

**Investigating the Relationship between Stakeholder Opinion about
Wildfire Management and Landscape Context Using GIS**

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1 **Abstract**

2 Colorado residents living in the wildland urban interface (WUI) were asked about
3 their perception of wildfire risk and their willingness-to-pay (WTP) for three fire
4 management procedures: fuel reduction by thinning, fire suppression and prescribed fires.
5 Respondent home locations were then digitized to enable the calculation of wildfire
6 danger variables from various GIS map layers. These two processes resulted in perceived
7 and actual wildfire risk variables which were then compared and analyzed.

8 Perceived and actual fire danger variables were then used as explanatory variables
9 in WTP functions. Results show that each fire management technique had different
10 variables that would increase a persons WTP. However, overall, WTP values for each of
11 the approaches were substantial. We believe this information shows that people living in
12 the WUI would be willing-to-pay for an annual “wildfire management fee” to offset risks
13 they consciously take by living in the WUI. This fee could potentially decrease the wildfire
14 management cost burden that is currently incurred by taxpayers.

15 **Introduction**

16 **Wildfire in the wildland urban interface**

17 Euro-American land use practices such as fire suppression, road construction,
18 exotic species introductions and logging have changed fire regimes in the United States.
19 In several areas, most specifically in the Western states, this meant what was once
20 frequent low intensity small acreage fires has become infrequent high intensity large
21 acreage fires (Allen *et al.* 1998 and 2002; Covington and Moore 1994; Swetnam 1999;
22 Cooper 1960; Mutch *et al.* 1993; Arno *et al.* 1995; Fule *et al.* 1997; Veblen *et al.* 2000).
23 These changes have become extremely vivid in the past 30 years where the number of
24 wildfires reported by U.S. Wildland Fire Agencies has decreased by one million from 1.872
25 million during the period of 1975-1984 to 884,000 during the 1995-2004 period. During
26 this same time period, acreage burnt by wildfire has increased by 11 million acres from
27 36.755 million during 1975-1984 to 47.750 million between 1995 and 2004. These
28 changes are directly reflected in wildfire suppression or initial attack costs where in less
29 than 10 years, costs have increased from \$256 million in 1997 to \$1.326 billion in 2003
30 (NIFC 2004).

31 The increase in costs is not only linked to the increase in the size of wildfires, but
32 also the significant influx of homes into the wildland urban interface (WUI) (area of forest
33 and residential interface). Are WUI residents aware of wildfire risk to their homes? A 2004
34 study by Monroe and Nelson in Minnesota and Florida found that 84% of homeowners
35 were aware of their homes risk to wildfire (Monroe and Nelson 2004). In 2002, Higgason
36 found 48-78% of Colorado WUI respondents aware that wildfire was a threat to their
37 homes (Higgason 2002). Therefore, it seems that people living near public lands that have
38 the risk of a wildfire burning their home are aware of the dangers of wildfire to their

39 property. These results represent their “perceived” risk; however, the perceived risk may
40 not equal the “actual” wildfire risk.

41

42 **Factors affecting wildfire risk**

43 To calculate the “actual” risk of a home burning, several attributes must be
44 considered. The literature suggests these attributes include defensible space, vegetation
45 type, slope and previous wildfire locations (Vicars 2003; WHIMS 2002; VCFCA 2000;
46 Romme 2003; Larimer County 2003). Having defensible space refers to having the area
47 immediately surrounding the home free of objects such as firewood and piles of dead
48 branches that can burn (WHIMS 2002; Larimer County 2003). The primary defensible
49 space zone to consider begins with the outside wall of the home and continues to
50 approximately 30 meters surrounding the home. This zone includes both home attributes
51 such as wooden shingles, metal shingles, and spark arrestor chimney caps as well as
52 regular maintenance attributes such as removing leaves and needles from a roof or storing
53 firewood, gas and propane beyond the 30 meter perimeter (Vicars 1999; WHIMS 2002;
54 Larimer County 2003).

55 Having this immediate defensible space zone is directly linked to a home being
56 spared in a wildfire. Homes with proper defensible space zones that were hit by the 2002
57 Colorado Missionary Ridge fire were all saved (Binkley 2003), while some homes with
58 defensible space that were hit by the 2002 Hayman fire¹ were also saved. Even though
59 having defensible space has been directly linked to saving homes from wildfire, defensible
60 space is not mandatory in most of Colorado. Of the four counties involved in the Hayman

¹ In 2002, Colorado experienced the largest wildfire in the states written history, the Hayman Fire. The Hayman fire encompassed 136,760 acres (CUSP, 2003) covering four Colorado counties. During its rage, it destroyed 132 homes out of a potential 794 (Cohen and Stratton, 2003).

61 fire, Teller, Park, and Douglas Counties did not have any defensible space regulations for
62 wildland-urban fire risks. Jefferson County, on the other hand, did require defensible
63 space, but only on homes of sizes greater than 400 ft² that were built after 1996. While
64 many of the homes did fit the size qualifications, they were built prior to 1996 and therefore
65 few, if any, fell into this category (Cohen and Stratton 2003).

66 In addition to the immediate defensible space area, the secondary defensible
67 space zone should also be considered. The location of this area begins at the house edge
68 and continues to the 100 meter perimeter surrounding the structure (Vicars 1999; VCFCFA
69 2000). In this area it is recommended to remove dead tree limbs, prune lower branches of
70 trees as well as mow lawns to keep small vegetation below three inches in height (Vicars
71 1999; WHIMS 2002; Larimer County 2003).

72 While defensible space zones are important, vegetation quantity and type is also
73 an important consideration. If there is no vegetation beyond the 100 meter zone, a fire
74 would not be able to travel from outside the area to the home vicinity (unless started in the
75 vicinity). Therefore, we must understand the full fire risk to a home or property. This full
76 fire risk area is estimated to be the 1600 meter perimeter surrounding the home. In this
77 area, vegetation type should be evaluated in detail because some vegetation is highly
78 flammable, while some is not. For instance, dense conifer forests are ideal conditions for
79 crown fires. Deciduous forests, however, are unlikely to sustain crown fires.

80 In Colorado, the vegetative landscape consists of a variety of classes each with
81 their own fire regimes (Romme *et al.* 2001; Theobald *et al.* 2003). These Colorado fire
82 regimes have been the study of many research reports. Brown *et al.* 1999, studied fire
83 events in the 4000 ha area of the montane ponderosa pine-Douglas fir Cheeseman Lake
84 forest of central Colorado. They recorded 77 fire years and 486 fire scars from 1197

85 through 1999. Overall fire interval averages varied across the landscape between 1 and
86 29 years. However, when researching individual stands, it was found in a majority of the
87 areas that wildfires occurred at intervals of 1 to 10 years in length. In addition, there were
88 a few areas with very long fire intervals of greater than 100 years.

89 Veblen *et al.* 2000, studied ponderosa pine forests at elevations of 1830 to 2800
90 meters in the northern Colorado Front Range. In this study, low elevation ponderosa pine
91 forests on the northern Front Range were found to experience frequent surface fires. High
92 elevation ponderosa pine – Douglas fir – lodgepole pine forests had lower fire frequency
93 but fires were stand-replacing.

94 After characterization of the vegetation, it is then important to consider the
95 landscape slope. As is well known, the steeper a slope is, the faster the rate of fire spread
96 will be. Therefore, a building on a steep slope faces a higher fire hazard than one on a flat
97 slope. This does not mean that there are more fires on steep slopes than flat slopes; it just
98 means that if a home is on a steep slope and a fire is coming towards the home, the risk
99 that the fire will reach the home is significantly greater (Ryan 1976).

100 In addition to vegetation type and slope, data on recent wildfire occurrence is also
101 an important determinant of actual wildfire risk. If a wildfire went through an area in the
102 past few years, the chances of a high intensity wildfire occurring is lower in that area
103 because there will be less fuels available to burn.

104 In this study, we use a survey to collect perceived fire danger information from
105 residents living in the WUI and compare these perceptions to actual fire danger
106 information calculated from spatial modeling in the area surrounding the respondents
107 home.

108

109

110 **Past studies of willingness-to-pay (WTP) to reduce wildfire danger**

111 We believe that awareness and experience coupled with perceived and real risk of
112 residential damage due to wildfire should influence WTP for wildfire management policies.
113 A few wildfire studies have been conducted in the past to study this WTP. Loomis *et al.*
114 2002, studied Florida residents and asked them for their WTP for prescribed burning in
115 their areas. They found Florida residents to have a WTP of \$557/annually (90%
116 confidence interval: \$387-\$1249) for prescribed burning. Winter and Fried, 2001, asked
117 respondents in Crawford County, Michigan for their WTP to reduce wildfire danger to their
118 homes by creating a defensible space. They found respondents has a WTP for an annual
119 fee of \$57/ year in increased property taxes which would be used to pay for vegetation
120 removal on their property (Winter and Fried 2000, 2001). While these studies did calculate
121 WTP, they did not analyze the relationships between WTP and wildfire risk in depth.

122

123 **Objectives of this study**

124 In this paper, we interview Colorado residents living within the WUI to determine
125 their perceived risk of wildfire and their WTP to reduce this risk. We then calculate the
126 actual fire danger to survey respondents homes by looking at fire danger variables such as
127 defensible space, vegetation in the surrounding area, slope and previous wildfires. Once
128 this information is obtained, we test whether perceived and actual wildfire risks are
129 comparable. Then, we evaluate whether perceived wildfire danger and actual or
130 calculated wildfire danger variables have a statistically significant effect on WTP for fire
131 management approaches such as prescribed fire, fuel removal by thinning and fire
132 suppression.

133 We believe that Colorado residents living in the WUI are knowledgeable about
134 wildfire and wildfire frequency and would express a positive WTP for fire management on

135 public lands near their homes. Our hypothesis is that perceived fire danger and actual fire
136 danger will have an affect on WTP for fire management approaches. Therefore, we are
137 expecting WTP for fire management to be higher if their perceived fire danger and actual
138 fire danger are relatively high.

139

140 **Study area**

141 This study was conducted in towns located in the Front Range of Colorado.
142 Because we are investigating public wildfire perceptions and actual wildfire risk, we
143 selected areas where homes were potentially at risk from wildfire.² All respondents were
144 located in the WUI of Colorado within 10 miles of a public land. The selected towns
145 included: Leadville, Nederland, Rollinsville, Estes Park, Masonville, and Red Feather
146 Lakes. All towns selected were very close to and/or bordered by either National Forest or
147 National Park lands.

148

149 **Methods**

150 To test the hypothesis that both perceived fire danger and actual fire danger were
151 related to the WTP for fire management of respondents in the WUI of Colorado, we
152 needed to accomplish two tasks. Our first task was to conduct a survey to determine WUI
153 residents values for perceived fire danger as well as their WTP for fire management. The
154 second task was to conduct a spatial analysis to determine actual wildfire danger.

155

² On average, only 3% of Colorado residents live in the wildland urban interface. The counties we looked at averaged a population of over 17% living in the wildland urban interface (Stewart *et al.*, 2003). We could not find statistics for each individual town, but we believe that all the towns we looked at had over 50% of their population living in the wildland urban interface.

156 **The survey**

157 To elicit perceived fire risk and WTP data, we used a phone, mail, phone survey
158 entitled, “Managing Fires on Public Lands: What Do You Think?”³ Respondents were
159 initially contacted by phone and asked if they would complete a survey. Of those people
160 that agreed to participate in the study, a follow-up phone interview was scheduled
161 approximately seven days from the initial call and a survey was mailed to their homes.
162 This was enough time for the participant to receive the mail survey and go through it at
163 their leisure before the follow-up phone interview. During the follow-up phone interview,
164 the respondent was asked for their responses to the mail survey and then asked to place
165 their survey in the self addressed stamped envelope to be mailed back to us. In this way,
166 we had their results logged in twice: once from the phone interview and again from the
167 mail survey.

168 Survey participants were contacted randomly during the summer of 2001 through
169 numbers in the phone book from WUI towns bordering public lands in Colorado.⁴ The
170 data from 73 respondents were used in this study representing an 86% survey response
171 rate.

172 The survey encompassed eight pages of questions and two color pictures
173 (ponderosa pine forest in Colorado one year after a low intensity prescribed burn and
174 ponderosa pine forest in Colorado one year after a high intensity wildfire) that were
175 inserted into the survey for use with some of the questions (Kaval 2004). While many of

3 The survey was initially developed and then modified in a series of focus groups. The modified survey was then pretested and consideration of all pretesting comments resulted in the surveys’ final version.

4 We used the phone book to obtain potential survey respondents as we were targeting wildland urban interface towns and wanted to make sure the people we were calling were in the area of interest. The phone book was more targeted to do this than random digit dialing. We acknowledge that this method does omit people with unlisted phone numbers which may affect the representativeness of our sample.

176 the questions in the survey related to WUI residents opinion of wildfire, this analysis
177 concentrated on questions related to wildfire risk perception and WTP.

178 Two questions were used to discover respondents perceived risk. The first
179 question asked respondents whether they felt that their home was in danger of wildfire.
180 The second question asked respondents an open ended question regarding how often
181 they felt that high intensity wildfires occurred in their area. Responses included answers
182 such as: once every 5 years, twice a year, and once every 30 years.

183 Our next set of questions was based on the contingent valuation method.
184 Contingent valuation is a method in which the value of non-market goods is assessed by
185 measuring a persons WTP (Ciriacy-Wantrup 1947). Contingent valuation has been
186 recommended by the National Oceanic and Atmospheric Administration (NOAA) Panel as
187 a legitimate method for non-market good valuation. Information is typically gathered by in-
188 person, phone, or mail surveys or in combination (Arrow *et al.* 1993; Hanemann 1994).
189 We used the contingent valuation method to find survey respondents values towards
190 wildfire management approaches. Respondents were to use their perceived fire frequency
191 information as well as the high intensity wildfire and low intensity prescribed fire pictures to
192 answer WTP questions about the public lands in their area. Again, all towns in this study
193 were very close to and/or bordered either by National Forest or National Park lands.

194 Current wildfire management approaches vary by area but may typically include
195 one or a combination of the following three approaches: prescribed fires, fuel reduction by
196 thinning, and fire suppression. These are the three fire management approaches we used
197 in our WTP questions. Prescribed fires, or controlled burns, are those fires that are set
198 purposely in a designated area to remove underbrush and dead wood which reduces
199 available fire fuel. The goal of fuel reduction is to reduce future wildfire intensity. While
200 there are rare instances where prescribed fires may get out of control, most of the time

201 they do not escape the pre-set boundaries. However, when prescribed burns do get out of
202 control, they sometimes cause substantial damage and expense. These large out of
203 control fires get in the media and hence, negative perceptions about prescribed burning
204 may come about.

205 Fuel reduction by thinning (removing underbrush and some standing trees by hand
206 or machine) is another approach that typically yields a reduction in wildfire intensity. In our
207 survey we used the term “fire prevention” to describe this manual thinning process
208 because it was a term that people related to in our focus groups. We realize that the fire
209 community might not use this term for this approach.

210 Fire suppression, or initial attack, includes having fire crews on standby that are
211 located close to fire prone areas of forests. The purpose of fire suppression crews is to
212 extinguish all fire starts immediately before fires are given the chance to spread.

213 Fire management definitions alongside respondents wildfire risk knowledge,
214 enabled them to answer the WTP questions. A similar WTP question was asked for all
215 three management approaches:

216 Using (prescribed burning, fire prevention or fire suppression) public land
217 management agencies could reduce the frequency of high intensity
218 wildfires in the National Forests and/or National Parks in your area by
219 half. Would you pay an increase of \$X⁵ a year more in taxes for a
220 program such as this?

221 (Circle One) Yes No

222

⁵ \$X for each question was filled in with values ranging from \$5 through \$1500 (ranges were determined during focus group sessions prior to the official survey distribution). While the dollar amount between participants was different, the values for prescribed fire, fuel reduction by thinning and fire suppression was the same for each participant.

223 **Spatial analysis**

224 To calculate actual fire danger or the actual risk of a home burning, several
225 variables were considered, all recommended by earlier studies for quantifying fire risk.
226 Variables included defensible space, vegetation type, slope and previous wildfires. These
227 variables were created by conducting a spatial analysis using GIS (ESRI) that used 4 map
228 layers: vegetation, home point locations, slope, and wildfire locations.

229 The first layer in our spatial model consisted of the locations of the 73 respondents
230 homes. We mapped locations via field visits to each individual home to obtain: 1. the UTM
231 coordinates obtained with a Garmin Global Positioning System (GPS) unit; 2. the degree
232 to which a 30 meter defensible space was created (WHIMS 2002; Larimer County 2003);
233 3. general vegetation characteristics; and 4. pictures of the home and the surrounding
234 area.

235 As recommended by Vicars (2003), WHIMS (2002), VCFCA (2000), Romme (2003)
236 and Larimer County (2003) we looked at three vegetative zones. As stated previously, the
237 first (from the house to approximately 30 meters) was calculated during the site visits. For
238 these purposes, a home with a proper defensible space from the site visit meant that either
239 the home was located in a town area with no danger of wildfire affecting it or that there
240 was a 30 meter clearing around the perimeter of the home. More specifically, this meant
241 that there were no observed debris on roofs, there were no woodpiles or other flammable
242 vegetation in the 30 meter perimeter and that propane tanks were located 30 or more
243 meters from the edge of the home. Out of the 73 respondents homes, 23 had either the
244 proper defensible space and/or were located in a town area where there was no fire
245 danger. The second zone was the 100 meter perimeter and the third was the 1600 meter

246 perimeter. The vegetative area information for these two zones would come from our
247 vegetative map layer.

248 The vegetation layer is a fine grained (~1 ha) statewide landcover map of Colorado
249 based on the National Land Cover dataset (Theobald *et al.* 2003). Although finer-grained
250 vegetation maps are available for National Forest land, they do not extend onto private
251 lands, so we did not use them.

252 We then cross referenced data on heat release,⁶ spread rate,⁷ and flame length⁸
253 for 18 Colorado vegetation types based on the Romme *et al.* (2001) study using GIS and
254 Behave (a fire behavior model).

255 The next layer of data was slope, computed from the USGS Digital Elevation Model
256 (30 m) (USGS 2001). As stated previously, the steeper a slope is, the faster the rate of
257 fire spread will be. Therefore, homes on steep slopes face higher fire hazard than those
258 on flat slopes.

259 The final layer depicted locations (mapped as fire perimeter polygons) of wildfires
260 that occurred in the year 2000 in the Western United States.⁹ We initially looked at all
261 wildfires in Colorado, plus wildfires in all states bordering Colorado, to see which were
262 closest to respondents homes. Using GIS, we calculated that the closest fires were two
263 fires called the Bobcat Gulch and the High Meadow Fire, both in Colorado. These fires
264 were represented by shapefiles. The High Meadow fire burned 10 500 acres and
265 destroyed 51 homes in the Denver vicinity. The Bobcat Gulch fire burned 10 600 acres
266 and destroyed 22 homes in the Fort Collins–Masonville area.

6 “Heat release (btu/ft²), an indicator of the total potential damage from a fire, varies with fuel model type and fuel moisture, but is independent of slope and wind (Romme *et al.*, 2001)”

7 “Rate of spread (chains/hour where one chain is 66 feet) is affected by fuel model, fuel moisture, slope and wind (Romme *et al.*, 2001)”

8 “Flame length (ft) is influenced by fuel model, fuel moisture, slope, and wind. Flame length is often used as a general descriptor of fire intensity and difficulty of suppression: a flame length of four feet is considered the upper limit for hand crews (Romme *et al.*, 2001)”

267

268 **Spatial variable calculations**

269 Spatial data layers enabled us to calculate new variables related to actual fire
270 danger. The first variable we created was the distance to the closest fire. This task was
271 completed with a proximity analysis by measuring the distance from the homepoint to the
272 nearest edge of the closest wildfire. Note that none of the respondents homes had been in
273 a wildfire. The closest home to a fire was approximately 2145 meters from the perimeter
274 of the Bobcat Gulch Fire while the furthest from a home was approximately 83 200 meters.

275 Next, we created 100 meter and 1600 meter buffers around locations that
276 represented respondents homes in order to take into consideration the fire danger of the
277 surrounding area (Figure 1).

278 We then calculated the type and amount of vegetation within each 100 m buffer.
279 For example, the vegetation within the 100 meter buffer of one of the respondents homes
280 consisted of 1.8 hectares of ponderosa pine montane, 0.27 hectares of ponderosa pine/
281 Douglas fir, 0.63 hectares of lodgepole pine and 0.36 hectares of short grass prairie. Once
282 this information was obtained, we were able to combine it with Romme's (2001) heat
283 release, flame length and fire spread information to determine potential wildfire danger
284 (Table 1).

285 The fire danger of the immediate area (100 meter buffer) yielded 3 variables:

286 Heat100 – Average heat release in the 100 meter buffer

287 Spread100 – Average spread potential in the 100 meter buffer

288 Flame100 – Average flame length in the 100 meter buffer

9 Since the survey was completed in early 2001, we focus on fires that occurred in the previous year, 2000.

289 To compute the fire danger in the surrounding 1600 meter area, we weighted
290 vegetation types so that vegetation closer to the house mattered more (0 to 400 m: 1; 400
291 – 800 m: 0.75; 800 – 1200 m: 0.5; 1200 – 1600 m: 0.25). This resulted in 3 weighted
292 average variables for wildfire danger over a 1600 meter radius surrounding the
293 homepoints:

294 Avgheat - Weighted average of heat

295 Avgspread - Weighted average of spread

296 Avgflame - Weighted average of flame

297 We then computed the average slope within the 1600 meter buffer. This variable
298 “Slope” was calculated as a weighted average using the same techniques that were used
299 to create Avgheat, Avgspread, and Avgflame.

300

301 **The willingness-to-pay (WTP) model**

302 To test our hypothesis that perceived fire danger and actual fire danger will have
303 an affect on WTP for fire management approaches; we created two sets of models. The
304 first set related only perceived fire danger (survey response variables) and WTP values,
305 while the second set related both perceived fire danger as well as actual or calculated fire
306 danger (the spatial variables) to the WTP values.

307 We ran six logistic regression models¹⁰ in total: the first three represented WTP
308 with perceived fire risk and the last three represented WTP with both perceived and actual
309 fire risk. The three WTP variables were: WTP for fire prevention or fuel reduction by
310 thinning, WTP for fire suppression or initial attack, and WTP for prescribed fire. These
311 three variables were coded with 1= “yes, they are WTP,” and 0= “no, they are not WTP.”

¹⁰ The logistic regression model is appropriate to use since the dependent variable is binary where 1= “the respondent is WTP for the particular activity” and 0 = “the respondent is not WTP.”

312 The independent variables are: Bid, Danger, Freq, Firedist, Defspace, Heat100,
313 Spread100, Flame100, Avgheat, Avgspread, Avgflame, and Slope (See Table 2 for exact
314 definitions of each variable).

315 Prior to running the regressions, we checked the correlations of the variables.
316 Many of them had a high correlation. Therefore, we did not use all of them in the same
317 model. The two most highly correlated variables were Avgflame and Avgheat (0.8799)
318 and Flame100 and Heat100 (0.8738).¹¹

319

320 **Results**

321 **General comparisons of perceived and actual wildfire risk**

322 The two questions used to determine respondents perceived risk included whether
323 they felt their home was in danger of wildfire and how often they felt that high intensity
324 wildfires occurred in their area. Results show that 64% of respondents indicated they had
325 concern that a wildfire could burn their home. Wildfire frequency results show that almost
326 18% of respondents felt high intensity wildfires occurred at least once a year in their area,
327 while almost 92% of respondents felt that these wildfires occurred at least once every 30
328 years in their area. A small percentage (<5%) believed that fires occurred less than once
329 every 50 years.

330 Using the spatial data, we were able to categorize levels of wildfire danger in the
331 100 meter and 1600 meter buffer zones (Table 3). Categories included none, low,
332 moderate and high wildfire danger. For the vegetation in the 100 meter buffer zone, we
333 find that 5% of respondents have no wildfire danger surrounding their home, at the same
334 time, none of these respondents felt their home was in danger of wildfire. For the low

¹¹ Refer to Kaval, 2004 for more detail of all variable correlations.

335 wildfire danger category, 33% of homes fell in this category with 63% of respondents
336 believing their home was in danger of wildfire. 40% of homes fell in the moderate wildfire
337 danger category with 62% of respondents in this category feeling their home was in
338 danger of wildfire. 22% of homes fell in the high wildfire danger category and 88% of
339 respondents in this category felt their home was in danger of wildfire. This seems to show
340 that people that do not have wildfire danger in the 100 meter defensible space zone
341 surrounding their home are aware that they do not have wildfire danger. Most of the
342 people that live in an area where the vegetation for the surrounding 100 meters is of a high
343 wildfire potential also are aware of this danger. However, in the low wildfire danger strata,
344 nearly two-thirds of households believed their home was in danger of wildfire.

345 If we think about this more generally, 38% of the homes have either no or low
346 wildfire danger in the 100 meter buffer of vegetation surrounding their home, while 62% of
347 homes have either a moderate or high wildfire danger. Therefore, we can say that, on
348 average, 62% of homes have a likely chance of being burned in a wildfire. At the same
349 time, 64% of the respondents felt that their home was at risk of wildfire. So, on average,
350 perceived wildfire danger is similar to actual wildfire danger. This correspondence breaks
351 down somewhat when analyzed by the separate calculated risk categories.

352 Next we looked at the vegetative wildfire danger in the 1600 meter buffer zone.
353 Here we find that all homes have some type of wildfire danger. Twenty-seven percent of
354 the homes have a low wildfire danger, while 30% of the people in these homes felt their
355 home was in danger of wildfire. 51% of homes were in the moderate fire danger category
356 with 76% of these respondents feeling their home was in danger of wildfire. While 22% of
357 the homes were in the high wildfire danger category with 81% of these respondents being
358 aware their home is in danger of wildfire. We find these results to be slightly different than
359 the results from the 100 meter vegetative buffer zone. We again find a large majority of

360 people in the high danger areas are aware of their home in danger of wildfire, and at the
361 low risk level, a lower percentage of people believed their home to be at risk of wildfire.

362 This information generally exhibits a positive relationship between calculated fire
363 risk and perceived risk. Results show that vegetative dangers in the one mile buffer zone
364 are better understood, on average, by respondents than the dangers closer to their homes.
365 However, at the high levels and low levels of wildfire risk in both vegetative zones (100
366 meter and 1600 meter) people seem knowledgeable of their risk.

367

368 **The base models: using only perceived fire risk, no spatial variables**

369 Prior to running the perceived and actual wildfire risk models, we calculated the
370 average WTP for the three fire management procedures with a simple logit model using
371 only the variable bid amount. From this, it was found that fire prevention had an average
372 WTP of \$599, fire suppression had an average WTP of \$507 and prescribed burning had
373 an average WTP of \$655. These values represent a per-household fee to be paid
374 annually in their taxes in perpetuity.

375 Once average WTP was calculated, three base models were run, one each for
376 WTP for fire prevention (fuel reduction by thinning), fire suppression (initial attack), and
377 prescribed fire (Equations 1, 2 and 3 in Table 4). Independent variables included the
378 dollar amount respondents were asked to pay or their bid amount (Bid), whether they felt
379 their home was in danger of wildfire (Danger), and the frequency that they believed high
380 intensity wildfires occurred in the area (Freq). Logit results are located in Table 4:

381 The first row in Table 4 represents fire prevention or fuel reduction by thinning. In
382 this model we see that WTP is influenced by whether the respondent feels their home is in
383 danger from wildfire. If they feel their home is in danger of wildfire, they have a higher

384 WTP for fire prevention. By converting the coefficient into a WTP amount¹², we find that
385 the respondent will increase their WTP for fire prevention by \$338.25 annually if the
386 respondent feels their home is in danger of wildfire. This value is an average per
387 household value.

388 The second row represents fire suppression or initial attack. In this model we also
389 see that WTP is influenced by whether the respondent feels their home is in danger from
390 wildfire. If they feel their home is in danger, they have a higher WTP for fire suppression
391 by \$586.50 annually.

392 The third row represents the logit model for WTP for prescribed fire. In this model,
393 we find WTP is influenced by the perceived length of the high intensity fire return interval.
394 If the length of time between high intensity wildfires increases, the respondent has a lower
395 WTP. For instance, if the frequency of a high intensity fire is perceived to currently be
396 once every 5 years and increases to once every 20 years, the respondent will have a
397 lower WTP for prescribed fire. Therefore, we find that the respondents are willing-to-pay
398 \$12.67 more for each year they perceived that high intensity wildfire frequency increases.

399

400 **The base models + spatial variables (perceived fire risk and calculated fire risk)**

401 The next set of logistic regressions represents not only the perceived fire danger
402 reported by the respondents, but also what we are calling the actual fire danger calculated
403 by the spatial models. Because different variables influenced the various fire management

12 As interpretation of the coefficients in the logit models may be difficult, we converted the significant coefficients to WTP values. To convert logit coefficients to WTP, we divide the coefficients for all values except the bid amount by the absolute value of the bid coefficient (Cameron, 1988; Richardson, 2002).

404 prescriptions, we will be presenting the best models from each of the management
405 prescriptions. Logit results are presented in Table 5.

406 The first logit model (row 1, equation #4), represents WTP for fire prevention or fuel
407 reduction by thinning. In this model, we find that if the respondent has a defensible space
408 surrounding their home, they have a higher WTP for fire prevention by \$364.50. We
409 believe that people who engage in defensible space might see the public program as
410 being a complement to their efforts. We also found that if the average heat level within the
411 100 meter area immediately surrounding the home increases, the respondent will be
412 willing-to-pay \$0.50 more for each increase in BTU/ft² of heat. For the WTP for fire
413 suppression (initial attack) (row 2, equation #5), the respondent has a higher WTP if the
414 weighted average heat measure within 1600 meters of home increases. In other words,
415 the respondent will be willing-to-pay \$2.67 more for each increase in BTU/ft² of heat in the
416 1600 meter area surrounding their home.

417 The last row of Table 5 (equation #6) presents the logit model for prescribed or
418 controlled fire on public lands. In this model, none of the spatial variables have a
419 significant impact on WTP, although the perceived fire risk high intensity wildfire interval
420 remains significant. Here we see the respondent is willing-to-pay \$13.00 more if the
421 frequency of high intensity fire increases when the average heat and defensible space
422 variables are also considered. This difference in WTP from perceived fire frequency in
423 equations 3 and 6 is not significant.

424 The inclusion of actual fire risk calculated from the spatial data substantially
425 increased the explanatory power of the logit WTP equations for fire prevention and fire
426 suppression (nearly doubling the explanatory power for the fire suppression model).

427

428 **Discussion and conclusions**

429 In this paper we show that perceived wildfire risk and actual wildfire risk have an
430 impact on an individuals willingness-to-pay (WTP) for fire management. This empirical
431 study involved several steps. First, we conducted a survey to obtain perceived wildfire risk
432 values as well as WTP values for fuel reduction by thinning, fire suppression or initial
433 attack and prescribed or controlled fire for people living in the Colorado wildland urban
434 interface (WUI). Next, we needed to determine actual wildfire danger of respondents
435 homes. This involved both site visits and GIS modeling. Fire danger zones evaluated
436 included the 30 meter immediate defensible space zone, the 100 meter secondary
437 defensible space zone and the 1600 meter vegetative zone surrounding each of the
438 respondents homes. Important modeling layers included home locations, vegetation,
439 slope and previous wildfire locations.

440 Sixty four percent of respondents perceived their home to be in danger of wildfire.
441 This was comparable to the actual 100 meter vegetative danger showing 62% of homes
442 were in danger of wildfire. However, when vegetative fire risk results were broken down
443 into more specific categories; none, low, moderate, and high wildfire danger, results
444 indicated a positive but weak relationship between actual and perceived risk. People living
445 in areas that did not have wildfire danger, were aware of this fact. People that were in high
446 danger wildfire areas were also aware of their fire danger risk. However, in the low and
447 moderate fire danger areas, it seems that respondents may have overestimated their
448 wildfire danger.

449 We then compared perceived fire danger with the actual vegetative wildfire danger
450 in the 1600 meter perimeter surrounding the home. When homes are in a zone of high
451 wildfire danger, respondents are very knowledgeable (there were not any areas without

452 fire danger in the 1600 meter calculations). In addition, people in the moderate wildfire
453 danger areas also were knowledgeable that their homes were in danger of wildfire. Fewer
454 people in low vegetative fire danger felt their homes were in danger of wildfire.

455 From the results of both the 100 meter and 1600 meter zones, it seems that when
456 there is no danger of wildfire, people know. When there is a high danger of wildfire, most
457 people also know. However, in the low and moderate fire danger areas, it seems that
458 people are more aware of the vegetative danger in the 1600 meter buffer zone
459 surrounding their home than they are with the 100 meter zone. Therefore, when targeting
460 education of WUI respondents, focus should be drawn firstly to people living in areas of
461 moderate risk of wildfire as they do not seem to completely understand their risk. People
462 in low risk areas also do not fully understand their risk, but their risk is low, so education
463 does not need to be a priority in this region. And people living in high risk or no risk zones
464 are already knowledgeable of their areas so education does not need to be a priority in
465 these regions either.

466 After perceived and actual wildfire risk comparisons were complete, we analyzed
467 WTP for the three fire management approaches. Results show that respondents were
468 willing-to-pay an annual amount in their taxes in perpetuity for the government to perform
469 either prescribed fires, fire suppression (initial attack) or fire prevention (fuel reduction by
470 thinning) on the public lands (in this study, public lands were typically National Forest or
471 National Park lands) surrounding their homes. This implies that fire management is
472 important to our respondents.

473 More specifically, for the model considering WTP for fire prevention (fuel reduction
474 by thinning) and perceived fire risk, we find that if respondents feel their home is in danger
475 of wildfire, they will pay more (\$338 annually in their taxes). If we include the spatial
476 variables in our model, we find the explanatory power of the model increases and the

477 significant variables change. First, we see that perceived fire danger is no longer
478 significant and is now replaced by actual fire danger. If the home has defensible space
479 created in the first priority zone (home edge to 30 meters), then the people in those homes
480 are more likely to pay for fire prevention (\$364). In addition, if the actual vegetative fire
481 danger in the 100 meters surrounding the home increases, people are more willing-to-pay
482 for fire prevention by \$0.50 for each increase in BTU/ft² of heat. We believe this shows
483 that people who are knowledgeable about the fire risk in the 100 meter zone surrounding
484 the homes are the ones interested in creating defensible space. As stated previously, fire
485 prevention is a manual fuel reduction technique. Clearing a defensible space is also a
486 manual reduction process. Therefore, it seems logical that people interested in manual
487 reduction are also interested in paying the government to do manual reduction on the
488 public lands surrounding their home. Creating a defensible space around a home takes a
489 great deal of time and effort. For these people, protecting their homes and paying for fire
490 management in the surrounding area is important.

491 Fire suppression, or initial attack, suggests that once a fire has started, it is put out
492 immediately, typically before it has a chance to spread. This approach is costly because it
493 requires a great deal of manpower; people need to be standing by and ready for action
494 when wildfires start. With the base model we found similar results to those for fire
495 prevention, that is, if they felt their home was in danger of a wildfire, they would pay more
496 (\$586 more). When adding in the spatial variables, the explanatory power of the model
497 increases substantially and we find that if the calculated fire danger in the 1600 meter
498 buffer zone increases, the respondent is more WTP for fire suppression by \$2.67 for each
499 increase in BTU/ft² of heat. Again, perceived fire danger has become insignificant.

500 The final fire management approach we looked at was prescribed fires on public
501 lands near the respondents home. Here we found that the respondents WTP increased by

502 \$12.67 per year of perceived increased fire frequency. Therefore, a person that thought
503 high intensity wildfires occurred every 5 years near their home would have a higher WTP
504 for prescribed fires than if they believed the high intensity wildfires occurred in their area
505 only once every 50 years. When we added spatial variables to the prescribed fire model,
506 the explanatory power of the model increased only slightly, however, the results remained
507 similar – their WTP increased with their perception of high intensity wildfire frequency (\$13
508 per year of increased fire frequency).

509 In general, if perceived wildfire risk variables were considered and actual wildfire
510 risk variables were not, perceived risk variables had a significant impact on WTP. When
511 actual fire danger variables were added to two of the models; fire prevention and fire
512 suppression, perceived risk was no longer important for explaining WTP, but actual fire
513 danger variables were. Adding actual fire danger variables to these two models also
514 increased the models explanatory power significantly. For the third model, prescribed fire,
515 adding actual fire danger variables only slightly increased the explanatory power of the
516 model and the variable of significance, perceived fire frequency, stayed the same.

517 From these results, we see that people that are interested in manually keeping
518 their own primary defensive space area clear from wildfire risk are willing-to-pay for the
519 government to manually keep public lands clear. People that believe the fire danger in the
520 1600 meter area surrounding their home is high are more willing-to-pay for fire
521 suppression. And people that believe high intensity wildfire occurs frequently on the public
522 lands in their area are more willing-to-pay for prescribed fire.

523 We believe our study shows that a persons perception of the risk of wildfire danger
524 increases their WTP for fire management. Respondents were WTP for all three
525 approaches whether we included perceived or spatial risk variables. Therefore, these
526 findings should be useful in identifying which households within the WUI would pay for the

527 three different wildfire management approaches presented in this paper. We believe that
528 these results also imply that the government could start charging a wildfire management
529 fee to people living in the WUI. This fee could lessen the burden of wildfire management
530 that is currently placed across all taxpayers.

531 We believe the inclusion of spatial data into the perceived wildfire danger models
532 provided useful information to fire managers for targeting households that support wildfire
533 fuel reduction. Firstly, this information enabled us to make the comparison between actual
534 and perceived wildfire risk. Secondly, this information increased the explanatory power of
535 our models and showed that spatial variables played a significant role in WTP. We
536 recommend that researchers surveying people on their WTP for wildfire management also
537 include actual fire risk variables calculated from GIS data into their WTP models.

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Tables

Table 1. Fire Danger Statistics.

<u>Vegetation type</u>	<u>Average flame length</u>	<u>Average spread rate</u>	<u>Average heat release</u>
Urban, open water, tundra	0.000	0.000	0.000
Dryland crops, irrigated crops, riparian vegetation, subalpine meadow	2.567	23.000	116.000
Foothills/ mountain grassland	3.700	10.000	606.000
Deciduous oak, big sagebrush	12.200	23.333	3420.000
Aspen	3.633	7.000	824.000
Spruce fir, Douglas fir, mixed conifer	3.233	7.667	601.000
Juniper	3.567	3.333	1622.000
Pinyon juniper	3.633	7.000	734.000
Ponderosa pine	12.200	17.333	2292.000
Overall average	7.005	10.535	1289.366

*Adapted from Theobald *et al.*, 2003 and Romme *et al.*, 2001

Table 2. Variable names, descriptions and expected coefficient signs.

<u>Variable Name</u>	<u>Variable Description</u>	<u>Expected Coefficient Sign</u>
Bid	Bid Amount for WTP Questions: (\$5-\$1500)	-
Danger	Whether the respondent feels there is a risk their home will catch on fire (1=yes, 0=no)	+
Freq	Frequency of wildfire reported by respondent. Once every 10 years=10, once every 100 years=100	-
FireDist	Estimated distance in meters from homepoint to edge of closest wildfire in 2000	-
DefSpace	If the home has a 9.144 meter (30 foot) defensible space (1=yes, 0=no)	+
Heat100	Average heat coefficient in the 100 meter buffer area	+
Spread100	Average spread coefficient in the 100 meter buffer area	+
Flame100	Average flame coefficient in the 100 meter buffer area	+
Avgheat	Weighted average heat coefficient in the 1600 meter buffer zone	+
Avgsread	Weighted average spread coefficient in the 1600 meter buffer zone	+
Avgflame	Weighted average flame coefficient in the 1600 meter buffer zone	+
Slope	Weighted average slope coefficient in the 1600 meter buffer zone	+

Table 3. Comparison of Actual and Perceived Wildfire Danger.

<u>Calculated Vegetative Fire Danger</u>	100 Meter Buffer Zone		1600 Meter Buffer Zone	
	<u>Percentage of Homes</u>	<u>Percentage of People in the Vegetative Zone that Felt Their Home Was in Danger of Wildfire</u>	<u>Percentage of Homes</u>	<u>Percentage of People in the Vegetative Zone that Felt Their Home Was in Danger of Wildfire</u>
None	5%	0%	0%	0%
Low	33%	63%	27%	30%
Moderate	40%	62%	51%	76%
High	22%	88%	22%	81%

Table 4. Logit results for the base models (perceived fire risk only).

<u>WTP</u>	<u>C</u>	<u>Bid</u>	<u>Danger</u>	<u>Freq</u>
1. WTP for Fire Prevention (P-Values) <i>McFadden R² = 0.223</i>	0.945 (0.134)	-0.004 (0.044)	1.353 (0.044)	-0.018 (0.240)
2. WTP for Fire Suppression (P-Values) <i>McFadden R² = 0.118</i>	0.251 (0.665)	-0.002 (0.099)	1.173 (0.055)	-0.007 (0.646)
3. WTP for Prescribed Fire (P-Values) <i>McFadden R² = 0.165</i>	1.706 (0.016)	-0.003 (0.040)	-0.175 (0.798)	-0.038 (0.064)

Table 5. Logit results for the spatial variable models (perceived fire risk + actual or calculated fire risk).

<u>WTP</u>	<u>C</u>	<u>Bid</u>	<u>Danger</u>	<u>Freq</u>	<u>Defspace</u>	<u>Heat100</u>	<u>AvgHeat</u>
4. Fire Prevention (P-Values) <i>McFadden R² = 0.285</i>	-0.686 (0.499)	-0.004 (0.024)	0.919 (0.236)	-0.026 (0.167)	1.458 (0.096)	0.002 (0.103)	
5. Fire Suppression (P-Values) <i>McFadden R² = 0.195</i>	-2.142 (0.086)	-0.003 (0.075)	0.479 (0.496)	-0.013 (0.477)	0.227 (0.725)		0.008 (0.027)
6. Prescribed Fire (P-Values) <i>McFadden R² = 0.176</i>	0.829 (0.478)	-0.003 (0.058)	-0.402 (0.599)	-0.039 (0.062)	0.364 (0.575)		0.002 (0.437)

Figures

Figure 1. Visualization of a Sample Homepoint with Vegetative Buffer Zones Surrounding It.

