on the classification of the distance from water sources. The raster layers for response time (*Rs*), access (*As*), and water sources (*Ws*) are combined to calculate the overall suppression weight (*S*).

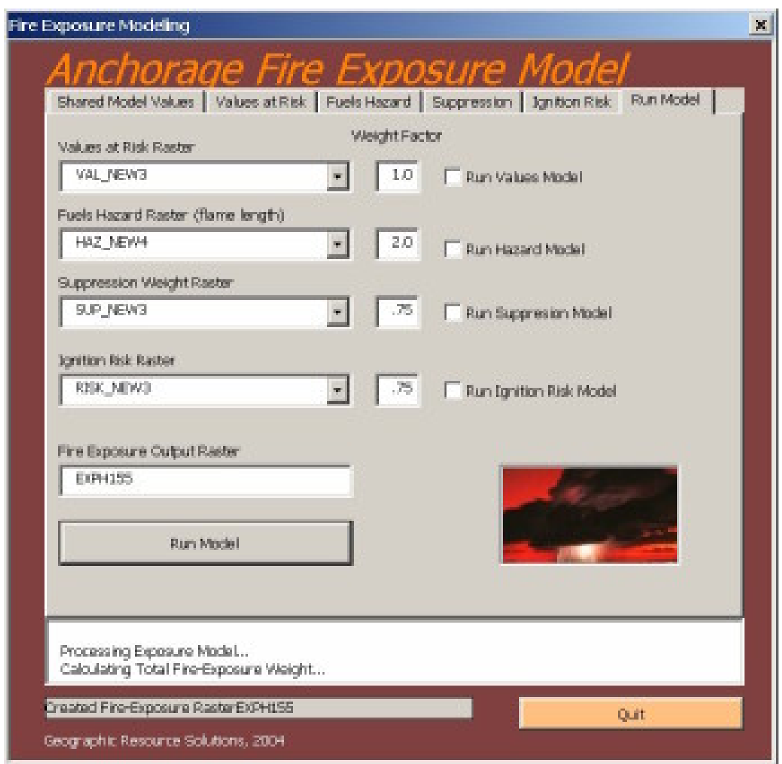
$$S = Rs + As + Ws$$

AFEM DSS Application Development

The AFEM DSS is the implementation of the AFEM model as a software application within an interactive mapping environment. The first version of the AFEM was manifested in the Fire Exposure Assessment Form. This initial version of the AFEM model, allowed the member of the Fire Science Team to operate the model and evaluate the weights and categories. After the acceptance of this initial AFEM design, GRS began work on the on the AFEM Decision Support System (DSS).

The mapping environment selected for the AFEM DSS was ArcMap - a module of the ArcGIS product suite from ESRI (Redlands, CA). Early in the project, GRS and MOA agreed to investigate the Modelbuilder module within ArcGIS (V. 9) as a development and delivery environment for the AFEM DSS. Modelbuilder allows the user to design and implement a GIS based model by interactively dragging process tools and data objects into a visual diagram of the model. GRS obtained a Beta version of ArcGIS version 9 and began to develop the model in this environment.

During the development and tuning of the AFEM GRS discovered that the ArcGIS Modelbuilder environment has two significant faults that affected the stability of the model. The first is that the model components are not processed in the order in which they appear in the model diagram, but in the order in which they are placed in the model. Therefore, if the model is modified to change or add components, it will not run in the order of the diagram. The second Model builder issue was that the parameters of key tools are reset each time a model is open. This did not allow for the persistent storage of key reclassification values. Despite these issues, the interactive environment of Modelbuilder was



quite powerful and GRS continued to use it during the design and testing of the DSS.

After the model process was designed and tested in Modelbuilder, GRS re-implemented it as an application using Visual Basic and ArcObjects. This gave the AFEM DSS a great deal more consistency and stability. It also and allowed for the customization of the user interface. The resulting AFEM DSS application now runs independent of Modelbuilder and is compatible with ArcGIS and ArcView version 8.2 or greater. (See the AFEM DSS User's Guide for additional details on this application.)

Integrated into the mapping software, the AFEM DSS provides a user-friendly interface to the AFEM modeling process while allowing the flexibility to perform analyses of complex what-if scenarios. The AFEM DSS provides the user with immediate feedback on a modeling scenario by displaying the model outputs in the map display as they are created.

Although the AFEM application is the core of the DSS, the AFEM DSS is really a combination of the input GIS data, the parameter tables, the *FireModel* VBA application, the ArcMap *FireModel* document, and the project directory structure that contains all these components.

Acknowledgements

The Municipality of Anchorage and GRS would like to acknowledge the following individuals for their contributions to the development of this model as well as their support in the many other technical aspects of this project:

Andres Abeyta, IGIST
Charlie Barnwell, Municipality of Anchorage IT/GIS
Brad Cella, National Park Service, Alaska Support Office
Dan Cheyette, Graduate Student, University Alaska Fairbanks
Jack Cohen, USFS, Fire Sciences Laboratory, Missoula, MT
Warren Elkins, Municipality of Anchorage IT/GIS
Mark Finney, USFS, Fire Sciences Laboratory, Missoula, MT
Jason Geck, Alaska Pacific University GIS
Susan Howard, Municipality of Anchorage IT/GIS
Jennifer Klugh, Anchorage Fire Department
John Koltun, GRS
Sue Rodman, Anchorage Fire Department
John See, Alaska Department of Natural Resources
Brian Sorbel, National Park Service, Alaska Support Office
Carl Tobin, Alaska Pacific University
Michelle Weston, Anchorage Fire Department

The Fire Science Team:

Brad Cella, National Park Service, Alaska Support Office
Dan Cheyette, Graduate Student, University Alaska Fairbanks
Jack Cohen, USFS, Fire Sciences Laboratory, Missoula, MT
Cliff Eames, Alaska Center for the Environment
Chris Hays, U.S. Bureau of Land Management
Chris Olson, Alaska Department of Natural Resources
Jennifer Klugh, Anchorage Fire Department
John Koltun, Geographic Resource Solutions
Karen Laing, U.S. Fish and Wildlife Service
Sue Rodman, Anchorage Fire Department
Michelle Schuman, USDA Soil Conservation Service
John See, Alaska Department of Natural Resources
Brian Sorbel, National Park Service, Alaska Support Office
Brian Sterbenz, U.S. Bureau of Land Management
Michelle Weston, Anchorage Fire Department

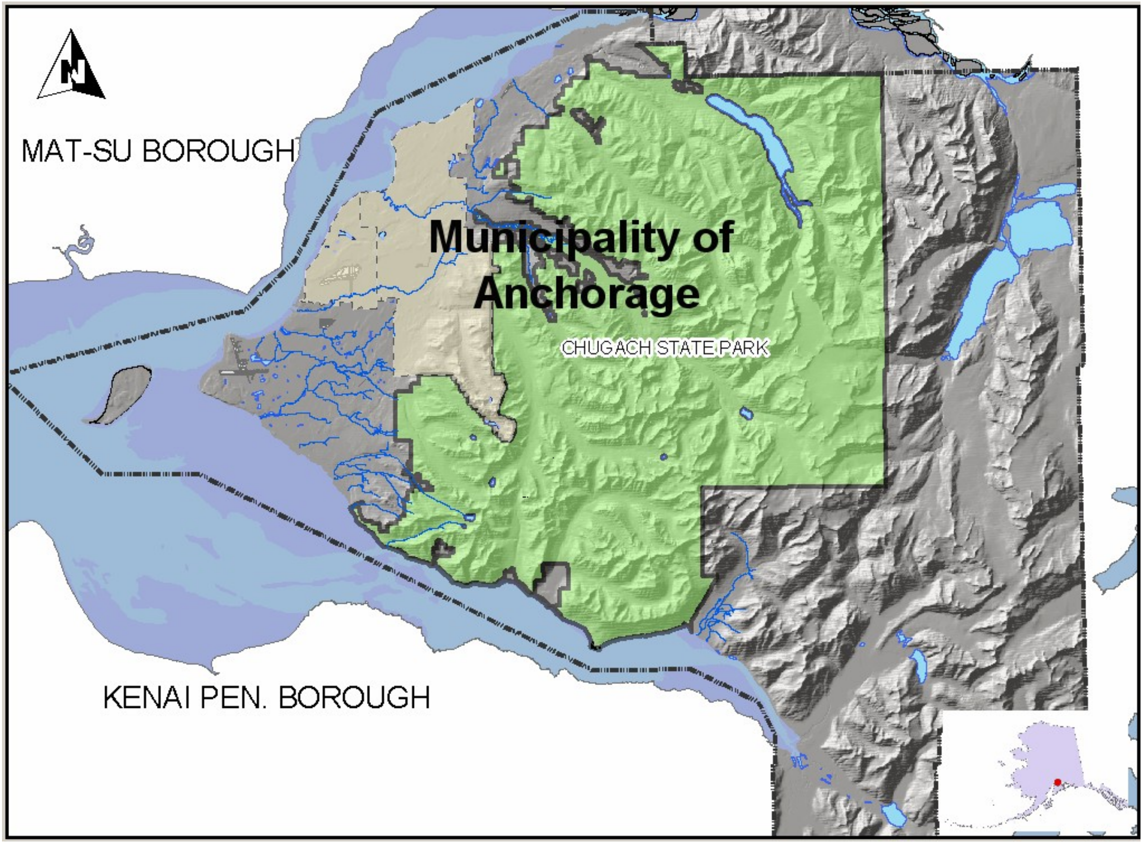
Maps

The following maps represent the component and exposure outputs from AFEM. These maps were calculated using the default data sets and parameter tables that are delivered with the AFEM project.

The colors and values that are expressed in these maps do not represent a final analysis of fire issues in the Municipality of Anchorage. The AFEM can use interactively by fire professionals to evaluate different scenarios and conditions. The output values and map appearance can be radically altered with relatively minor changes in input parameters and the definition of categories and adjective descriptions in the final maps. Users should thoroughly review the AFEM documentation to gain an understanding of the model and how the components influence one another. For a detailed description of the values displayed in these maps and their derivation, please refer to the *AFEM User's Guide.*

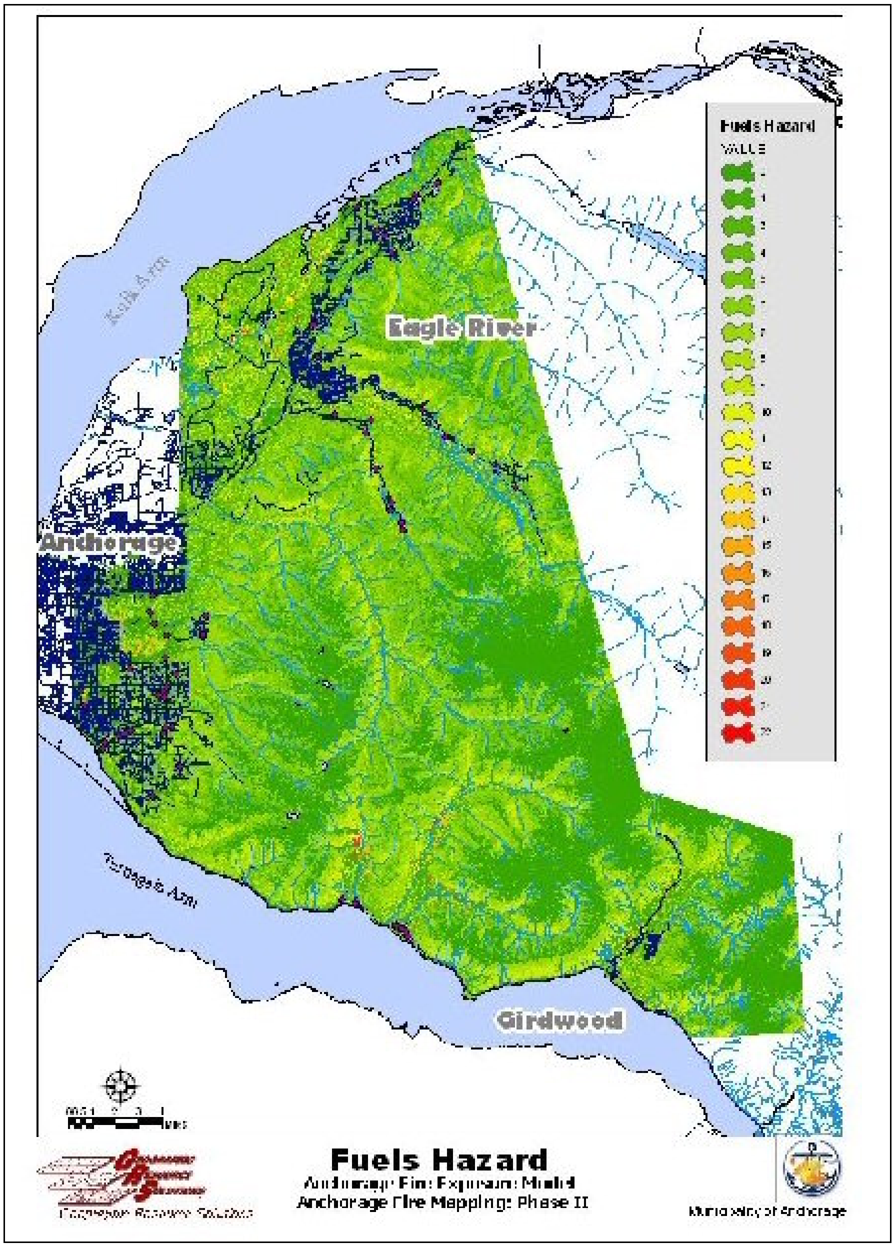
The data used for these maps are limited in content, scope, precision, and accuracy. The results from the model are intended for neighborhood and regional assessments and should not be used to evaluate the exposure of an individual parcel.

Study Area

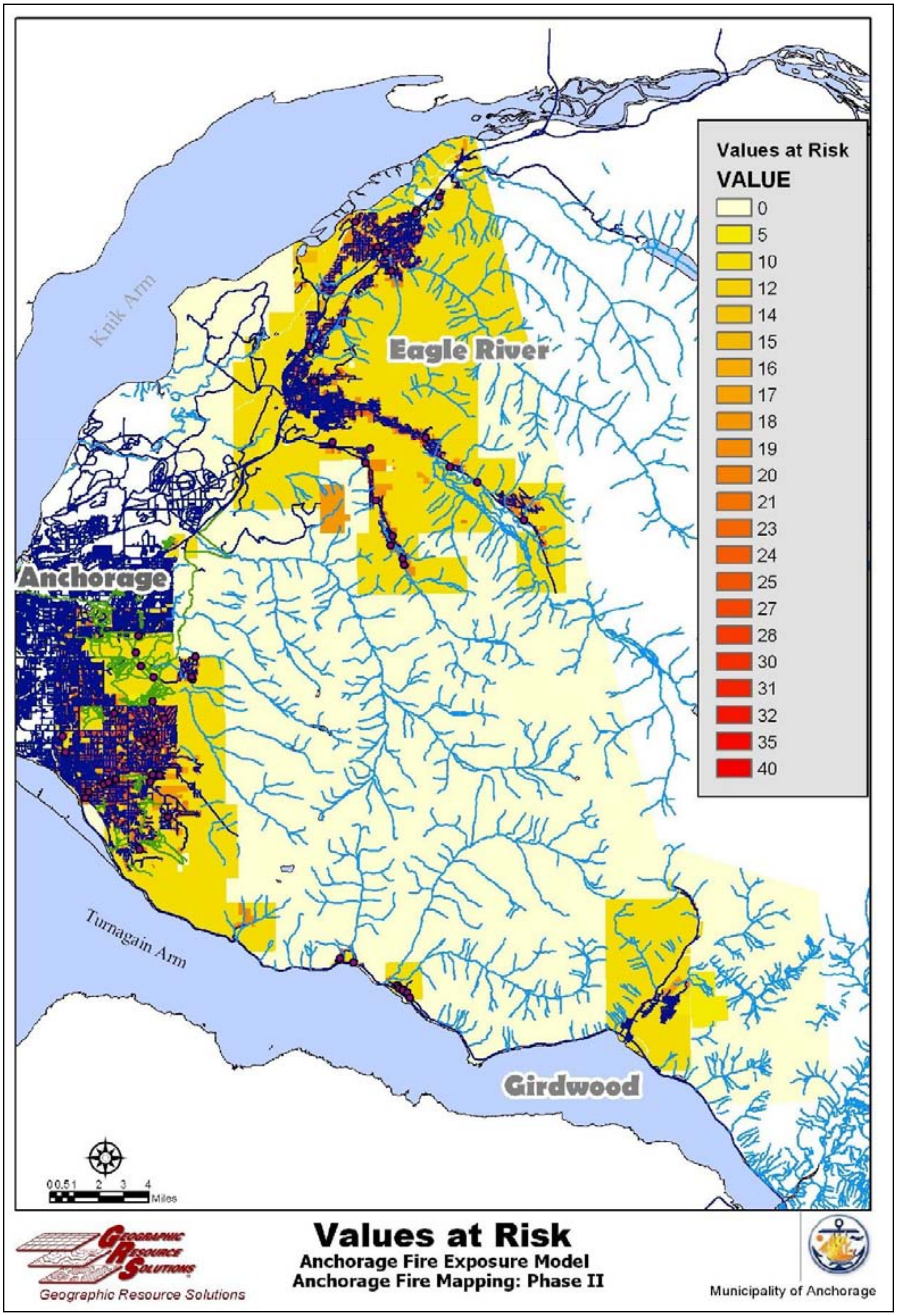


MAT-SU BOROUGH
Municipality of Anchorage
CHUGACH STATE PARK
KENAI PEN. BOROUGH

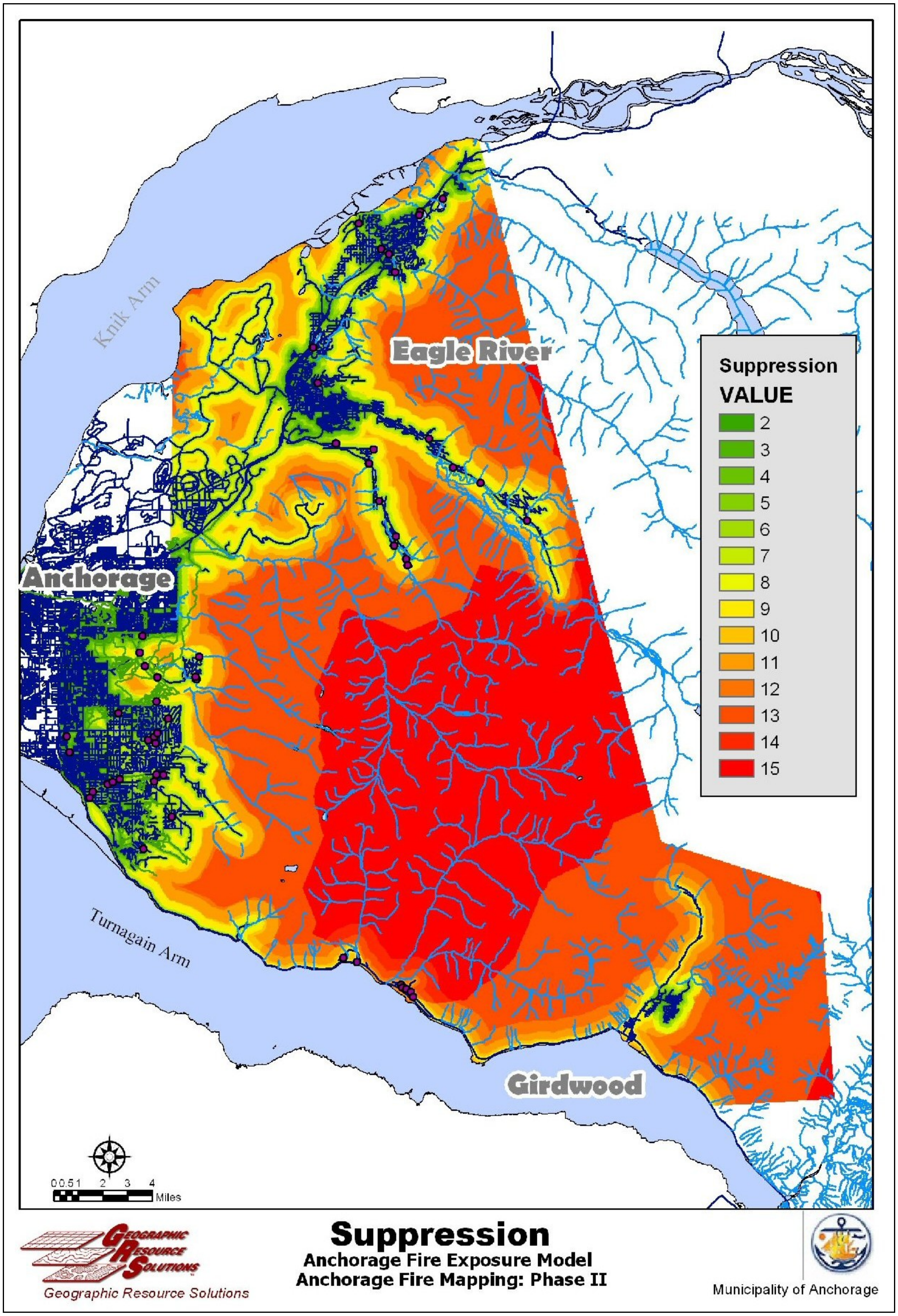
Fuels Hazard



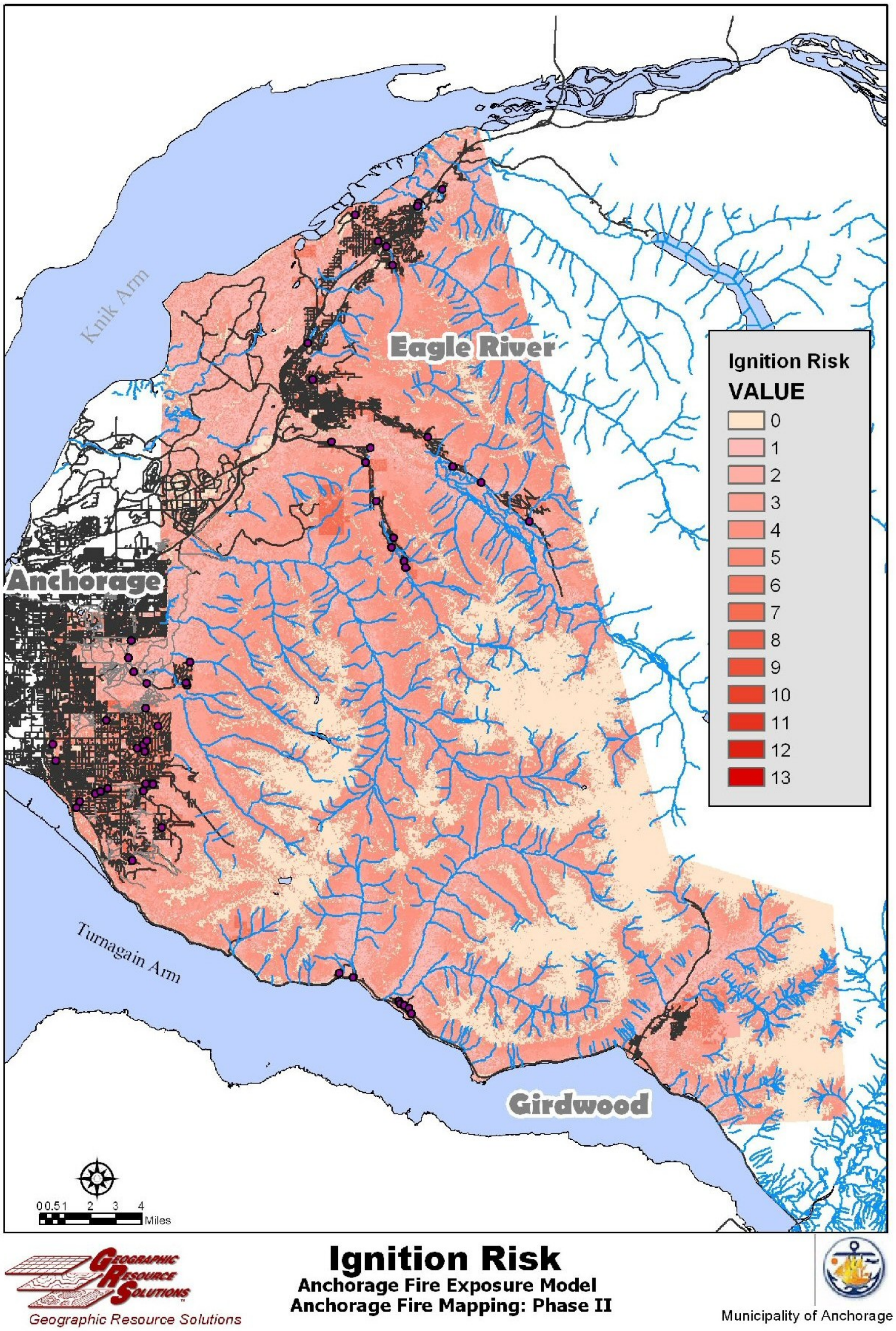
Values at Risk



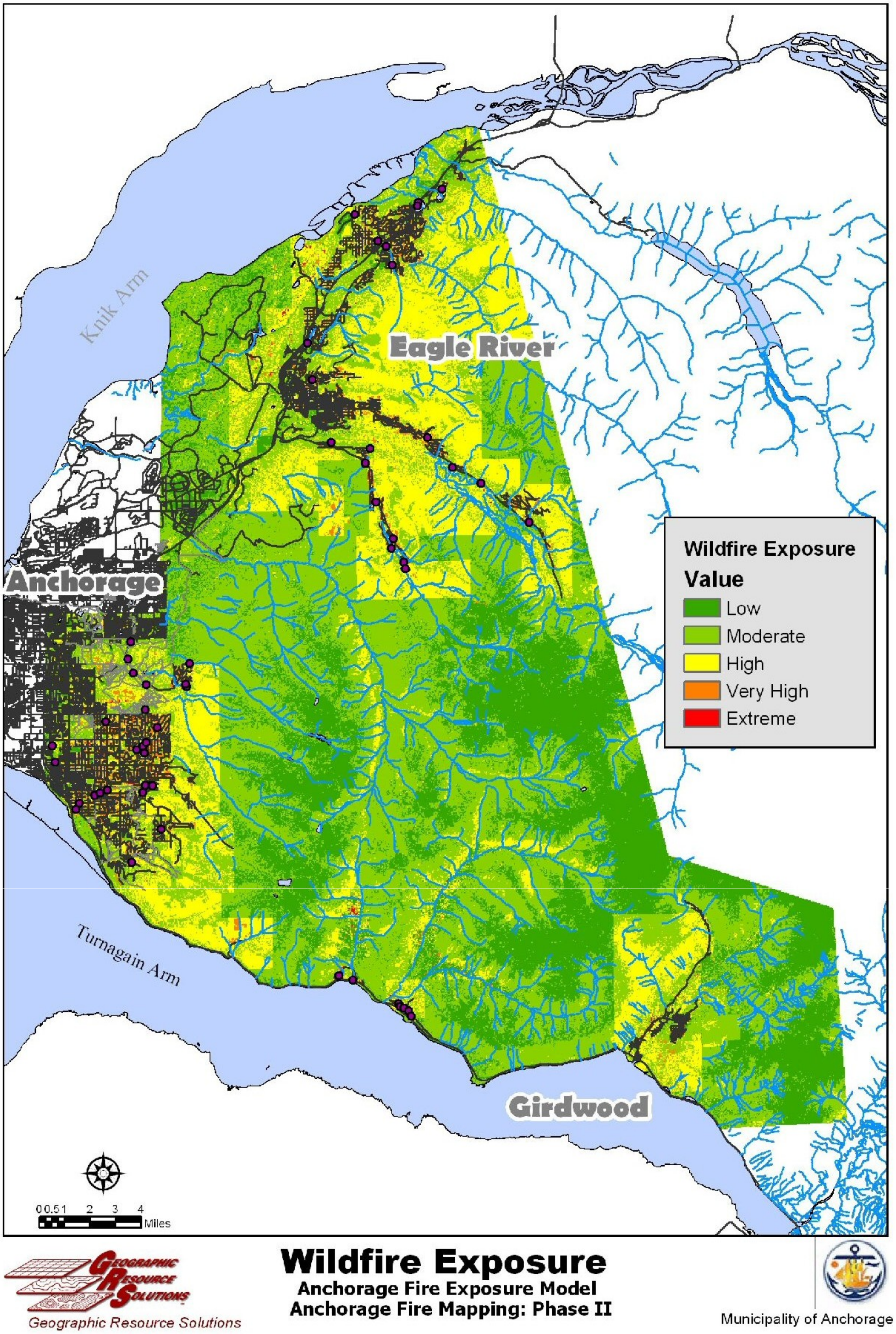
Suppression



Ignition Risk



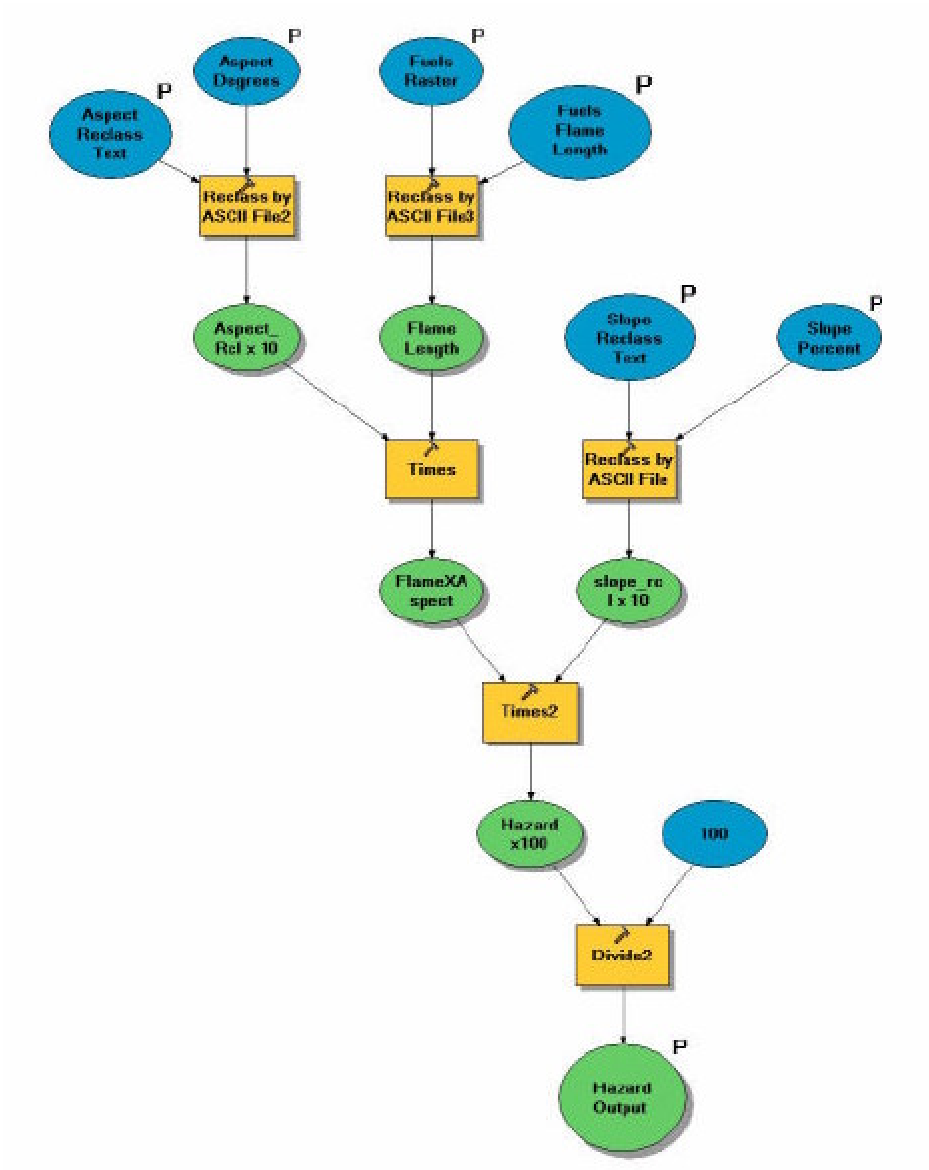
Exposure



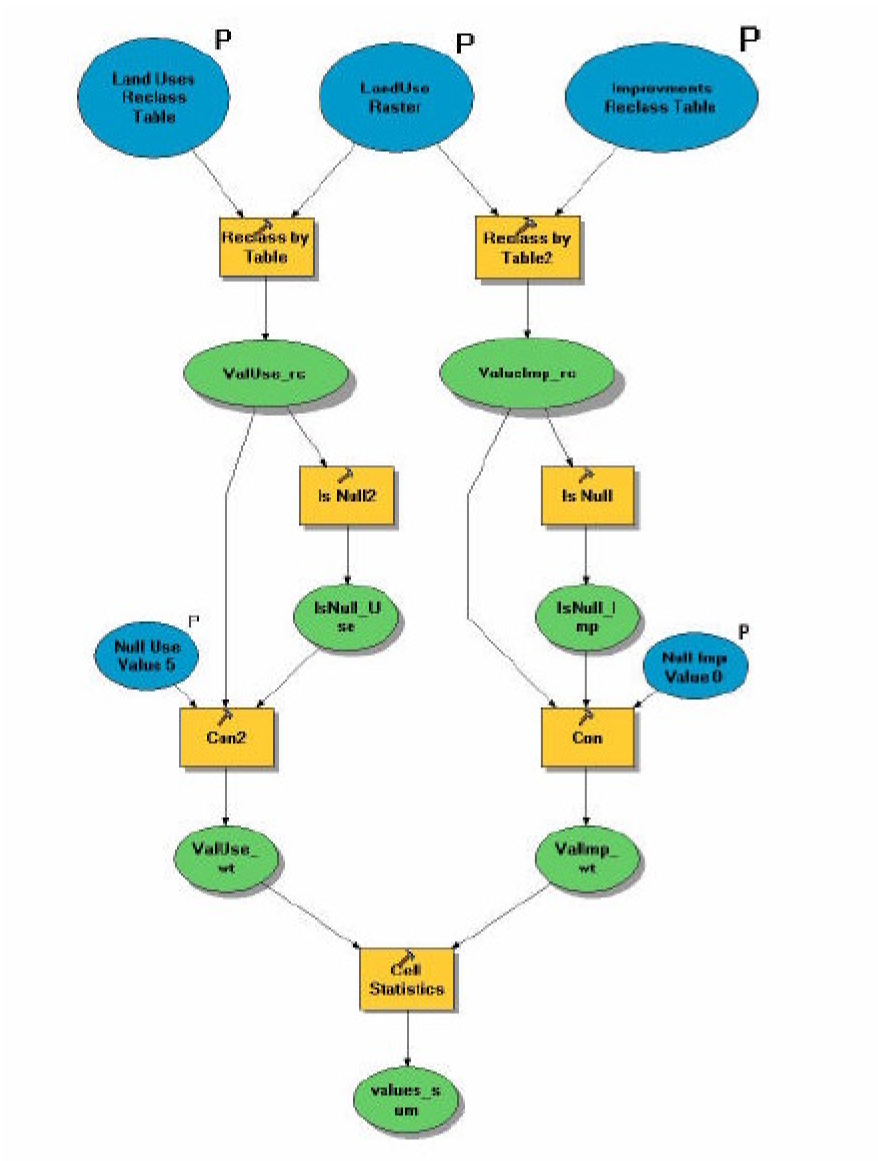
Knik Arm
Eagle River
Anchorage
Turnagain Arm
Girdwood
Wildfire Exposure
Value
Low
Moderate
High
Very High
Extreme
0 0.5 1 2 3 4
Miles
Geographic Resource Solutions
Wildfire Exposure
Anchorage Fire Exposure Model
Anchorage Fire Mapping: Phase II
Municipality of Anchorage

Model Diagrams

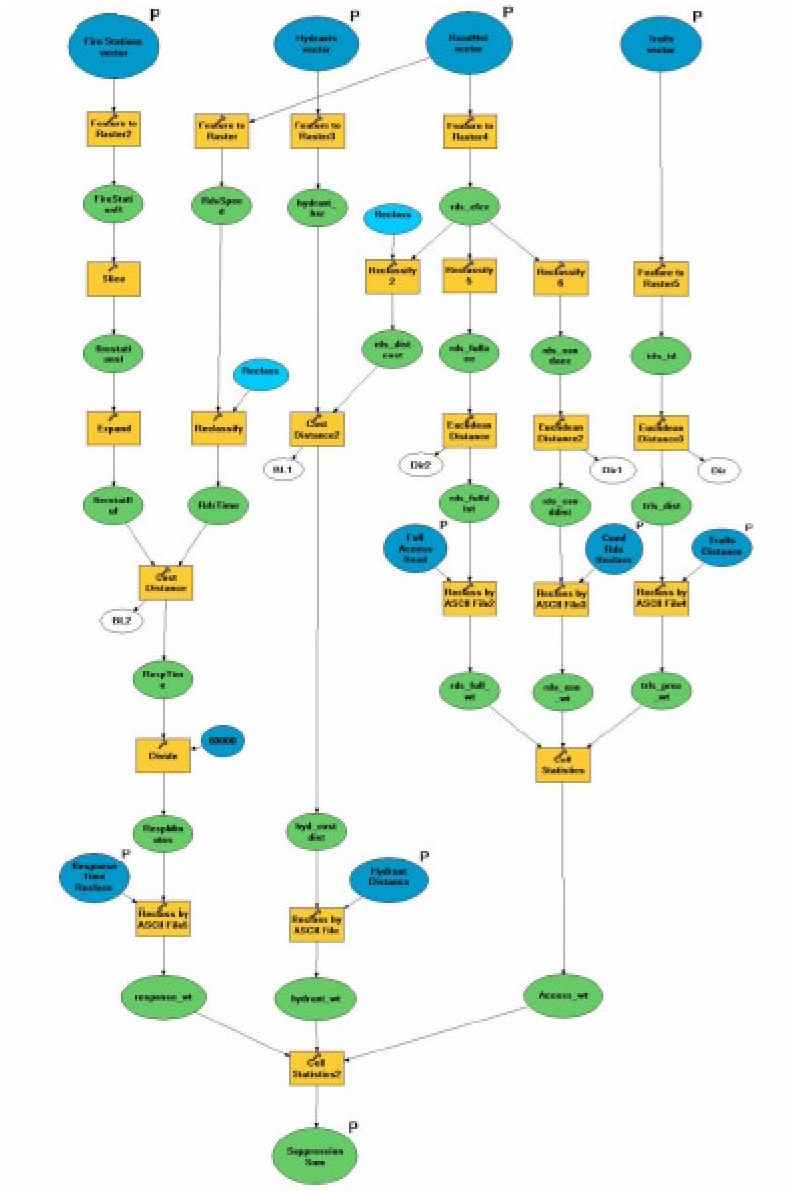
Hazard Model



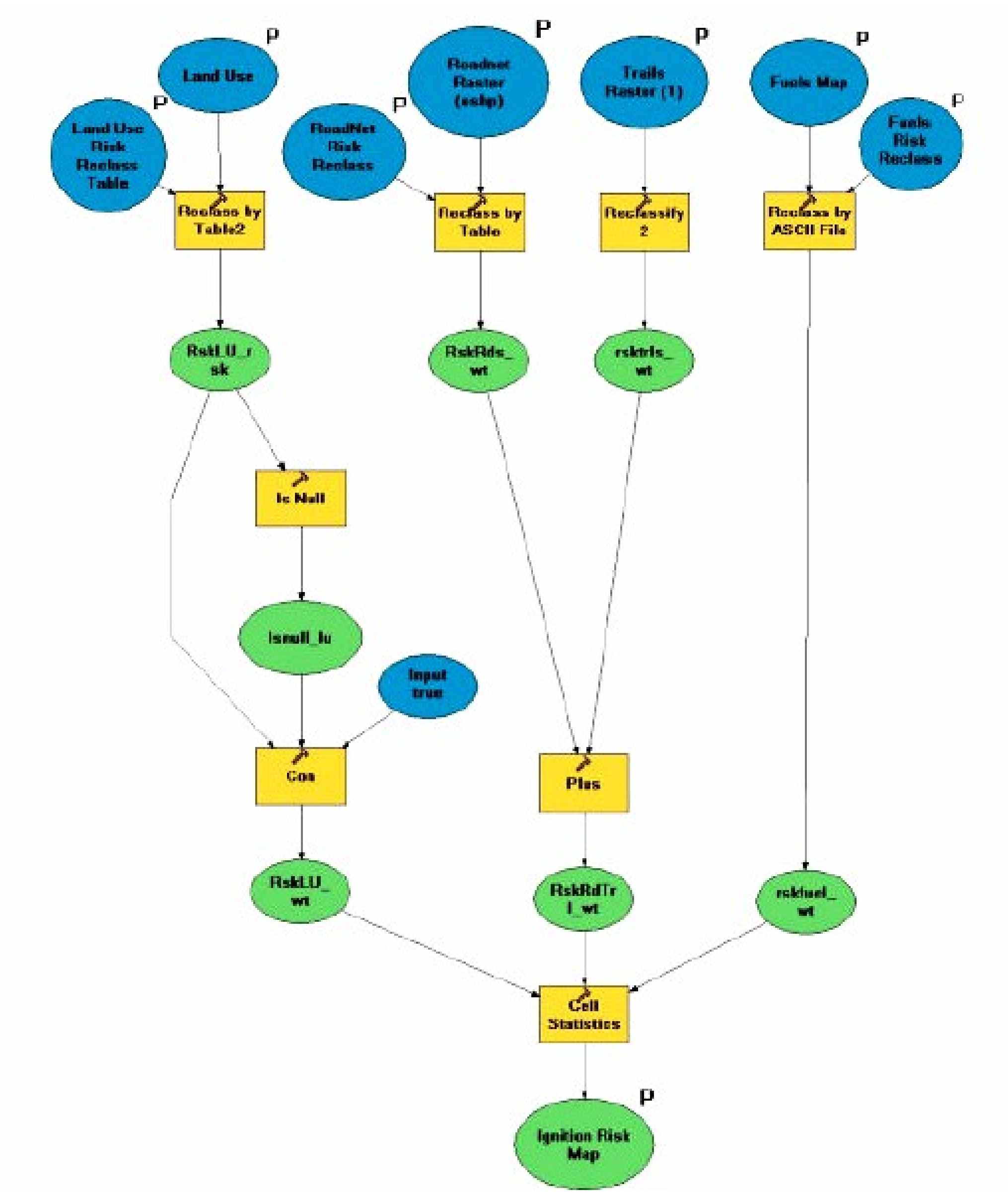
Values at Risk Model



Suppression Model



Ignition Risk Model



References

Abeyta, Andres, Final Report, MOA Image Classification/Fire Hazard Modeling--Image Processing Project Utilizing MOA Imagery, study for Municipality of Anchorage, June 22, 2001.

Anderson, H.E. 1982. *Aids to Determining Fuel Models for Estimating Fire Behavior*. USDA Forest Service General Technical Report INT-122.

Burgan, R.E., R.C. Rothermel, 1984. *BEHAVE: Fire Behavior Prediction And Fuel Modeling -Fuel Subsystem.* U.S. Department of Agriculture, Forest Service, General Technical Report INT-167. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Caprio, T., Conover, C., Keifer, M., Lineback, P., *Fire Management And GIS: A Framework For Identifying And Prioritizing Fire Planning Needs*. Sequoia Kings Canyon National Park, Three Rivers, California.

Cheyette, Dan, unpub. Unpublished thesis work on development of custom fuels models within the Municipality of Anchorage. Under contract with Municipality of Anchorage, Anchorage, AK.

Cohen, J., 1991. A Site-Specific Approach For Assessing The Fire Risk To Structures At The Wildland/Urban Interface. Proceedings of the Fire and the Environment, Symposium. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Cohen, Jack D. 1995. *Structure Ignition Assessment Model (SIAM)*. In: Weise, David R.; Martin, Robert E., technical coordinators. Proceedings of the Biswell symposium: Fire Issues And Solutions In Urban Interface And Wildland Ecosystems. 1995 February 15-17; Walnut Creek, CA. Gen. Tech Rep. PSW-GTR-158. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 85-92.

Cohen, Jack D. 2000. *Examination Of The Home Destruction In Los Alamos Associated With The Cerro Grande Fire July 10, 2000*. USDA Forest Service, Fire Sciences Laboratory, Web: http://www.firelab.org.

Cohen, Jack D. 2002. *Wildland-Urban Fire- A Different Approach*. USDA Forest Service, Fire Sciences Laboratory: Web: http:// www.firelab.org.

Cohen, Jack D. 2003. Personal communications, Anchorage, Alaska. Fire Scientist, USDA Forest Service, Fire Sciences Laboratory.

Farris, C.A., C. Pezeshki, and Leon F. Neuenschwander. 1999. *A Comparison Of Fire Probability Maps Derived From GIS Modeling And Direct Simulation Techniques*. In Proceedings from the Joint Fire Science Conference and Workshop, Vol. 2. Moscow, Idaho: University of Idaho. pp. 130-137.

Finney, M., 1994. *A Fire Area Simulator for Fire Managers*. Proceedings of the The Biswell Symposium, February 15-17, 1994, Walnut Creek, CA.

Finney, Mark A. 1998. *FARSITE: Fire Area Simulator-Model Development And Evaluation*. Res. Pap. RMRS-RP-4, Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Gross, M., 1998. *National Fire Danger Rating System*. National Weather Service Forecast Office, Seattle, Washington, Web: http://www.seawfo.noaa.gov/fire.

Harkins, K. C., P. Morgan, L. M. Neuenschwander, A. Chrisman, C. Jacobson, M. Grant, and N. Sampson, unknown. *The Idaho Panhandle National Forests Wildfire Hazard-Risk Assessment*. Department of Forest Resources, University of Idaho, Web: http://www.fs.fed.us/ipnf/eco/projects/nzfirerisk.

Hawkes, B. et. al., 1997. *A Wildfire Threat Rating System for The Mcgregor Model Forest*. McGregor Model Forest Association, Prince George, British Columbia, Canada.

Johnson, Marie-Annette, 2001. *WHIMS Manual, Boulder County Wildfire Mitigation Group,* Publication of the Boulder County Land Department, Boulder, Colorado.

Kuiper, J. A., 1999. *Grid-Based Modeling for Land Use Planning and Environmental Resource Mapping*. Proc. Nineteenth Annual ESRI User Conference, San Diego, California.

Leathwick, J.R., BriggsSpatial, C.M., 2001 *Prediction of WildFire Hazard Across New Zealand.* Landcare Research Contract Report: LCR 0001/081, National Rural Fire Authority, Wellington, New Zealand.

Majorhazi, K., 2002. *Wildfire Threat Analysis: Technical Documentation*. National Rural Fire Authority, Wellington, New Zealand, Web: http://www.fire.org.nz.

Radke, J., 1995. *A Spatial Decision Support System for Urban/Wildland Interface Fire Hazards* Procedings, ESRI User's Conference, 1995.

Rothermel, R.C. 1972. *A Mathematical Model For Predicting Fire Spread In Wildland Fuels*. USDA For. Serv. Res. Pap. INT-115.

Schlobohm, P., Brain, J., 2002. *Gaining an Understanding of the National Fire Danger Rating System.* PMS 932, Ogden, UT: U.S. Department of Agriculture, Department of the Interior, National Wildfire Coordinating Group.

Unknown. *Canadian Forest Fire Danger Rating System (CFFDRS),* Natural Resources Canada, Web: http://cwfis.cfs.nrcan.gc.ca.