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# Regional governance and hazard information: the role of co-ordinated risk assessment and regional spatial accounting in wildfire hazard mitigation

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With the threat of wildfire hanging over many communities in the Western and Southern United States, wildfire mitigation is evolving into a significant public responsibility for rural and urban edge county governments. Regional governance is an important piece of the effort to reduce wildfire risks although still weakly developed as a policy arena. This project explores two dimensions in which planning support systems can support regional governance: assessing patterns of wildfire risk accumulation; and, evaluating land use planning alternatives and their effects on cumulative risk levels. These tools are examined for regional governance using a prototype planning information system, the Alternative Growth Futures (AGF) tool, a scenario-building approach developed at the University of Colorado Denver. The project develops a hybrid urban growth model that integrates logistic regression techniques and methods for simulation of growth alternatives. This model is used to evaluate the attractiveness of undeveloped building sites with respect to natural amenities, distance to primary urban services and site characteristics such as slope. The model and scenario-testing framework are reasonably robust and suggest that regional spatial accounting methods have potential as a framework for inter-governmental and public discussion around wildfire planning.

**Keywords:** wildfire; hazard; planning; regional; governance; Colorado

## 1. Introduction

With the threat of wildfire hanging over many communities in the Western and Southern United States, wildfire mitigation is evolving into a significant public responsibility for rural and urban edge county governments. The traditional public safety responsibility of county governments puts them at the intersection of two social and ecological trends. On the one hand, rapid residential development in fire-prone areas of many counties is increasing the overall vulnerability of county residents to injury or loss of property from wildfire (Collins 2005). On the other hand, climate change along with other ecological processes such as pest infestation

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and effects of fire suppression may increase the probability of serious fire events (Werner and Neumann 1998). Hundreds of cities and counties across the Intermountain West are working on strategies to mitigate wildfire risk (United States Forest Service 2002).

Community planners have been implementing subdivision and land use mitigations for hazard risk for some time (Burby *et al.* 2000). These mitigations include water supply, perimeter roads and landscaping or construction requirements (Murphy *et al.* 2007). Discussions about land use mitigations have become more urgent over the past few years because of the recent experience of catastrophic wildfires as well as increasing understanding of climate change and interactions between weather and other influences over wildfire activity (Gan 2006). Federal Emergency Management Administration (FEMA) and state planning requirements have also been tightened over the past decade. Planners in Western US counties are considering more aggressive land use controls to address wildfire risk, even in small, rural counties that tend to have strong property rights traditions (Muller and Schulte 2004). Even so, relatively little work has been undertaken to model development patterns and assess the effects of these patterns on future hazard levels.

Decisions about fire risk have the potential to dramatically reshape the landscape of rural or urban edge areas over the next 50 years. These decisions may take place on an individual, community or regional scale. In many communities across the West, however, decision makers are hindered by poor access to technical information or local knowledge about the probability and possible effect of wildfire events (Winter and Fried 2000). Moreover, many small communities have few opportunities for structured dialogue about potential consequences of fire (Gardner *et al.* 1987). As several researchers have suggested, communities may have opportunities to make greater use of risk or vulnerability assessments as they discuss options for reducing wildfire vulnerability and balancing risk reduction with other goals of regional development (Burby and Dalton 1994, Burby 1999, Burby *et al.* 2000).

Regional governance could be an important piece of the effort to reduce wildfire risks but remains weakly developed as a policy arena (Busenberg 2004). The obstacles to inter-jurisdictional co-ordination in wildfire management are comparable to other areas of regional governance, including growth management, environmental review, revenue sharing and sustainable development. However, regional wildfire planning also has a special set of problems because it occurs across disparate systems of public and private land ownership and management, including the US Forest Service, Bureau of Land Management, state departments of forestry, watershed districts and county government. Even considering these obstacles, several regions across the country have been experimenting with wildfire governance at a cross-jurisdictional scale. For example, the Colorado Front Range Fuels Treatment Partnership Roundtable is a consortium of agencies interested in regional solutions to wildfire risk in the Fort Collins to Colorado Springs corridor (Cooperative Conservation Case Study 2008). The Roundtable includes: local governments, state agencies such as the Colorado State Forest Service; federal agencies such as the US Forest Service and Bureau of Land Management; environmental organisations such as Nature Conservancy and the Wilderness Society; other entities such as watershed councils; and academic researchers. Activities of the Roundtable are supported largely through member organisations. It is active in three areas: advocacy for funding and authorities to aid wildfire mitigation; education to local governments and agency staff within the region; and development of demonstration initiatives.

Organisations such as the Roundtable have been important in sparking awareness and initiating new activities around wildfire mitigation. Their design, however, focuses on voluntary activities such as research and education rather than stronger forms of regional governance, including comparative assessments across jurisdictions, monitoring of jurisdictional performance, and more aggressive modes of co-ordination. This paper explores a stronger governance model based on the role of Metropolitan Planning Organisations (MPOs) in analysing land use change. Following their federal mandate, MPOs evaluate patterns of land use change to support discussion and decision making about how and where transportation investments should occur. Federal legislation over the past two decades has extended the mandate for MPOs to incorporate broader environmental and sustainability review and stronger co-ordination with local land use plans (Handy 2008). The MPO model suggests opportunities for a complementary planning information system supporting analysis and dialogue about land use change-related risk accumulation. This project modifies an existing planning support system, the Alternative Growth Futures (AGF) model, for two types of analysis: (1) assessment of trends of wildfire risk accumulation into the future, and (2) evaluation of land use planning alternatives and how they affect regional and local risk levels (Muller and Yin 2001, Muller *et al.* 2002, 2003). The approach relies on a spatial accounting technology, which is conceptually a spreadsheet with rows representing a unit of landscape (in this case a square hectare) and columns describing the attributes of this landscape unit at different points in time and under different scenarios and assumptions. This extended spreadsheet is used to track variation and change in risks across landscapes and time, and simulates the consequences of scenarios describing alternative sets of mitigation policies governing location and density of development. The paper is guided by three questions. To what extent and where are risks accumulating in the Colorado Front Range as a result of urban and ex-urban development? How is risk accumulation affected by alternative land use policies? How can spatial accounting for the accumulation of wildfire risks be used in regional governance efforts?

## 2. Background

The arid Intermountain West is among the fastest growing regions in the country. Between 1990 and 2000, the population of Arizona, Colorado, Idaho, Montana, New Mexico, Utah and Wyoming grew 30%, while the national growth rate was 13%. Much of this growth is occurring in fire prone areas of the outer metropolitan ring. With drought and other ecological changes in this region, its residents are increasingly likely to be exposed to wildland fire.

The Colorado Front Range encapsulates many of the general issues with wildfire vulnerability in the Intermountain West. The Front Range in Colorado extends from Fort Collins in the north to Pueblo in the south (see Figure 1). Depending on definition, this region includes 10–15 counties that are integrated by commuting patterns and are either urbanised or in a rapid growth phase. The study area covers the six primary counties in this region, with private forested lands experiencing development pressures. These are the counties in the region that are generally considered to have significant wildfire hazards. They include, from north to south, Larimer, Boulder, Jefferson, Douglas, El Paso and Pueblo Counties.

The rate of projected population increase in these counties varies from approximately 15% to 130% during the 20-year forecast period, with half the counties gaining between 30% and 50% in population (Table 1). In certain parts of the Front Range there is already an extensive interface between forested areas and residential settlement, both in the form of large lots and scattered subdivisions. In this region, termed the wildland-urban interface (WUI), human decisions are interacting with fire ecology and other natural processes at multiple scales and through a variety of feedback loops.

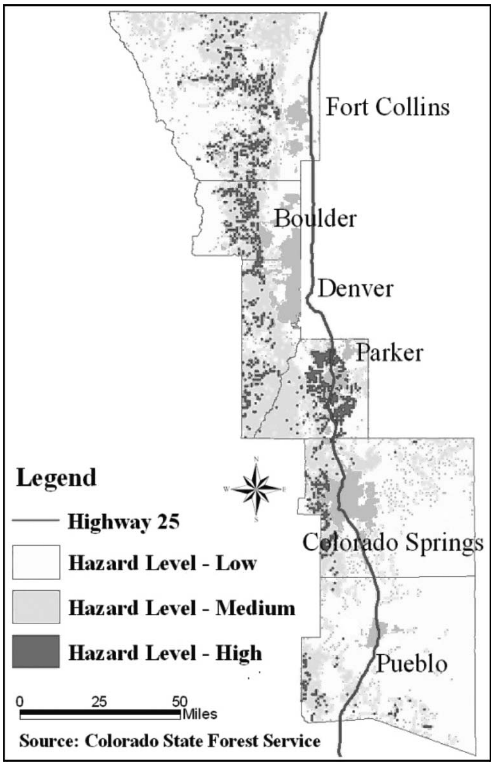


Figure 1. Distribution of wildfire risk: Colorado Front Range.

Table 1. Population forecasts by county.[1]

| Counties | July, 2000 | July, 2020 | July, 2035 | Percentage Change: 2000–2035 |
|---|---|---|---|---|
| Colorado | 4,338,789 | 6,287,021 | 7,819,775 | 80.2 |
| Boulder | 296,018 | 340,355 | 386,151 | 30.4 |
| Douglas | 180,689 | 417,330 | 532,529 | 194.7 |
| El Paso | 520,571 | 754,745 | 938,219 | 80.2 |
| Jefferson | 528,010 | 603,182 | 684,166 | 29.6 |
| Larimer | 253,131 | 373,471 | 480,691 | 89.9 |
| Pueblo | 142,054 | 194,008 | 243,990 | 71.8 |
| Totals | 1,920,473 | 2,683,091 | 3,265,746 | 70.0 |

Notes: [1]Source: Colorado Department of Local Affairs (2008), Population Forecasts by County, Population Forecasts in Five-Year Increments, 2000–2035. Table 3: Preliminary Population Forecasts by County. Over the past five years, state forecasts for the six-county study area have varied within a narrow range. Simulations in this paper are constructed on an earlier forecast with approximately similar aggregate growth rates.

Stressors at multiple scales and feedback loops introduce complexities difficult to manage at the community level (Hayes *et al.* 2004). For example, in-migrants are often attracted to locations with dense tree cover and views, both of which are associated with higher-hazard areas. Residential development in turn tends to increase availability of fuel and likelihood of a fire. Climate trends, habitat fragmentation and insect infestations may act as environmental stressors, amplifying the likelihood of fire. At another scale, both political and natural systems in many fire-prone areas are under stress. Most important, rural county governments and volunteer fire departments face significant pressures associated with high rates of development. For example, reliable water supply is often not available in WUI areas, exacerbating difficulties faced by firefighters. Interactions among these social and environmental stressors create planning problems that span county and community lines.

According to classic theory of intervention, regional governance may be an appropriate scale to address complex problems of spillover among different management units (Konoshima *et al.* 2008). Risk-related spillovers occur between neighbours, between subdivisions, between public and private landowners, between communities, between public agencies and between time periods. In a highly interactive system of this kind, the failure by any participant to take adequate actions to avoid or mitigate risks creates potential costs or damages that may flow in multiple directions. From an economic and institutional perspective, regions can pursue economies of scale in infrastructure investment such as water systems (Gramlich 1994), manage risks through informal organisation and regional social capital (Putnam 1993), or adopt policies to reduce intra-regional, inter-organisational transaction costs (Feiock 2007). From a bio-regional and collaborative perspective, regions are a useful unit for policy development because they have common ecological and institutional characteristics and can benefit from shared assessment of problems and mutual education (McTaggart 1993, Wilding 1997). The growth management literature focuses on managing the spatial allocation of development for compactness, conservation and efficiency, in general assuming that intra-regional allocation can be guided while inter-regional migration cannot be controlled. Less attention has been paid in this literature to problems of risk and resilience. In the regional governance system described in this paper, risks are evaluated across the landscape to make them more visible and provide a foundation for inter-jurisdictional discussion about how to reduce them.

There are three components to the planning information system proposed here: a land development model; a platform for testing land development scenarios; and a model of physical wildfire hazard. With respect to the first of these components, an extensive body of research has been published related to regional applications of land development models. The paper draws broadly on the experience of the cellular automata approach (Batty and Xie 1997, Clark and Gaydos 1998), land use conversion research (Veldkamp and Lambin 2001, Theobald 2005, Radeloff *et al.* 2005) and regression-based land conversion models. Regression models are designed to capture the calculations of developers and homeowners who are surveying and comparing raw land sites within an ex-urban market. Logistic regressions statistically evaluate influences on land conversion between two historical points; these have been interpreted as factors in development profitability (Landis and Zhang 1998). They are attractive for this project because their implementation across a region entails a relatively low-cost and can be accomplished quickly. The core

AGF model emphasising natural amenity-related variables has been discussed elsewhere (Muller and Bradshaw 1995, Bradshaw and Muller 1998, Muller and Yin 2001).

Scenario-building methods provide a powerful tool for assessing wildfire risks because they are suited for the exploration of the complex relationships and high degree of uncertainty characteristic of ecological-social systems. They support "mental exercises" intended to address "intrinsic shortcomings of human cognition" (Xiang and Clarke 2003, p. 889). Scenario planning is related to visioning, strategic planning and mediation as devices to help decision makers evaluate accepted wisdom, conceive risks and opportunities, and redefine interests and objectives (Hopkins and Zapata 2007). Scenario-building exercises may be particularly useful for understanding problems that cross-disciplinary and professional domains or challenge the accepted wisdom in any specific domains. Scenario-building has been used in a wide variety of planning environments, notably in industries such as energy supply and institutions such as the military (Schwartz 1991, Schoemaker 1993). Ecologists are increasingly turning to scenarios to assess dynamic and complex systems (Costanza and Ruth 1998, Peterson *et al.* 2003). In the land use arena, scenarios have been used in regional econometric and transportation models, and forecasts of housing demand or the future urban footprint (Myers 2001, Landis and Reilly 2003, Bradshaw and Muller 2004). Even so, scenario construction has not been fully integrated into the planners' toolkit (Couclelis 2005). In the context of the mechanics of a planning information system, scenario construction relies on restrictions and weightings of land development units to mimic land use policies (Klosterman 1999).

Wildfire hazard models describe fire behaviour with respect to varying meteorological conditions, structure type, landscaping, canopy, understory, topography and other factors. Higher-resolution data have recently been made available through federal initiatives such as LandFire (Landfire 2008). Commercial firms have developed models and decision tools at a community level for risk assessment (Red Zone 2006). GIS overlay models are available through county governments and state agencies. In the Colorado Front Range area, for example, several counties have deployed hazard overlay models, and a statewide overlay-based hazard assessment has been developed by the Colorado State Forest Service (Edel 2002). Subdivision risk levels can be evaluated through use of checklists (National Fire Protection Association 1997). For the purposes of this prototype, the study selected an overlay model developed by the Colorado State Forest Service, which is described in the following section.

## 3. Study design

This project is constructed in three steps. First, the results of a logistic regression are used to build a development probability surface for all six counties based on a case study of Western Boulder County. Second, policy scenarios are developed to generate settlement patterns defined by alternative regulatory scenarios. Each scenario builds out to the Colorado state population growth forecast disaggregated to the county level for the year 2020 (see Table 1). Finally, development probabilities are compared to wildfire hazard defined by vegetation, topography and historical fire disturbance. The project is designed to introduce planning tool applications and illustrate relative magnitudes of risk rather than document specific risk effects.

### 3.1. Model of residential location

In the first phase, spatial allocations are established based on a land use conversion model built on 1 ha grid cells. Three primary groups of independent variables are considered (Table 2). *Neighbourhood Morphology*: Variables include distance to the nearest urban development and number of developed cells in a neighbourhood. *Accessibility factors*: Variables include travel time to nearby highways, roads and streets and commercial areas. *Biophysical Surroundings*: Variables include proximity of streams and trees, proximity of public land, proximity of open space. Based on these variables, a logit regression is used to estimate the probability that households will locate in a specific land unit. Preference rankings generated by this regression provide the basis for in-migration or movement by householders and strategic decisions by developers. As cells are occupied they declare their status and are prohibited from accepting additional households or landowners. Thus, at each step of the model, an increment of households is distributed among a queue of eligible locations.

Three types of logistic regressions are used: a univariate regression on all variables; a full, multivariate model including all variables; and a reduced form of the model with key variables. The data were re-evaluated using a decision tree method. Boulder County provides the primary case study for this research ($n$ = 120,161). Boulder County was selected because among Front Range counties it has the longest history of ex-urban development and the most diverse array of relevant biophysical environments and development conditions. Cells were excluded from the analyses if they were developed prior to 1980 (11.5%); if they were designated as open space prior to 1980 (4.8%); if they were located within city limits (19.7%); or if they had missing data on one or more candidate variables (10%). This resulted in the deletion of 36,783 cells and an intact sample size of 83,378 cells.

The overall sample was divided into five random sub-samples of approximately 16,676 cells each. One sub-sample was used to train the regression models and the other four were reserved for validation purposes. The outcome of interest is cell

Table 2. Variable definitions.

| Variable type | Variable name | Abbreviation |
|---|---|---|
| *Neighborhood Morphology* | Distance to high density areas | Hdenkm |
| | Distance to low density areas | Ldenkm |
| | Distance to school | Schlkm |
| | Number of developed cells in a neighbourhood | Neighdev |
| *Accessibility factors* | Travel time to nearby highways | Hwykm |
| | Travel time to nearby roads and streets | Dsrd100 |
| | Travel time to nearby airport | Airpkm |
| | Distance to high density areas | Hdenkm |
| | Distance to low density areas | Ldenkm |
| *Biophysical Surroundings* | Public land buffer | Pubbuf |
| | Water body buffer | Watbdbuf |
| | Ditch buffer | Ditchbuf |
| | Stream buffer | Strembuf |
| | Slope | Slope |
| | Special district/ water and sewer availability | Spedist |
| | Foothills or plain areas | West |

development during the period 1980–2000. There were 2724 cells developed during this period, yielding a base rate of development of 3.27%. Over-fitting is not an issue because there are few candidate variables relative to the effective sample size. The effective sample size is 517 (517 cells developed out of 16,676) and there are only 14 candidate variables. The full model is also fairly parsimonious. Although there is competition between some of the candidate variables, the variables are not highly collinear.

The reduced form of the model is as follows: Log $(p/1 - p) = (-2.65) +$ distance to road * $(-1.28) +$ distance to low-density development *$(-0.98) +$ adjacent developed sites* $(0.03) +$ within a special district * $(0.34) +$ slope * $(0.09)$. The first four variables in the reduced model are significant at a 0.05 level. Special district is marginally significant (0.051) and slope has a $p$-value of 0.357.

Receiver Operating Characteristics (ROC) analysis is used to evaluate how accurately predictions from the training model discriminate between developed and undeveloped cells in new data. Thus, the ROC curve is a plot of the true positive rate against the false positive rate for each cut-point of the scale. The area under the curve provides an overall measure of the performance of the risk scale, interpreted as the probability that a randomly selected developed cell will have a higher risk score than a randomly selected undeveloped cell (DeLong *et al.* 1988, StataCorp 2002).

Sub-county allocations are also tested under the assumption that level of demand is variable by sub-market and density level as permitted under zoning rules. For this research it is assumed that the model of consumer preference is constant across sub-markets and density levels. Two primary sub-markets characteristic of this region are delineated – ex-urban lots in the mountains and ex-urban lots in the plains. These are identified through visual assessment of development patterns, exploratory statistical and census research and discussions with planners and developers. An iterative proportional fitting method is employed to allocate population into these two sub-markets. The proportion of county population increase occurring in each major sub-market during the reference period is identified, and this proportion is applied to future growth. The next step is to identify available lots at each density. This is done by identifying lot availability under existing zoning constraints at different densities. Finally, new development is allocated by iteratively fitting proportions of new density up to the maximum number of new units assigned to the sub-market. The study begins by building out the lowest density. If there is insufficient room to accommodate development at each density level, development spills to the next highest density. This procedure – building up the density ladder – reflects the authors' experience of ex-urban land markets. The strongest demand in unincorporated markets tends to be at low-density levels where homeowners have larger lots, more privacy and proximity to natural amenities such as trees and public lands. Development at these densities is generally inhibited by local planning regulation, commuting accessibility and other factors. Homeowners in ex-urban markets are effectively 'trading up' the density scale until they identify a suitable ex-urban location (see Appendix).

### 3.2. *Platform for testing land use planning scenarios*

Scenario design in this project is based on primary alternatives for ex-urban land development in the region, which are scripted as transition rules. These alternatives are conceptualised in terms of their implications for wildfire risk. Four primary scenarios are developed: current planning; hazard zoning; cluster design; and urban services. These scenarios are tested at a sub-regional scale in order to explore in greater detail the landscape and policy processes underpinning our simulation. As above, Boulder County was selected as the case study area because of the history of ex-urban development in the county and the diversity of development sites.

#### *3.2.1. Scenario 1: current planning*

The *Current Regulation* Scenario is the baseline. It describes the regulatory *status quo* including zoning and subdivision rules. Relevant regulations are reviewed, mapped and translated into density rules and development constraints. Rules are organised according to a three-step selection process. Following common county regulatory practice in Colorado, the rules permit development on any parcel larger than 35 acres down to a 35-acre per unit aggregate density. For parcels less than 35 acres, county zoning rules are tracked to allocate residential density across zones. Houses are sited on cells with the highest probability within a selected parcel. Using these development rules, new residential units are allocated across the entire probability surface described above. As a secondary scenario, some zoning rules are relaxed and development is permitted to more closely follow the probability surface.

#### *3.2.2. Scenario 2: hazard zoning*

The *Hazard Zoning* Scenario is based conceptually on three types of development rules: FEMA flood zoning, wildfire hazard overlay zones, and use of a systematic site review process in designated wildfire hazard areas. Wildfire hazard zones have been implemented in some counties and are under consideration in a number of others, e.g. Jefferson County, Colorado. Referring to the FEMA model, wildfire zoning would be based on identification and mapping of wildfire hazards according to regionally or nationally consistent criteria derived from forest ecology and fire behaviour research. In this scenario development is excluded from areas with the highest class of wildfire risk according to the hazard model described below and development is reallocated across the remaining parcels.

#### *3.2.3. Scenario 3: cluster design*

Fire-resistant cluster development is another design option under discussion in the wildfire planning community. Cluster design includes three primary elements: a set-aside of open space; higher densities and smaller lots on the developed segment

Table 3. Scenario design.

| Scenario | Density | Type of regulation |
|---|---|---|
| Current Planning | Variable | Multiple |
| Hazard Zoning | Variable | Location |
| Cluster Design | Variable | Lot size/open space |
| Urban Services | 1–4 du/ac* | Infrastructure |

*dwelling unit per acre.

of a parcel; and layout of developed lots and open space according to natural features and ecological factors. The simulation here is derived from typical rural cluster design in Colorado such as in Larimer County (Larimer County, 1999, 2002). Prospective parcels for cluster development are selected for feasible size (70 acres). Development probabilities for each grid cell are aggregated and the parcels ranked according to overall probability. Neighbourhoods within the highest-ranked parcels are scanned as potential cluster sites based on aggregate neighbourhood probabilities. The highest ranked neighbourhood is built out to target densities with an undeveloped remainder set-aside as open space. If additional room is available within the parcel the second highest-ranked neighbourhood is built out, and so on. Clusters are built out until a population target is reached.

#### *3.2.4. Scenario 4: urban services*

The *Urban Services* Scenario is a fourth generic land use alternative discussed in the wildfire planning community. It assumes that new development is fully-serviced with the infrastructure necessary to substantially improve response to wildfires and mitigate risks of injury or loss. Full services are defined as underground utilities, roads over 20 m in width, two access roads into each subdivision, appropriate signage, water supply available through fire hydrants located in or near the subdivision, and a proximate fire station. Specialised fire resistant designs could also be included in this package such as location of a perimeter road around the subdivision that would serve as a fire break. This is a highly restrictive scenario in the Boulder County context. The rules assume that fully-serviced infrastructure provision would occur primarily at sites adjacent to existing municipal boundaries.

### *3.3. Hazard model*

A hazard model developed with the Colorado State Forest Service (CSFS) is used to generate the hazard effects described in this paper (Edel 2002). This is an overlay model that classifies landscape themes corresponding to model variables, assembles themes in a database, and ranks landscape units based on an aggregate of hazard, risk and value summations. Hazard variables include slope, fuel hazard, aspect and disturbance regime. Risk variables include lightning strike density and presence of roads and railroads. Value is comprised of only one variable, housing density. Weights are constructed on previous research and expert judgement including Colorado State Forest Service District Ranger evaluations (Edel 2002). As apparent in Figure 1, much of what is classified in this model as high and medium wildfire hazards are distributed across the ponderosa pine areas of the foothills to the west of the Fort Collins, Boulder, Denver, Parker, Colorado Springs corridor. The high risk area surrounding Parker is a peninsula of pine forest extending east into the Colorado plains. It is important to point out that the CSFS method is six years old and does not incorporate recent advances in fire regime and behaviour modelling. Risks are influenced by factors beyond the scope of overlay techniques including weather patterns, micro-climates and social practices. Much of the current scientific debate related to fire management in the Front Range focuses on evaluation of historical dynamics and problems of spatial heterogeneity including climate change, historical fire regime and frequency and intensity of wildfires in different ecosystems (Veblen 2003). Nonetheless, the CSFS model has played an important role in wildfire planning in Colorado and is used by the Front Range Fuels Treatment Partnership as a basis for initiatives related to private lands. It is adequate for purposes of prototype development in this paper. Outputs from more refined methods can be substituted as they are available.

Finally, the method was extended in a simple fashion to the entire state of Colorado. The intention was to develop an approximate idea of risk acumulation in other regions in the state and assess areas where a regional wildfire strategy may be appropriate. To examine this problem, the regression model described above was run on data collected for each county in the state. To simplify the data-processing task, a conservative low-density development assumption was used for all counties, and then the findings were qualitatively re-reviewed based on knowledge of different growth regimes. This method may lead to an overprediction of development around roads and in counties such as Pitkin (location of Aspen) with strict growth controls. In the final step, risk data were used from the Colorado State Forest Service to create an overlay of development probability and wildfire risk. The product of this effort is a risk map for the state of Colorado, which offers a general indication of hot spots of risk accumulation across the state.

## 4. Discussion

The following discussion is presented in four sections, shifting between the regional, county and statewide scales that frame the alternative approaches. These scales have been selected to examine opportunities for nesting of spatial accounts: the model constructed at a regional and statewide scale and tests of policy development occurring in the local jurisdiction. The discussion begins with the allocation model, including logistic regression results. Next, the simulation of projected development in the Front Range counties is discussed and its implications for wildfire risk accumulation across the region. There is then a move to the Boulder County case study, the scale at which wildfire planning scenarios are evaluated and their implications for risk reduction. Finally, there is a discussion about the extension of the risk accumulation model across the state of Colorado and its application in assessing potential hot spot regions.

### *4.1. Allocation model*

The area under the ROC curve (AUC) statistic for the full logistic model is 0.80. The literature suggests that this is a reasonable level of accuracy. Based on the prediction of growth during the historical study period, there is a projection about where future growth is likely to occur assuming structures of ex-urban residential preference and demand remains constant. These model outputs are intended as frames for planning discussion rather than single point forecasts.

Table 4 shows the results of fitting the full model. Distance to road, distance to low-density development, neighbourhood density and presence of a special district are significant or near significant at the 0.05 threshold. Distance to road has the highest explanatory power and the expected sign. Residential location tends to occur in areas closer to low-density development and with a small positive relationship to increasing density in the near neighbourhood. There is also a suggestion that location within special districts has a positive effect on probability of development. Other variables are not significant, including distance to nearest school, distance to

Table 4. Results of full residential location model.

| Variable | Logit | Odds ratio | Robust SE | z-statistic | *p*-value |
|---|---|---|---|---|---|
| Intercept | −2.595 | 0.07 | 0.425 | −6.10 | 0.000 |
| dsrd100 | −1.284 | 0.28 | 0.115 | −11.18 | 0.000 |
| schlkm | −0.002 | 1.00 | 0.004 | −0.60 | 0.551 |
| hdenkm | 0.033 | 1.03 | 0.038 | 0.85 | 0.393 |
| ldenkm | −0.889 | 0.41 | 0.245 | −3.63 | 0.000 |
| airpkm | −0.003 | 1.00 | 0.003 | −1.26 | 0.207 |
| hwykm | −0.004 | 1.00 | 0.008 | −0.55 | 0.586 |
| neighdev | 0.029 | 1.03 | 0.003 | 9.78 | 0.000 |
| pubbuf | 0.001 | 1.00 | 0.002 | 0.48 | 0.633 |
| watbdbuf | −0.001 | 1.00 | 0.001 | −0.70 | 0.482 |
| ditchbuf | 0.000 | 1.00 | 0.001 | −0.17 | 0.861 |
| strembuf | −0.086 | 0.92 | 0.144 | −0.59 | 0.553 |
| spedist | 0.356 | 1.43 | 0.182 | 1.95 | 0.051 |
| slope | 0.055 | 1.06 | 0.056 | 0.98 | 0.327 |
| west | 0.107 | 1.11 | 0.192 | 0.56 | 0.576 |

nearest high-density development, distance to nearest airport, distance to nearest highway, location near public lands, water bodies, ditches, streams or in the western part of the county and slope of the site.

A simple model based on accessibility to county roads and historical development pattern explains much of the variation in the data. Regional and network accessibility variables were not significant in this model. This result may in part be a product of the difficulties in incorporating long distance network variables into models of this type. There may not be enough variation across the study area to provide a meaningful test of variables such as distance to commercial airport. Moreover, accessibility factors such as congestion that may exert stronger influence could not be included in the model. Network distances to school have greater variation in values than the long distance variables but are still not significant. In order to better understand the effects of distance to school, it is probably necessary to further explore empirical patterns, including demographics and schooling behaviour of households locating in ex-urban areas. None of the neighbourhood biophysical variables were significant, providing little support in this model for theory of amenity-based location preference. One explanation is that ex-urban dwellers do not demand such amenities in their immediate surroundings but drive to public lands, water bodies and other features for both active and passive recreation. Places with existing low-density settlement are attractive, in part because they are likely to include private land, sometimes have already been subdivided with a supply of developable lots, and are likely to possess site conditions amenable to further development. High-density settlement was not significant in this model, however, which may be a product of county land use policy or the lower amenity values of more dense areas.

The proportional fitting model supports the modification of assumptions about underlying growth dynamics. For example, the proportions of urban and ex-urban growth can be modified to explore the implications of a shift in migration patterns. As described below, growth rules such as densities and prohibited areas can be modified to accommodate or simulate possible shifts in regulatory regimes.

### *4.2. Analysis of risk accumulation: front range region*

Figure 2 describes the results of the growth model for the Colorado Front Range. Attractiveness of development sites is defined by ranking and classification of probability outputs from logistic regressions. The most attractive sites are closest to cities including Fort Collins, Boulder, Golden and Lakewood (Denver suburbs). As appears to be the case across much of the Western United States, the foothill areas are strongly attractive for development. A large proportion of the area has little or no development attractiveness. In many case these lands may be publicly-owned or otherwise undevelopeable because of geographic constraints.

Development attractiveness is compared with wildfire hazard in Table 5. Wildfire hazard is defined by topography, vegetation type and disturbance history based on mapping by the Colorado State Forest Service. It is apparent from this Table that development is migrating to areas of relatively high risks. The

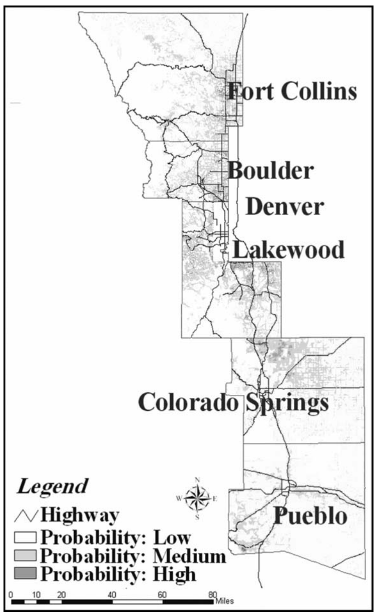


Figure 2. Distribution of development probability: Colorado Front Range.

Table 5. Hazard level of attractive development sites. Percentages of potential attractive development sites by level of wildfire hazard.

| Hazard Level | Boulder | Douglas | Jefferson | El Paso | Larimer | Pueblo |
|---|---|---|---|---|---|---|
| Low | 0.37 | 0.03 | 0.91 | 0.66 | 0.84 | 1.16 |
| Medium Low | 58.88 | 35.60 | 22.17 | 64.93 | 63.27 | 74.69 |
| Medium High | 25.76 | 35.37 | 65.42 | 27.67 | 30.17 | 15.86 |
| High | 6.51 | 19.45 | 8.54 | 1.86 | 4.28 | 1.11 |

Notes: Percentage of attractive development areas in each level of wildfire hazard. Percentages do not sum to 100 because of a remainder representing vacant land in incorporated areas. High fire hazard levels are defined by ratings of 12 and 13 on a 13-point scale.

counties tend to divide into three groups. In this model, less than 30% of the attractive lands in Pueblo and El Paso are in the two higher risk categories. Boulder and Larimer counties have 30–35% in the higher-risk categories. Douglas and Jefferson counties have over 50% in these two categories. Relative risks are emphasized because absolute risk levels should be interpreted with caution in this model.

### *4.3. Scenario analysis: Boulder County*

Under current regulations, much of the development projected for Boulder County occurs in higher hazard areas. The areas immediately to the west of the city of Boulder represent the largest overlap between risks and projected development, but most of the other development areas are also located in or near wildfire hazard zones. Boulder County has focused on reducing these risks through mitigation, most important in site planning. There have been strong demands from county residents to relax development regulations in Boulder County, for example reducing the 35-acre minimum lot size. Regulatory relaxation of this kind is likely to result in higher risk levels.

Table 6 evaluates the effect of the four scenarios on reduction of risk on the places with highest hazard. In displaying these scenarios, the focus is on the western region of Boulder County because of its complex risk characteristics including steep topography and mixed forests extending from a prairie and ponderosa pine zone at its eastern edge to a high alpine zone on the west. Several *Current Planning* sub-scenarios were modelled. One of these sub-scenarios is represented in Figure 3, representing a relaxation of current zoning rules. In this and other *Current Planning* scenarios, all or the great majority of development is projected to locate on high or medium-hazard sites. Surprisingly, the *Hazard Zoning Scenario*, represented in Figure 4, provides no benefit in restricting growth on medium-hazard parcels. This result is a product of the supply in Boulder County of medium-hazard lots with relatively high development probabilities. Restrictions on high hazard parcels force a substantial percentage of agents to shift their location choices to less desirable parcels. However, they tend to choose medium-hazard sites, frequently located in the same area, rather than low-hazard sites many of which are found in different landscapes. The *Cluster Development Scenario* is somewhat effective in reducing both high- and medium-level risks. Because this scenario forces development into relatively high-density patches, agents seek larger parcels that can satisfy the

Table 6. Effect of growth scenarios on risk.

| Risk level | Current Planning % | Hazard Zoning % | Cluster Zoning % | Urban Services % |
|---|---|---|---|---|
| Low | 0 | 0 | 23 | 10 |
| Medium and high | 100 | 100 | 77 | 0 |

Notes: A conservative risk assumption is employed in this group of policy scenarios. Low risk corresponds to a relatively high degree of wildfire safety, similar to wildfire risk levels in many suburban areas of the Front Range. This assumption is adopted because it focuses attention on what are thought to be the current risk expectations of many exurban residents in Colorado. In comparison to Table 5, this classification expands acreage in the medium- and high-risk category and reduces acreage in the low-risk category.

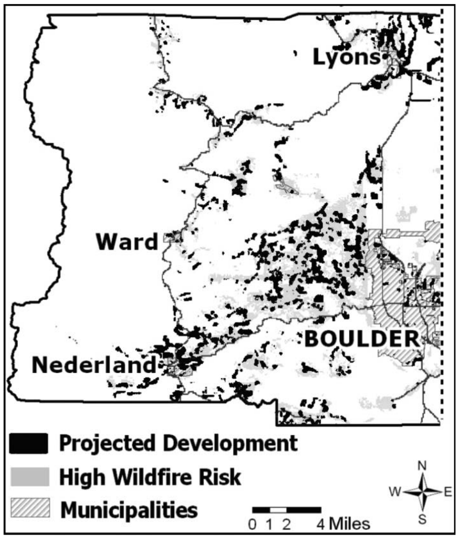


Figure 3. Effects of relaxed regulation: Western Boulder County.

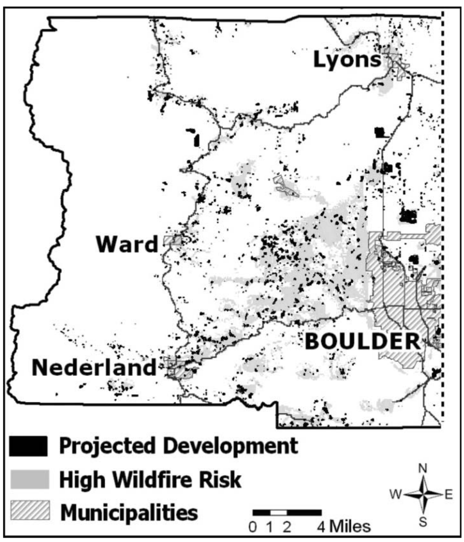


Figure 4. Effects of hazard zoning: Western Boulder County.

scenario's open space and density rules, most importantly, neighbourhoods with relative high average probabilities among proximate cells. Within the geography of Boulder County, this combination of requirements related to parcel size and concentrated development attractiveness tends to push new units toward areas with lower hazard levels. The *Urban Services Scenario* provides very strong risk reduction benefits, but is draconian in the sense that all development occurs adjacent to existing municipalities and is mitigated through defensive infrastructure. Overall, many of the scenario results were unexpected, suggesting the difficulties that county

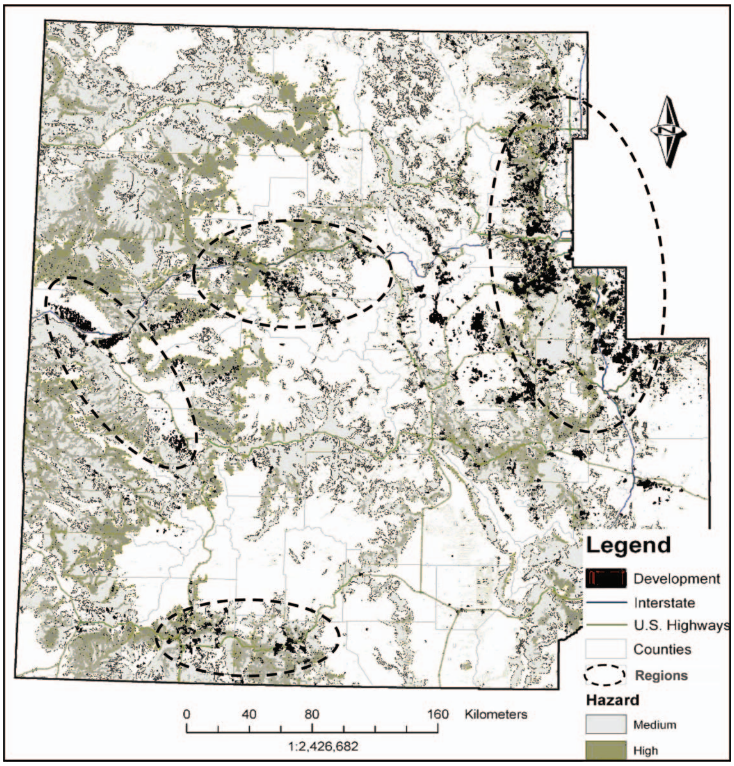


Figure 5. Development probability and wildfire risk: target areas for regional initiatives: State of Colorado.

land use planners face in managing risk and predicting the results of risk regulation over large areas of mixed terrain and ecological type, public and private ownership, and complex demands for residence-related natural amenities.

### *4.4. Statewide assessment*

Clearly, the Front Range is the most important region in the state in terms of the overlay of development probability and wildfire risk. As indicated in Figure 5, however, other regions also have significant coincidence of development and risk. Three additional regions on the map have been circled where risk accumulation appears to be concentrating: the Durango area in the southwestern part of the state, the Grand Junction and Tri-County area in the far western part of the state, and the I70 Corridor in the middle of the state. These areas suggest opportunities for regional collaborations.

## 5. Conclusions

As the fire events of the last few years suggest, wildfire risks are accumulating at a rapid rate across much of the west. Organisations such as the Front Range Fuels Treatment Partnership Roundtable have taken important steps toward creating a regional framework for risk reduction focusing on education and demonstration. This paper explores opportunities for strengthening the role of regional partnerships through the systematic comparison of risks, performance and scenarios across jurisdictions. A central feature of the approach is a planning information system developed in collaboration with agencies such as Councils of Government. A template for this information system is the land use modelling programme managed by MPOs. This information system would be used in formation of priorities and policy alternatives at the regional scale. Specific land use or program design would occur at a local scale through processes such as Community Wildfire Protection Plans or comprehensive plans.

The research suggests that future development in the Front Range is attracted to areas of relatively high wildfire hazard. However, there is considerable variability by county. Strong demand is projected for higher hazard building sites in Jefferson and Douglas County; moderately strong demand in Boulder, El Paso and Larimer Counties; and little demand in Pueblo County. No attempt was made to tabulate the risk accumulation surface at a sub-county level although this may be an appropriate next step. The research could also benefit by incorporating higher-resolution hazard data, rolling up local data and analysis into a regional mosaic, and exploring other risk factors such as climate change, which introduces substantial uncertainty into wildfire risk accumulation models.

The study focuses on the county and sub-county level in development of mitigation policy scenarios. These scenarios are prototypes, but demonstrate that analysis of this kind is useful at least in illustrating ranges of policy options and relative magnitudes of effects. The *Urban Services Scenario*, defined as relatively dense rural subdivisions with high infrastructure investment, provides the strongest protection from wildfire, although it may not be desirable for many homebuyers in this area. The *Cluster* and *Hazard Zoning* scenarios are dependent on detailed patterns of demand and geography and suggest that proposed policies need to be assessed carefully in both dimensions. The *Cluster Scenario* provides significant wildfire protection in terms of moving development away from both medium and high hazard areas. The *Hazard Zoning Scenario* provides relatively little benefit in terms of directing growth away from both medium and high-risk areas. These scenarios can be mixed in various ways as tests of more heterogeneous and realistic urban forms. For example, rural clusters and subdivisions could be located in medium-to-high hazard areas; large lot development in low-to-medium hazard areas. The analysis of these scenarios produced unexpected results, which hints at the difficulties in managing wildfire risk through traditional growth management tools such as zoning. In complex physical environments such as forested regions and fire regimes, regulatory design needs to account for multiple and interacting influences over risk. Comprehensive land use regulation can be expensive in this context particularly in relation to the limited planning resources available to many rural and county governments.

As envisioned in this paper, scenario planning could occur in any jurisdiction but its support system should be developed at the regional level. What are the benefits of a regional infrastructure? If organised effectively, regional planning processes offer economies of scale in collection and processing of spatial data, a platform for comparison and learning across jurisdictions, and a vehicle for building partnerships across the multiple organisations involved in wildfire risk reduction. As demonstrated in this research, regional risk accounting can be used to assess magnitudes and patterns of risk accumulation resulting, both from ex-urban development as well as natural processes. Regional efforts to identify hotspots could help agencies define priorities for community wildfire protection plans, fuels treatment projects, infrastructure investments and other activities. Regional risk evaluations can support education about wildfire and advocacy around needs for new resources and authorities. Finally, a regional modelling infrastructure can be employed in regional or local visioning exercises, assessments of alternative policies, and as a vehicle for helping both decision makers and the public understand policy effects. Of course there are many obstacles to regional action, particularly when it depends on voluntary commitment by local governments and land management agencies. Nonetheless, stronger co-ordination among jurisdictions – and performance evaluation frameworks such as spatial accounting – may become accepted as a necessity if future wildfire disasters continue to occur at the frequency of the last decade.

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## Appendix

### Iterative proportional fitting

Identification of growth increments for each sub-market is described in the following equation.

$$N = (S_\alpha - S_\beta)/(C_\alpha - C_\beta) * (C_\gamma - C_\alpha)$$

N = increment of new lots in sub-market
C = number of lots in the county
S = number of lots in the sub-market
$\alpha$ = year 2000
$\beta$ = year 1980
$\gamma$ = year 2020

Having identified growth increments for each sub-market, number of lots to be built at different densities in each sub-market are then identified.

$D_n = L_{n\alpha}/S_{n\alpha} * N$

D = increment of new lots at density n
L = number of actual lots at density n
n = 1, 2, 3

$M = \Sigma(D_n - A_n)$

A = Available lots at density n
M = Maximum number of lots in the sub-market