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

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Abstract

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

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

Keywords

Contingent valuation

GIS

wildfire

wildland urban interface

JEL Classification

Q51, Q54, Q34

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Introduction

Wildfire in the Wildland Urban Interface

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

The increase in costs is not only linked to the increase in the size of wildfires, but also the significant influx of homes into the wildland urban interface (WUI) (area of forest and residential interface). Are WUI residents aware of wildfire risk to their homes? A 2004 study by Monroe and Nelson in Minnesota and Florida found that 84% of homeowners were aware of their homes risk to wildfire (Monroe and Nelson 2004). In 2002, Higgason found 48-78% of Colorado WUI respondents aware that wildfire was a threat to their homes (Higgason 2002). Therefore, it seems that people living near public lands that have the risk of a wildfire burning their home are aware of the dangers of wildfire to their property. These results represent their “perceived” risk; however, the perceived risk may not equal the “actual” wildfire risk.

Factors affecting wildfire risk

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

Having this immediate defensible space zone is directly linked to a home being spared in a wildfire. Homes with proper defensible space zones that were hit by the 2002 Colorado Missionary Ridge fire were all saved (Binkley 2003), while some homes with defensible space that were hit by the 2002 Hayman fire[1] were also saved. Even though having defensible space has been directly linked to saving homes from wildfire, defensible space is not mandatory in most of Colorado. Of the four counties involved in the Hayman fire, Teller, Park, and Douglas Counties did not have any defensible space regulations for wildland-urban fire risks. Jefferson County, on the other hand, did require defensible space, but only on homes of sizes greater than 400 ft^2 that were built after 1996. While many of the homes did fit the size qualifications, they were built prior to 1996 and therefore few, if any, fell into this category (Cohen and Stratton 2003).

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

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

In Colorado, the vegetative landscape consists of a variety of classes each with their own fire regimes (Romme *et al.* 2001; Theobald *et al.* 2003). These Colorado fire regimes

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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).

have been the study of many research reports. Brown *et al.* 1999, studied fire events in the 4000 ha area of the montane ponderosa pine-Douglas fir Cheeseman Lake forest of central Colorado. They recorded 77 fire years and 486 fire scars from 1197 through 1999. Overall fire interval averages varied across the landscape between 1 and 29 years. However, when researching individual stands, it was found in a majority of the areas that wildfires occurred at intervals of 1 to 10 years in length. In addition, there were a few areas with very long fire intervals of greater than 100 years.

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

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

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

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

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

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

Objectives of this study

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

We believe that Colorado residents living in the WUI are knowledgeable about wildfire and wildfire frequency and would express a positive WTP for fire management on public lands near their homes. Our hypothesis is that perceived fire danger and actual fire danger will have an affect on WTP for fire management approaches. Therefore, we are expecting WTP for fire management to be higher if their perceived fire danger and actual fire danger are relatively high.

Study area

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

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.

Methods

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

The survey

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

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

The survey encompassed eight pages of questions and two color pictures (ponderosa pine forest in Colorado one year after a low intensity prescribed burn and ponderosa pine forest in Colorado one year after a high intensity wildfire) that were inserted into the survey for use with some of the questions (Kaval 2004). While many of the questions in the survey related to WUI residents opinion of wildfire, this analysis concentrated on questions related to wildfire risk perception and WTP.

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.

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

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

Current wildfire management approaches vary by area but may typically include one or a combination of the following three approaches: prescribed fires, fuel reduction by thinning, and fire suppression. These are the three fire management approaches we used in our WTP questions. Prescribed fires, or controlled burns, are those fires that are set purposely in a designated area to remove underbrush and dead wood which reduces available fire fuel. The goal of fuel reduction is to reduce future wildfire intensity. While there are rare instances where prescribed fires may get out of control, most of the time they do not escape the pre-set boundaries. However, when prescribed burns do get out of control, they sometimes cause substantial damage and expense. These large out of control fires get in the media and hence, negative perceptions about prescribed burning may come about.

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

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

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

> Using (prescribed burning, fire prevention or fire suppression) public land management agencies could reduce the frequency of high intensity wildfires in the National Forests and/or National Parks in your area by half. Would you pay an increase of $X[5] a year more in taxes for a program such as this? (Circle One) Yes No

Spatial analysis

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

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

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

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.

100 meter perimeter and the third was the 1600 meter perimeter. The vegetative area information for these two zones would come from our vegetative map layer.

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

We then cross referenced data on heat release,[6] spread rate,[7] and flame length[8] for 18 Colorado vegetation types based on the Romme *et al.* (2001) study using GIS and Behave (a fire behavior model).

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

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

Spatial variable calculations

Spatial data layers enabled us to calculate new variables related to actual fire danger. The first variable we created was the distance to the closest fire. This task was completed with a proximity analysis by measuring the distance from the homepoint to the nearest edge of the closest wildfire. Note that none of the respondents homes had been in a wildfire. The closest

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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)"

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

home to a fire was approximately 2145 meters from the perimeter of the Bobcat Gulch Fire while the furthest from a home was approximately 83 200 meters.

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

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

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

Heat100 – Average heat release in the 100 meter buffer

Spread100 – Average spread potential in the 100 meter buffer

Flame100 – Average flame length in the 100 meter buffer

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

Avgheat - Weighted average of heat

Avgspread - Weighted average of spread

Avgflame - Weighted average of flame

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

The willingness-to-pay (WTP) model

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

We ran six logistic regression models[10] in total: the first three represented WTP with perceived fire risk and the last three represented WTP with both perceived and actual fire risk. The three WTP variables were: WTP for fire prevention or fuel reduction by thinning, WTP for fire suppression or initial attack, and WTP for prescribed fire. These three variables were coded with 1= "yes, they are WTP," and 0= "no, they are not WTP." The independent variables are: Bid, Danger, Freq, Firedist, Defspace, Heat100, Spread100, Flame100, Avgheat, Avgspread, Avgflame, and Slope (See Table 2 for exact definitions of each variable).

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

Results

General comparisons of perceived and actual wildfire risk

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

Using the spatial data, we were able to categorize levels of wildfire danger in the 100 meter and 1600 meter buffer zones (Table 3). Categories included none, low, moderate and high wildfire danger. For the vegetation in the 100 meter buffer zone, we find that 5% of respondents have no wildfire danger surrounding their home, at the same time, none of these respondents felt their home was in danger of wildfire. For the low wildfire danger category, 33% of homes fell in this category with 63% of respondents believing their home was in danger of wildfire. 40% of homes fell in the moderate wildfire danger category with 62% of respondents in this category feeling their home was in danger of wildfire. 22% of homes fell

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."

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

in the high wildfire danger category and 88% of respondents in this category felt their home was in danger of wildfire. This seems to show that people that do not have wildfire danger in the 100 meter defensible space zone surrounding their home are aware that they do not have wildfire danger. Most of the people that live in an area where the vegetation for the surrounding 100 meters is of a high wildfire potential also are aware of this danger. However, in the low wildfire danger strata, nearly two-thirds of households believed their home was in danger of wildfire.

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

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

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

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

Prior to running the perceived and actual wildfire risk models, we calculated the average WTP for the three fire management procedures with a simple logit model using only the variable bid amount. From this, it was found that fire prevention had an average WTP of

$599, fire suppression had an average WTP of $507 and prescribed burning had an average WTP of $655. These values represent a per-household fee to be paid annually in their taxes in perpetuity.

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

The first row in Table 4 represents fire prevention or fuel reduction by thinning. In this model we see that WTP is influenced by whether the respondent feels their home is in danger from wildfire. If they feel their home is in danger of wildfire, they have a higher WTP for fire prevention. By converting the coefficient into a WTP amount[12], we find that the respondent will increase their WTP for fire prevention by $338.25 annually if the respondent feels their home is in danger of wildfire. This value is an average per household value.

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

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

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

The next set of logistic regressions represents not only the perceived fire danger reported by the respondents, but also what we are calling the actual fire danger calculated by the spatial

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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).

models. Because different variables influenced the various fire management prescriptions, we will be presenting the best models from each of the management prescriptions. Logit results are presented in Table 5.

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

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

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

Discussion and Conclusions

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

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

We then compared perceived fire danger with the actual vegetative wildfire danger in the 1600 meter perimeter surrounding the home. When homes are in a zone of high wildfire danger, respondents are very knowledgeable (there were not any areas without fire danger in the 1600 meter calculations). In addition, people in the moderate wildfire danger areas also were knowledgeable that their homes were in danger of wildfire. Fewer people in low vegetative fire danger felt their homes were in danger of wildfire.

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

After perceived and actual wildfire risk comparisons were complete, we analyzed WTP for the three fire management approaches. Results show that respondents were willing-to-pay an annual amount in their taxes in perpetuity for the government to perform either prescribed fires, fire suppression (initial attack) or fire prevention (fuel reduction by thinning) on the public lands (in this study, public lands were typically National Forest or National

Park lands) surrounding their homes. This implies that fire management is important to our respondents.

More specifically, for the model considering WTP for fire prevention (fuel reduction by thinning) and perceived fire risk, we find that if respondents feel their home is in danger of wildfire, they will pay more ($338 annually in their taxes). If we include the spatial variables in our model, we find the explanatory power of the model increases and the significant variables change. First, we see that perceived fire danger is no longer significant and is now replaced by actual fire danger. If the home has defensible space created in the first priority zone (home edge to 30 meters), then the people in those homes are more likely to pay for fire prevention ($364). In addition, if the actual vegetative fire danger in the 100 meters surrounding the home increases, people are more willing-to-pay for fire prevention by $0.50 for each increase in BTU/ft^2 of heat. We believe this shows that people who are knowledgeable about the fire risk in the 100 meter zone surrounding the homes are the ones interested in creating defensible space. As stated previously, fire prevention is a manual fuel reduction technique. Clearing a defensible space is also a manual reduction process. Therefore, it seems logical that people interested in manual reduction are also interested in paying the government to do manual reduction on the public lands surrounding their home. Creating a defensible space around a home takes a great deal of time and effort. For these people, protecting their homes and paying for fire management in the surrounding area is important.

Fire suppression, or initial attack, suggests that once a fire has started, it is put out immediately, typically before it has a chance to spread. This approach is costly because it requires a great deal of manpower; people need to be standing by and ready for action when wildfires start. With the base model we found similar results to those for fire prevention, that is, if they felt their home was in danger of a wildfire, they would pay more ($586 more). When adding in the spatial variables, the explanatory power of the model increases substantially and we find that if the calculated fire danger in the 1600 meter buffer zone increases, the respondent is more WTP for fire suppression by $2.67 for each increase in BTU/ft^2 of heat. Again, perceived fire danger has become insignificant.

The final fire management approach we looked at was prescribed fires on public lands near the respondents home. Here we found that the respondents WTP increased by $12.67 per year of perceived increased fire frequency. Therefore, a person that thought high intensity wildfires occurred every 5 years near their home would have a higher WTP for prescribed fires than if they believed the high intensity wildfires occurred in their area only once every

50 years. When we added spatial variables to the prescribed fire model, the explanatory power of the model increased only slightly, however, the results remained similar – their WTP increased with their perception of high intensity wildfire frequency ($13 per year of increased fire frequency).

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

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

We believe our study shows that a persons perception of the risk of wildfire danger increases their WTP for fire management. Respondents were WTP for all three approaches whether we included perceived or spatial risk variables. Therefore, these findings should be useful in identifying which households within the WUI would pay for the three different wildfire management approaches presented in this paper. We believe that these results also imply that the government could start charging a wildfire management fee to people living in the WUI. This fee could lessen the burden of wildfire management that is currently placed across all taxpayers.

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

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Table 1. Fire Danger Statistics.

Vegetation type	Average flame length	Average spread rate	Average heat release
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.

Variable Name	Variable Description	Expected Coefficient Sign
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	+
Avgspread	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.

	100 Meter Buffer Zone		1600 Meter Buffer Zone	
Calculated Vegetative Fire Danger	Percentage of Homes	Percentage of People in the Vegetative Zone that Felt Their Home Was in Danger of Wildfire	Percentage of Homes	Percentage of People in the Vegetative Zone that Felt Their Home Was in Danger of Wildfire
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).

WTP	C	Bid	Danger	Freq
1. WTP for Fire Prevention (P-Values) *McFadden R^2 = 0.223*	0.945 (0.134)	**-0.004** (0.044)	**1.353** (0.044)	-0.018 (0.240)
2. WTP for Fire Suppression (P-Values) *McFadden R^2 = 0.118*	0.251 (0.665)	**-0.002** (0.099)	**1.173** (0.055)	-0.007 (0.646)
3. WTP for Prescribed Fire (P-Values) *McFadden R^2 = 0.165*	**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).

WTP	C	Bid	Danger	Freq	Defspace	Heat100	AvgHeat
4. Fire Prevention (P-Values) *McFadden R^2 = 0.285*	-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) *McFadden R^2 = 0.195*	**-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) *McFadden R^2 = 0.176*	0.829 (0.478)	**-0.003** (0.058)	-0.402 (0.599)	**-0.039** (0.062)	0.364 (0.575)		0.002 (0.437)

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