Simulation of Residential Wildfire Risk for Flathead County, Montana

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Background

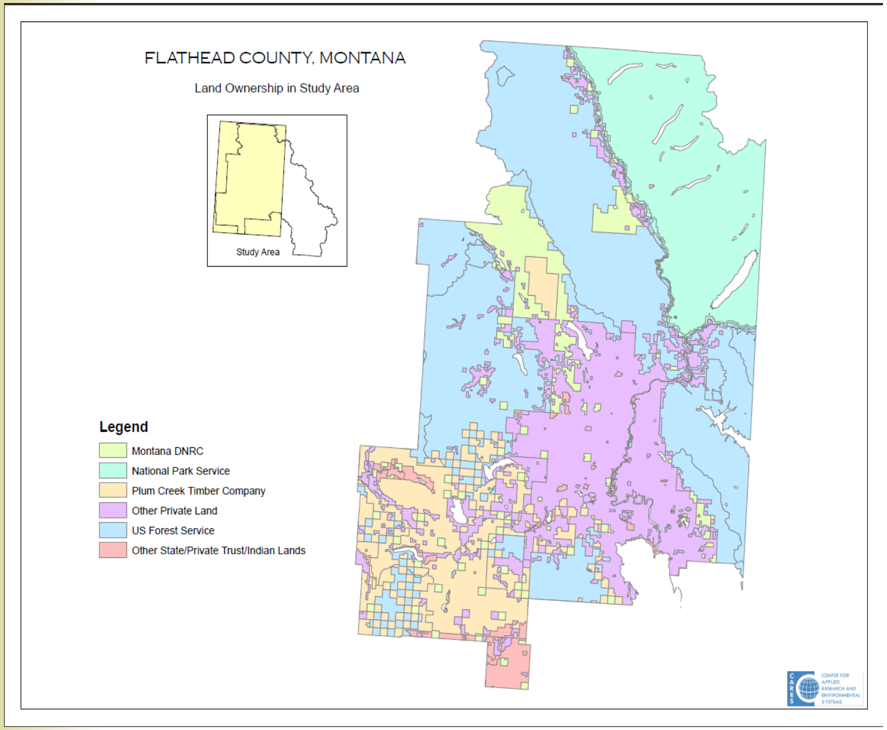
- Private property damages and suppression costs associated with wildland fire in the United States have increased dramatically.
- This trend is expected to continue as a result of climate change and expansion of residential development in the wildland–urban interface (WUI).

- Past research has identified and quantified wildfire risk to private property at several temporal and spatial scales.
- Little research focuses on the influence of various interacting social, economic, and ecological factors on <u>future</u> residential wildfire risk.

Objective

- Present an integrated framework for simulating future residential wildfire risk in the WUI with application to Flathead County, MT.

Study Area


FLATHEAD COUNTY, MONTANA
Land Ownership in Study Area
Study Area
Legend
Montana DNRC
National Park Service
Plum Creek Timber Company
Other Private Land
US Forest Service
Other State/Private Trust/Indian Lands

Risk Metric and Evaluation Period

- <u>Risk metric</u>: <u>E</u>xpected <u>r</u>esidential property <u>l</u>osses from <u>w</u>ildfire [E(RLW)]

- <u>Evaluation period</u>: 2010–2059 (50 years), consisting of five, 10–year subperiods:

  2010–2019;

  2020–2029;

  2030–2039;

  2040–2049; and

  2050–2059

Definition of E(RLW)

$E(RLW) = E_x(RLW) + E_n(RLW)$

$E_x(RLW)$ = present value in 2010 of expected wildfire losses for residential properties that existed in 2010; and

$E_n(RLW)$ = present value in 2010 of expected wildfire losses for new residential properties developed during the evaluation period.

- Existing residential properties are those that existed in 2010.
  - Identified using the Montana Computer Assisted Mass Appraisal (CAMA) parcel data for 2010 and designation of 2010 WUI.

- New residential properties are those developed during each subperiod.
  - They were determined using the residential development model.

- A new WUI was delineated at the end of each subperiod.

E(RLW) values

$E_x(RLW) = PV_{10}[E_{x1}(RLW), E_{x2}(RLW), E_{x3}(RLW), E_{x4}(RLW), E_{x5}(RLW)].$

$E_x(RLW)$ is the present value of the $E_x(RLW)$s for the five subperiods, and

$E_{xt}(RLW)$ is the undiscounted expected wildfire losses for existing residential properties during subperiod t.

E_{xt}(RLW) is defined as:

number of developed residential parcels in the 2010 WUI

probability that parcel j burns during subperiod t

number of existing residential properties in parcel j

probability that structures on property h in parcel j burn during subperiod t given parcel j burns during subperiod t

$$E_{xt}(RLW) = \sum_{j=1}^{m_x} pb_{jt} \left[\sum_{j=1}^{n_{xj}} \left[\left(pS_{hjt} VS_{xhjt} + \beta_{jt} TV_{xjt}\right)\right]\right.$$

total value of existing structure(s) on residential property h in parcel j during subperiod t

average percentage loss in aesthetic value of residential properties in parcel j during subperiod t given parcel j burns during subperiod t

total value of each existing residential property (structure and land) in parcel j during subperiod t

E_n(RLW) is defined in a similar manner as E_x(RLW).

Elements of E(RLW)

1. CAMA data and WUI (m_x);
2. residential development model (n_{xj});
3. estimating and assigning conditional burn probabilities to structures on individual residential properties (pS_{hjt});
4. simulating vegetative succession for a greenhouse gas emission scenario (pb_{jt});
5. estimating the probabilities that pixels in the WUI burn (pb_{jt}); and
6. assigning monetary values to residential properties (VS_{xhjt} and TV_{xjt}) and aesthetic property value losses due to wildfire (β_{jt}).

Simulating Residential Development

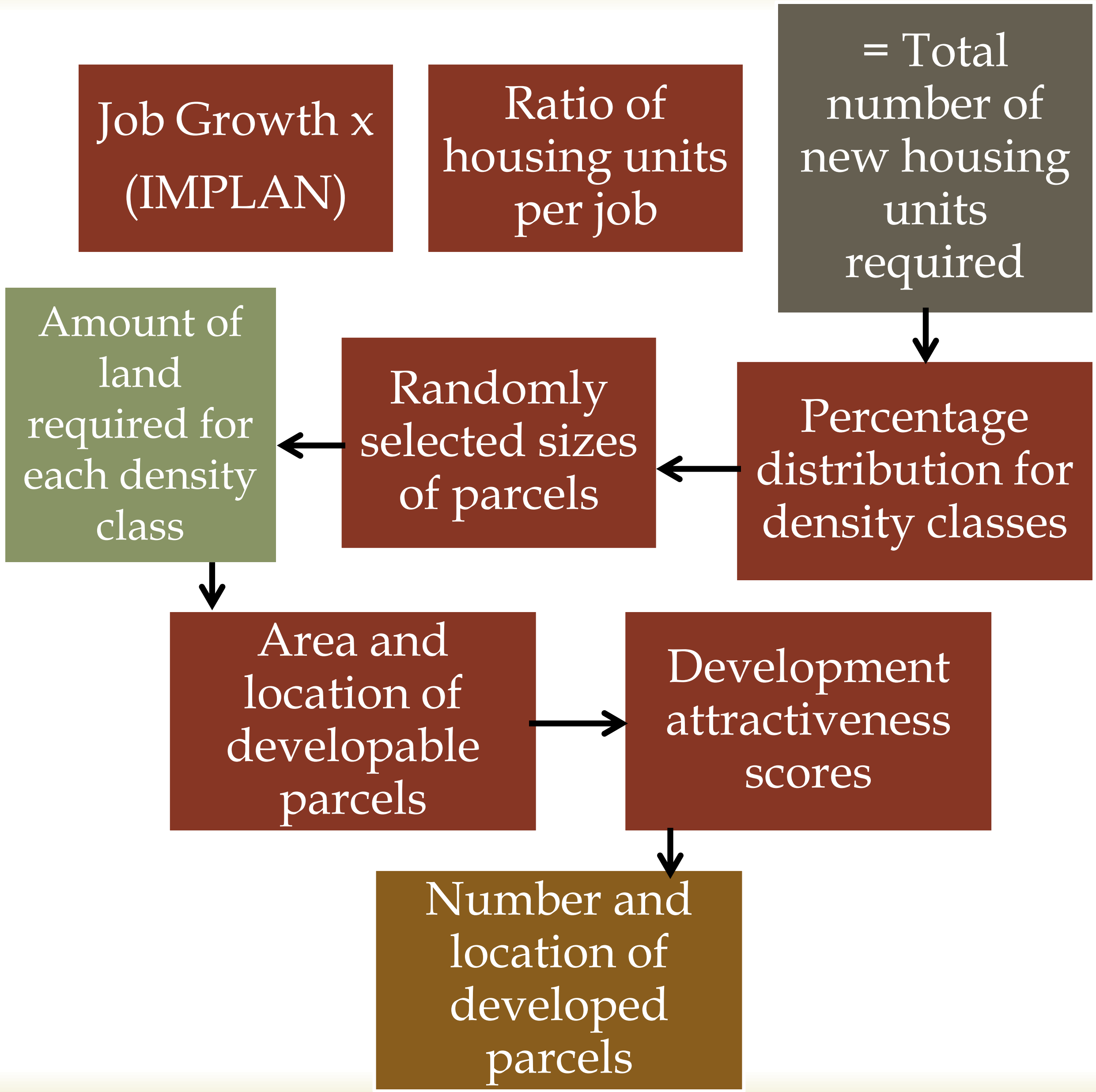
- Scenario Assumptions:
  - 2010 land use policy;
  - Moderate future economic growth; and
  - IPCC's A2 emission scenario

- Residential development in each subperiod was simulated using the revised Residential and Commercial–Institutional–Development (RECID2) model and the Impact Analysis for Planning (IMPLAN) regional economic analysis model.

RECID2 Model

Future job growth in eleven sectors of the Flathead County economy was estimated for the moderate economic growth scenario using the IMPLAN model for Flathead County.

That scenario assumes an annual average rate of growth of 2.2 percent, which was the annual growth rate for the economy of Flathead County between 2000 and 2008.


Job Growth x (IMPLAN)
Ratio of housing units per job
= Total number of new housing units required
Percentage distribution for density classes
Randomly selected sizes of parcels
Amount of land required for each density class
Area and location of developable parcels
Development attractiveness scores
Number and location of developed parcels

The DAS is a weighted sum of the minimum or maximum distances of developable parcels:

- maximum distance from major highways, edges of towns; and amenities (e.g., lakes), which are amenities; and
- minimum distance from disamenities (e.g., railroad tracks).

Delineating the WUI

- The WUIs for 2010 and five subperiods were delineated by combining elements of the Stewart et al., and the Radeloff et al. methods and Platt's Buffer from Structures method.
- The Stewart et al. method is based on the Federal Register definition for the WUI and utilizes housing density within Census blocks.
- Platt's method delineates the WUI based on parcels, which are the geographic units for housing development used in the study.

Conditional Burn Probabilities

- A conditional burn probability for a parcel is the probability that structures on that parcel burn given the parcel burns.
- A decision–tree approach was used to assign conditional burn probabilities to structures on developed parcels.
- Six values were assigned to the conditional burn probabilities for structures based on the reductions in probability of loss developed by Stockmann et al.

Simulating Vegetative Succession and Fuels for A2 Emission Scenario

- Changes in vegetation and fuels over the evaluation period were simulated using a modified version of the FireBGCv2 model.
- FireBGCv2 was calibrated for Flathead County using the procedures described in Keane *et al.*
- 2010 land cover and vegetative input parameters for FireBGCv2 were approximated using LANDFIRE EVT and Forest Inventory and Analysis (FIA) data for Flathead County.

Precipitation and temperature changes for the IPCC's A2 emission scenario were approximated by applying the offsetting or delta method to historical data for those parameters.

FireBGCv2 output for each subperiod was used to create a fuels maps that was inputted to FSim to simulate burn probabilities and intensities for 90–m^2 pixels in the study area for each subperiod.

- FireBGCv2 simulations were based on three potential forest treatments for six landownerships in the study area, priority areas for forest treatments, and other management considerations.

- Forest treatments:

    light partial thinning;
    heavy partial thinning; and
    prescribed burning.

Assigning Monetary Values to Residential Properties

- Existing (2010) residential properties
  - Structure and per hectare values were taken from the 2010 CAMA parcel database for Flathead County.
  - Property values were stratified into waterfront and non–waterfront properties in order to reflect differences in per–hectare values between the two.

- <u>New residential properties</u>
  - Each new residential property added during a subperiod was assigned structure and per hectare land values that were randomly selected from the 2010 pairs of structure and per hectare land values for either existing waterfront or existing non–waterfront residential properties in the same neighborhood.
  - Total land values for properties were determined by multiplying the randomly selected per hectare land value by the number of hectares in the property.

- Structure and land values for each new property were inflated to the subperiod in which that property was developed based on an inflation rate of 3.5 percent.

- <u>Aesthetic values</u>
  - Conditional probabilities of flame length categories produced by FSim were used to determine the average percentage loss in aesthetic value of residential properties given that the parcel on which the property is located burns (β).

Results

Residential Development

Density class	Subperiod 2010-2019	2020-2029	2030-2039	2040-2049	2050-2059
	Required				
High	61	67	74	82	92
Urban	78	85	94	105	117
Suburban	351	384	424	470	525
Rural	898	982	1,083	1,202	1,343
Exurban	6,150	6,727	7,416	8,232	9,196
Agricultural	29,363	32,119	35,408	39,306	$\boxed{43,908}$
Total	36,901	40,365	44,499	49,398	55,182
	Converted				
High	62	67	75	83	92
Urban	78	88	95	105	118
Suburban	354	385	433	473	778
Rural	923	983	1,089	1,203	1,357
Exurban	6,163	6,734	7,425	8,234	9,199
Agricultural	29,556	32,233	35,579	39,329	$\boxed{37,769}$
Total	37,137	40,491	44,696	49,427	49,314

Required > Converted

98-99% of land area

In hectares

WUI Metrics

Subperiod	Number of WUI parcels	Percent change between subperiods	Area of WUI parcels (ha)	Percent change between subperiods	Number of WUI residential structures	Percent change between subperiods	Area of the WUI (ha)	Percent change between subperiods
2010	15,518	-	41,014	-	15,518	-	294,473	-
2010–2019	16,463	4	67,820	65	20,368	31	307,565	5
2020–2029	17,099	4	88,030	30	25,055	23	323,701	5
2030–2039	17,786	4	121,413	38	30,007	20	359,482	11
2040–2049	18,439	4	164,947	36	35,246	18	403,002	12
2050–2059	19,117	4	202,410	23	42,071	19	426,535	6
Total change	3,356	20	161,396	393	26,553	171	132,062	44

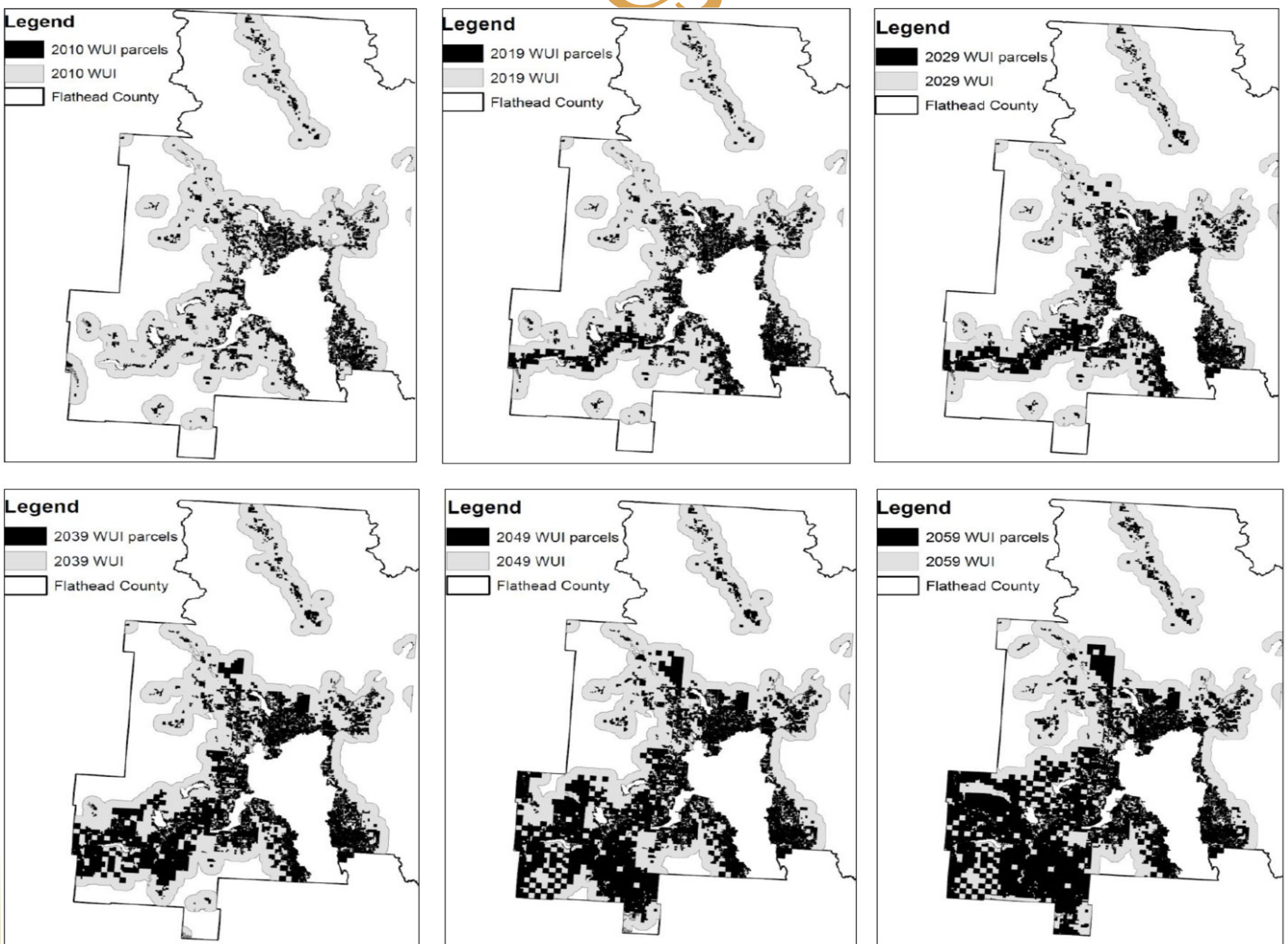
During the evaluation period, the:

- Number of WUI parcels increased 21%;
- Area of WUI parcels increased 393%;
- Number of WUI residential structures increased 167%; and
- Area of the WUI increased 45%.

- The increase in the number of WUI parcels is relatively small because the RECID2 model allows parcels developed at lower housing densities to be subdivided into higher density parcels.

- Of the four WUI metrics, the area of WUI parcels increases the most across subperiods due to dramatic increases in the amount of land converted to residential uses at the rural, exurban, and agricultural housing densities.

Area of WUI and Developed WUI Parcels



- The most significant growth in the area of the WUI and developed WUI parcels occurs in the southwest portion of the county, and to a lesser extent, the northwest quadrant.
- Growth of developed WUI parcels in earlier subperiods occurs primarily along existing transportation corridors and near established residential development.
- By 2039, patterns of WUI parcel development become more widespread, with less clustering of developed WUI parcels near transportation and population centers.

E(RLW) for Subperiods

Subperiod	Total E(RLW)	Percent increase	Weighted mean E(RLW)
		Nominal	
2000–2009	1,836,816	0	118
2010–2019	2,539,544	38	125
2020–2029	6,050,600	138	241
2030–2039	13,351,965	120	444
2040–2049	27,761,390	62	617
2050–2059	33,872,543	55	805
		Real	
2000–2009	1,836,816	0	118
2010–2019	1,938,584	6	95
2020-2029	4,234,429	117	169
2030–2039	6,014,398	42	200
2040–2049	7,503,927	24	213
2050–2059	8,937,346	19	212

- Nominal total E(RLW) increased monotonically from $1.8 million in 2000–2009 to $33.9 million in 2050–2059, or 1,744 percent.

- Real (inflation–adjusted) total E(RLW) increased monotonically from $1.8 million in 2000–2009 to $8.9 million in 2050–2059, or 387 percent.

- The greatest increases in nominal and real total E(RLW) occurred during subperiod 2020–2029, and amounted to 138 percent and 117 percent, respectively.

- Nominal weighted mean E(RLW) per residential property increased monotonically from $118 in 2000–2009 to $805 in 2050–2059, or 582 percent.

- Real weighted mean E(RLW) per residential property increased non–monotonically from $118 in 2000–2009 to $212 in 2050–2059, or 80 percent.

- Present value of E(RLW) for the evaluation period amounted to $11.4 million.

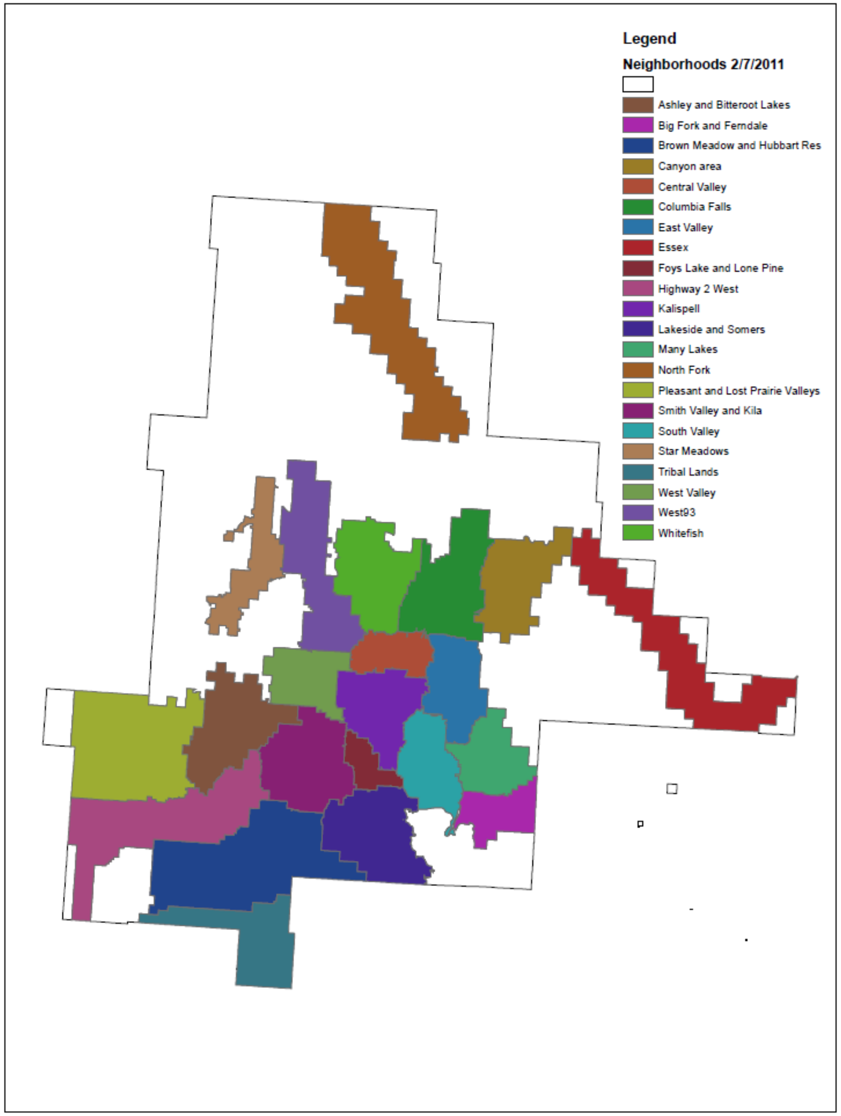
Hypothesis Testing

- Two sets of hypotheses about E(RLW) were tested:

1. There is not (H_{01}) vs. there is (H_{a1}) a statistically significant increase in nominal/real total E(RLW) across subperiods; and

2. Within each subperiod, there is not (H_{02}) vs. there is (H_{a2}) statistically significant variation in nominal weighted mean E(RLW)s across 21 neighborhoods in the study area.

Study area neighborhoods



- Because real total E(RLW) is not independent across subperiods, the first set of hypotheses was tested using the nonparametric Mann–Kendall test for trend.
- Because the simulated values of E(RLW) were not normally distributed, the second set of hypotheses was tested using the nonparametric Kruskall–Wallace one-way ANOVA test.

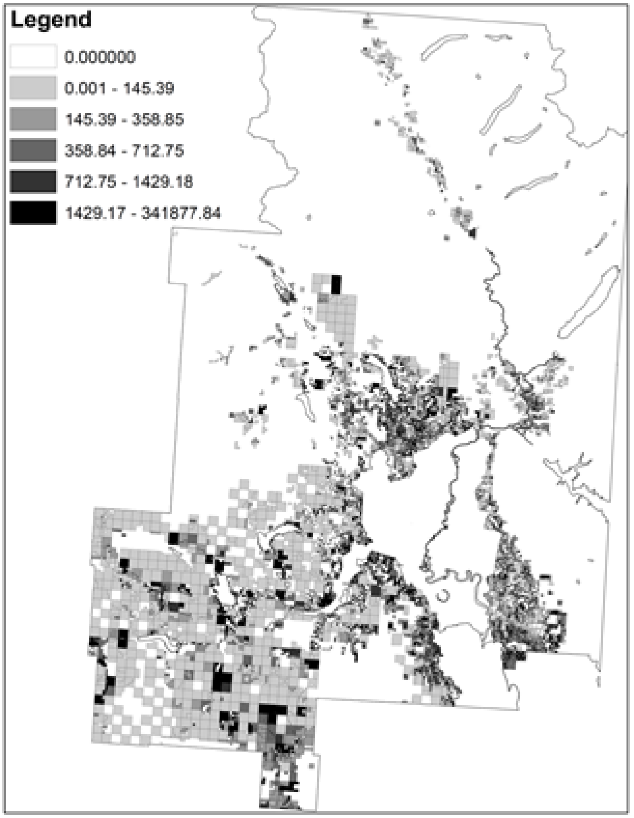
Results of Hypothesis Testing

- H_{01} is rejected in favor of H_{a1} for both nominal and real total E(RLW) ($p = 0.001$).
- Therefore, there is a statistically significant increase in total E(RLW) in the Flathead WUI across subperiods.

- H_{02} is rejected in favor of H_{a2} for all subperiods ($p = 0.001$), indicating that the variation in nominal weighted mean E(RLW) across the 21 neighborhoods is statistically significant for all subperiods.

- Therefore, some neighborhoods are at greater risk for residential wildfire losses than others.

Spatial Variability in E(RLW)



2050–2059

- There is substantial variability in parcel–scale E(RLW) across the WUI.
- Similar spatial variability occurs in all subperiods.
- The southwest portion of the 2059 WUI has parcels with relatively high E(RLW).

Conclusions

Specific contributions of the study:

1. Uses a comprehensive *monetary* wildfire risk metric [i.e., E(RLW)];
   - This allows E(RLW) to be aggregated to multiple spatial scales, and the potential benefits of wildfire–related management actions, namely reductions in E(RLW) associated with those actions, to be compared to the costs of those actions using benefit–cost analysis.

2. Moves beyond the simplifying assumption that all structures potentially impacted by a wildfire are consumed by assigning empirically–based probabilities that structures burn given the area around them burns;

3. Employs site–specific data and expands existing empirical models to simulate potential long–term residential development; and

4. Combines existing methods for delineating the WUI.

5. The methods employed in the study can be implemented using other assumptions and/or parameterizations of the models.

   For example, different assumptions and scenarios can be used for economic growth, climate change, land use policy, fuel reduction treatments, and homeowners’ wildfire mitigation behavior.

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Questions and Comments