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Simulating the sensitivity of residential wildfire risk to land use policy

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Abstract: An integrated model is used to simulate the sensitivity of expected residential losses from wildfire [E(RLW)]) and growth of the wildland urban interface (WUI) to three land use policies in Flathead County, Montana, during the period 2010–2059. The model accounts for the complex socio–ecological interactions among climate change, economic growth and associated residential development, land use policy, homeowners' wildfire loss mitigation actions, and forest treatments by various land management agencies. E(RLW) depends on the number of developed residential properties, the total value of residential properties, the probability that parcels containing residential properties burn, the conditional probability of residential wildfire losses, and the percentage of wildfire–related losses in aesthetic value for residential properties. E(RLW) is simulated for three land use policy scenarios (i.e., the county policy that existed in 2010, a moderately restrictive policy, and a highly restrictive policy), moderate economic growth, and the A2 greenhouse gas emissions scenario. As the land use policy becomes more restrictive compared to the 2010 policy, the amount and footprint of future residential development in the WUI decreases substantially. Relative to the 2010 land use policy, the moderately restrictive land use policy does and the highly restrictive land use policy does not significantly reduce E(RLW) in the Flathead County WUI. The methods presented here can be used to assess the extent to which more restrictive land use policies reduce residential wildfire losses or exposure to wildfire risk and identify residential areas with high wildfire risk in other WUIs.

***Keywords**:* simulation; wildfire risk sensitivity; wildland urban interface; land use policy

1 INTRODUCTION

Expansion of residential development in or adjacent to areas containing wildland vegetation, known as the wildland–urban interface (WUI), is a major determinant of residential property losses from wildfire and wildfire suppression costs in the United States. Land use policies aimed at wildfire protection (e.g., increasing housing densities and imposing requirements for home building materials and vegetation management) have a major influence on such losses and, unlike climate change and population growth, can be manipulated by local authorities. For that reason, modifying or revising land use policy could be an effective way for local authorities to reduce future WUI growth, residential losses from wildfire (or wildfire risk for short), and the costs of wildfire management (USDA and USDI 2009; Buxton et al. 2011; Bihari et al. 2012). Little research has been conducted that focuses on how land use policies influence future wildfire risk (Yin 2010; Platt et al. 2011; Syphard et al. 2012). Results of such research would allow land and wildfire management agencies (LWFMAs) to make more informed decisions about managing future wildfire risk.

This paper describes an integrated model for simulating expected residential losses from wildfire [E(RLW)]) and WUI growth. The model is parameterized to simulate the effects of economic growth and associated residential development, climate change, and land use policy on the extent and spatial pattern of residential development in the WUI, the size of the WUI, and E(RLW), and the sensitivity of E(RLW) and WUI growth to three land use policies for Flathead County, Montana.

2 STUDY AREA

The study area is Flathead County, which is located in northwest Montana. The county's environmental amenities, including Glacier National Park, extensive national forests, ski resorts, Flathead Lake, and the forks of the Flathead River, are a major driver of population growth, outdoor recreation, and tourism in the region. Median income in Flathead County is $24,721, 11.7 percent of residents are below the poverty line (US Census Bureau 2012), and housing patterns range from gated forest subdivisions to more isolated rural residences. The wood products industry accounts for approximately 22% of the wage income in the county. Dominant historical fire regimes in Flathead County are: moderate–frequency, mixed–severity with a fire–return interval of 30–100 years; and infrequent, mixed–severity with a fire–return interval of more than 100 years (GCS Research 2010). Flathead County has experienced a number of large, high–profile wildfires in recent years, including the 2003 Roberts Fire that burned 57,570 acres, closed portions of Glacier National Park, and forced evacuations; the 2003 Wedge Fire that burned 53,315 acres, damaged 8 homes and burned 29 outbuildings; and the 2007 Chippy Creek Fire that burned 99,090 acres and forced evacuations.

3 ECONOMIC GROWTH, CLIMATE CHANGE, AND LAND USE POLICY SCENARIOS

Simulation of E(RLW) and WUI growth is based on a moderate economic growth scenario, which specifies an annual average growth rate for the economy of Flathead County of 2.2% during the period 2010–2059, and a climate change scenario based on the IPCC's A2 emission scenario (IPCC 2007). The 2.2% growth rate is the annual average growth rate for the economy of Flathead County between 2000 and 2008. The annual average growth rate is allocated to the eleven sectors of the Flathead County economy based on the relationships between sectoral growth and total growth determined in an earlier study (Prato et al. 2007). The A2 emission scenario was selected because it is the most plausible scenario for which downscaled, monthly temperature and precipitation projections are currently available.

The sensitivity of E(RLW) to three land use policy scenarios is simulated. Policy scenarios are: (1) the Flathead County land use policy in effect during 2010 (hereafter referred to as the current restrictions (CR) policy); (2) a moderately restrictive (MR) policy; and (3) a highly restrictive (HR) policy. Each land use policy scenario specifies: (1) the percentages of new housing units required during each subperiod that are allocated to six residential housing density classes (i.e., high, urban, suburban, rural, exurban, and agricultural); (2) the type and density of residential development allowed in environmentally sensitive areas (i.e., wetlands, streams, rivers, lakes, ponds, and shallow aquifers) and within and outside sewer accessible areas; (3) setbacks of homes from wetlands and water bodies; and (4) no development on most public land, land in the 100–year floodplain, and parcels that have an average slope greater than 30%. The percentage of housing units in higher density classes and setbacks of houses from water bodies and wetlands or other environmentally sensitive areas increase between the CR and MR policy, and between the MR and HR policy. In addition, the density of residential development allowed in environmentally sensitive areas decreases as the land use policy becomes more restrictive. For all three land use policy scenarios, residential development on parcels that have access to sewers is restricted to the high, urban, and suburban density classes. The simplifying assumption is made that each land use policy stays in effect throughout the period 2010–2059. Prato et al. (2007, 2012) provide complete details about the specification of the three land use policy scenarios.

4 VEGETATION AND WILDFIRE BEHAVIOR MODELS

Vegetative succession over time for a specific climate scenario and placement of fuel reduction treatments (i.e., heavy partial thinning, light partial thinning, and prescribed burning) is simulated using the FireBGCv2 model (Keane et al. 2011). Limits are placed on the maximum acreage in each fuel reduction treatment per subperiod for each of six large forest landowners in the study area. Treatment parameters (e.g., range of tree diameters and species harvested) and maximum acreages treated per subperiod were obtained from local representatives of the six forest landowners. Placement of fuel reduction treatments is prioritized based on the Flathead County Community Wildfire Protection Plan (GCS Research 2010).

Vegetative changes over time simulated with FireBGCv2 are inputted to the FSim model (Finney 2007). The latter estimates the probability that each 90–m^2 pixel in the study area burns and conditional probabilities for four flame length categories for each pixel. Additional procedures are used to derive an average burn probability and potential aesthetic loss for each existing or future parcel in the study area during each subperiod.

Climatic data inputs for the FireBGCv2 model correspond to the Intergovernmental Panel on Climate Change's (IPCC's) A2 emissions scenario (IPCC 2007). Those inputs are derived by applying the offsetting or delta method (McGinn et al. 1999; Prato et al. 2010) to daily precipitation and temperature data acquired from a multiple–year sequence for an National Climate Data Center (NCDC) weather station in the study area and daily inputs of daylength and shortwave radiation derived from the Mountain Climate Simulator (MTCLIM) (Rutherford et al. 1989).

5 LAND USE CHANGE SIMULATION MODEL

An updated version of the Residential and Commercial–Industrial–Institutional Development (RECID) model, called the RECID2 model (Prato et al. 2012), is used to simulate future land use changes in terms of residential development in Flathead County during the period 2010–2059. The RECID2 model better reflects historical and potential future land use change and residential development patterns in Flathead County than the original RECID model (Prato et al. 2007).

The RECID2 model uses the assumed economic growth in eleven sectors of the Flathead County economy under a specified economic growth scenario in the Impact Analysis for Planning (IMPLAN) regional economic analysis model (Minnesota IMPLAN Group, Inc. 2014) to project the number of additional jobs in each sector during each of the five 10–year subperiods (i.e., 2010–2019, 2020–2029, 2030–2039, 2040–2049, and 2050–2059). The amount and location of land converted to residential development during a subperiod are determined by combining the amount of land required for development, the amount of land available for development, and the attractiveness of developable parcels for residential development. The total amount of land required for new residential development in each subperiod is determined by combining the number of new housing units required in each density class and randomly selected sizes of properties for housing units in each class. The amount of land available for development in a subperiod is determined by previous development and the land use policy scenario. Attractiveness of developable parcels for residential development is evaluated using development attractiveness scores (DASs) for parcels. A DAS is a weighted sum of the minimum or maximum distances of developable parcels from major highways, edges of town, amenities (e.g., lakes), and disamenities (e.g., railroad tracks). Spatial data required to run the RECID2 model come from the Flathead County GIS office and the Montana Cadastral Mapping (CAMA) database (Montana Cadastral 2010).

6 DELINEATION OF WUI

Since E(RLW) is simulated for residential properties in the WUI, it is necessary to delineate the WUI. WUI delineation was completed for 2010 to establish a baseline and at the end of each of the five subperiods for each land use policy scenario, resulting in a total of 15 WUI designations. WUI delineation involved integrating several procedures, including the GIS procedures outlined by Stewart et al. (2007) and Platt's Buffer from Structures Method (2010). Stewart's methods are more widely used and are based on the Federal Register definitions for the WUI that permeate the literature. Platt's method uses parcels and individual structures to delineate the WUI, which closely matches the geographic unit of analysis for E(RLW).

7 SIMULATION OF E(RLW)

E(RLW) is simulated for each individual residential property in the WUI existing at the end of each subperiod. Current residential properties (i.e., those containing residential structures in 2010) are identified using the Montana Computer Assisted Mass Appraisal (CAMA) parcel database for 2010 (Montana Cadastral 2010). Future residential development in the WUI is simulated using the RECID2 model and subperiod WUI designations.

E(RLW) accounts for the probability of wildfire occurrence, fire severity and residential property values. Five primary factors influence E(RLW): (1) the effects of climate change on vegetative growth and burn probabilities; (2) simulated residential development for the moderate economic growth scenario; (3) the land use policy scenario, which affects the location and density of residential development; (4) residential homeowners' decisions regarding vegetation management in the Home Ignition Zone and building materials used in residential structures; and (5) placement of three types of fuel reduction treatments on forested pixels in the study area. The first, second, fourth, and fifth factors are held constant when simulating the effects of a land use policy scenario on E(RLW). Parameters and assumptions for determinants of E(RLW) not listed above are based on empirical data specific to Flathead County or information obtained from professional land managers and other stakeholders. E(RLW) cannot be compared to or validated using actual wildfire losses in an historical period because it takes into account the probability of wildfire, whereas actual historical wildfire losses do not.

8 Specification of E(RLW)

E(RLW) is defined as the sum of the present value in 2010 of expected wildfire losses for residential properties that existed in 2010 [E_d(RLW)] and the present value in 2010 of expected wildfire losses for new residential properties developed during the five subperiods [E_w(RLW)]. Present values are based on a nominal discount rate of 6%. E_d(RLW) is defined as:

$$E_d(RLW) = PV_{10}[E_{d1}(RLW), E_{d2}(RLW), E_{d3}(RLW), E_{d4}(RLW), E_{d5}(RLW), \qquad (1)$$

PV_{10} stands for the present value in 2010. E_{dt}(RLW) is the undiscounted expected wildfire losses for existing residential properties during subperiod t defined as:

$$E_{dt}(RLW) = \sum_{j=1}^{md} pb_{jt}[(\sum_{h=1}^{ndj} pS_{hjt}VS_{dhjt}) + \beta_{jt}TV_{djt}] \qquad (t = 1,\ldots,5), \qquad (2)$$

where:

m_d = number of parcels in the 2010 WUI containing existing residential properties;
n_{dj} = number of existing residential properties in parcel j;
pb_{jt}= probability that parcel j burns during subperiod t;
pS_{hjt} = probability that structures on property h in parcel j burn during subperiod t given parcel j burns during subperiod t;
VS_{dhjt} = total value of existing structure(s) on residential property h in parcel j during subperiod t;
β_{jt} = average percentage loss in aesthetic value of residential properties in parcel j during subperiod t given parcel j burns during subperiod t; and
TV_{djt} = total value of each existing residential property (structure and land) in parcel j during subperiod t.

m_d and n_{dj} are determined using values from the 2010 CAMA database (Montana Cadastral 2010). pb_{jt} is derived from the outputs of the FSim model. More specifically, a GIS procedure developed in ArcMap10 is used to calculate a weighted average burn probability for a parcel using the burn probabilities for the 90–m^2 pixels that intersect that parcel. pS_{hjt} is simulated using a decision tree process and previous research on the effects of vegetative management or building materials on structure ignition (Cohen 2008; Stockmann et al. 2010). pS_{hjt} accounts for four different levels of vegetative management in the Home Ignition Zone and three structure ignition classes based on the exterior wall and building material codes described in the CAMA database (see Paveglio et al. 2012). VS_{dhjt} is the total value of all existing structures or buildings located on residential property h in parcel j during subperiod t. It is estimated by $VS_{dhjt} = (1 + \lambda)^r VS_{dhjo}$, where VS_{dhjo} is the total value of existing structures located on residential property h in parcel j in 2010 determined from the 2010 CAMA parcel data, λ equals 0.035, which is the annualized growth in average property values in the US during the past 20 years (i.e., 1991 to 2009) in decimal equivalent, and r equals 10 for t = 1, 20 for t = 2, 30 for t = 3, 40 for t = 4, and 50 for t = 5.

Simulation of β_{jt} is determined from previous research on property and home value reductions following wildfire (Stetler et al. 2010) and consultation with property assessors in the western US who have experience assessing properties impacted by wildfire and the flame length outputs of FSim. Assessors' responses, which are largely consistent with Stetler et al. (2010), served to expand and provide upper levels of β_{jt} that have not been considered in previous research. A GIS procedure is used to derive weighted average flame lengths for each existing or future parcel and apply one of four fixed amounts of aesthetic value lost to each property given the average flame length for that parcel in which that property is located (for details, see Prato et al., in press).

TV_{djt} is defined as $TV_{djt} = (1 + \lambda)^r\ TV_{djo}$, where TV_{dj0} is the sum of the assessed building and land values for existing residential properties located on parcel j in 2010, and r and λ are defined above. VS_{dhjt} and TV_{djt} are nominal values as of the end of each subperiod. $(pS_{hjt})(VS_{dhjt})$ is expected wildfire–related loss in the value of existing structures in residential property h in parcel j during subperiod t and $(\beta_{jt})(TV_{djt})$ is expected wildfire–related loss in the aesthetic value of existing residential properties (including structures and land) in parcel j during subperiod t given parcel j burns during subperiod t.

Due to space limitations, the specification of E_w(RLW) is not given. E_w(RLW) is defined in a similar manner to E_d(RLW). A complete specification of E_w(RLW) is given in Paveglio et al. (2013).

9 RESULTS AND RECOMMENDATIONS

Increasingly restrictive land use policies result in smaller values for all three WUI metrics, with larger reductions in the WUI metrics between the MR and HR than between CR and MR. The largest differences in the metrics across land use policy scenarios occur for the area of WUI parcels with an average reduction across subperiods of 18% between CR and MR, 59% between CR and HR, and 51% between the MR and HR.

On average, across subperiods, there are 5% fewer simulated WUI residential structures added to the WUI under MR than CR, 34% fewer under HR than CR, and 25% fewer under HR than MR. The total number of WUI residential structures added to the WUI increases more rapidly across subperiods with CR than MR and with CR than HR. However, the area of WUI parcels increases more rapidly across subperiods for CR than MR and for CR than HR because a significant amount of the growth in residential structures under MR/HR occurs in already developed areas of the county that are not in the WUI because they do not meet the wildland vegetation criterion, most notably for the Flathead and Smith Valleys.

The size of the WUI does not increase more rapidly over subperiods under CR than MR, but does increase more rapidly over subperiods under CR than HR. Because MR results in more compact residential development than CR, the size of the WUI in 2059 is 26,686 ha smaller (a 6% reduction) for MR than CR. Although MR results in a smaller footprint of developed WUI parcels and WUI size than CR, it still results in a large increase in the WUI relative to 2010. The size of the WUI in 2059 is 112,718 ha less (a 28% reduction) for HR than CR and 86,032 ha less (a 22% reduction) for MR than CR.

Simulated nominal E(RLW) values for all properties in the study area for each scenario and subperiod are given in Table 1. Total nominal E(RLW) is 32.5% lower with MR than CR and 12% lower with HR than MR by the end of the evaluation period. The smallest percentage increase in total nominal E(RLW) occurs during the 2010–2019 subperiod and the largest percentage increase occurs during the 2020–2029 subperiod under all three land use policy scenarios. Continued use of CR results in a total E(RLW) of $79.4 million by 2059. In contrast, total E(RLW) is $53.6 million under MR and $47.1 million under HR by 2059.

Additional testing of simulation results indicate that: (1) the three WUI metrics are substantially lower for MR and HR relative to CR; and (2) E(RLW) decreases significantly between CR and MR, but not between CR and HR. Tests for significant differences in the three WUI metrics and levels of E(RLW) across land use policy scenarios indicate there is not a significant decrease in E(RLW) between CR and HR. This result is somewhat surprising because, intuitively, one would expect a significant decrease in E(RLW) as the land use policy becomes more restrictive.

There are several explanations for the results described above. First, it appears there are diminishing returns, in terms of reducing residential wildfire risk, from more restrictive land use policies. That is, while the HR policy significantly reduces the number and area of private properties in the WUI, the additional land use restrictions imposed on residential development by that policy (e.g., increased density of residential development and buffers from environmentally sensitive areas) do not sufficiently restrict residential development in areas of high wildfire risk. In fact, some restrictions, such as additional setbacks from waterbodies or environmentally sensitive areas, could increase additional residential development in higher wildfire risk areas.

Second, the restrictions imposed by the three land use policy scenarios include only two factors that could affect residential wildfire risk–no residential structures allowed on slopes greater than 30% and the percentage of development occurring in high density housing. The first restriction is the same across all three land use policy scenarios; the percentage in the second restriction increases as the land use policy becomes more restrictive. A highly restrictive policy that is specifically designed to reduce wildfire risk (e.g., continuous enforcement of wildfire protection practices for residential properties in the WUI) might be more effective than the HR policy in reducing that risk.

Third, the finding that the HR policy does not significantly decrease E(RLW) relative to the CR policy could reflect the pervasive risk of wildfire in the study area, including: (1) the high levels of wildland vegetation outside of Flathead and Smith valleys; and (2) the tendency for sections of the study area to experience larger fires at longer or shorter fire return intervals or periodic fires to maintain dry forest types (Agee 1993; GCS Research 2010). Both factors increase the likelihood that new residential development occurs in areas with a high potential for large wildfire losses. Fourth, historical patterns of residential development in the study area may also contribute to high wildfire risk because that area already includes a large amount of WUI that is not influenced by future land use policies. These historical patterns influence where high density growth in the HR policy occurs and could expose new properties to larger potential wildfire losses (Bihari et al. 2012; Platt et al. 2011).

The methods presented here can be used to assess the extent to which more restrictive land use policies reduce residential wildfire losses or exposure to wildfire risk and identify residential areas with potentially high wildfire risk in other WUIs.

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Table 1. Subperiod and total nominal E(RLW)s for Flathead County's WUI under three land use policy scenarios

Variable	2010	2019	2029	2039	2049	2059	Total
E(RLW)-CR[a]	1.8	2.5	6.0	13.4	21.8	33.9	79.4
Δ[b] E(RLW)-CR[a]		.70	3.5	7.3	8.4	12.1	32.0
% Δ in E(RLW)-CR		38	138	121	63	56	1,744
E(RLW)- MR[a]	1.8	2.5	5.0	9.3	13.6	21.4	53.6
Δ in E(RLW)-MR[a]		.70	2.5	4.3	4.3	7.8	19.6
% Δ in E(RLW)-MR		37	98	86	46	58	1,065
E(RLW)- HR[a]	1.8	2.4	4.7	8.1	11.7	18.5	47.1
Δ in E(RLW)-HR[a]		.52	2.3	3.4	3.6	6.8	16.6
% Δ in E(RLW)-HR		28	99	72	44	58	906

a. In millions of dollars
b. Stands for 'change in'