WILDFIRE HAZARD AND EGRESS POTENTIAL

IN CENTRAL TEXAS NEIGHBORHOODS

THESIS

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Jordan Ryan Stewart, B.A.

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CHAPTER I

INTRODUCTION

Wildfire is a common hazard in areas where urbanization encroaches on undeveloped landscapes. Populations at risk in these environments may face the need to evacuate quickly, especially if their homes are not suitable for shelter in a fire event. With some suburban designs, the morphology of the neighborhood complicates egress. Traffic bottlenecks during last-minute evacuations have proven deadly in the wildland-urban interface (WUI), or on the urban periphery (UP). Some subdivisions have residents of hundreds of homes relying on only one or two exits (Wolshon and Marchive, 2007), requiring many evacuees to travel long distances to escape from their neighborhoods.

Limited egress exists in many subdivisions in the Balcones Canyonlands in and around the city of Austin, Texas. The region's population is growing rapidly and the regulatory climate of the state is generally favorable to development (Vaughan, 2009). Urban development in this region has expanded into slope-intensive, drought- and fire-prone "wildland" areas with limited road infrastructure and plentiful biomass for wildfire fuel. To manage this problem, the City of Austin has identified high risk zones for UP fires (City of Austin, 2008).

This research poses the following question: How hazardous are subdivisions, in terms of egress, in high-hazard wildfire areas of Austin?

To answer this, the circumstances are examined on three fronts. First, a neighborhood–by-neighborhood analysis using seven egress capacity tests inspired by the similarity of automobile-oriented wildfire evacuations to building-fire evacuations (Cova, 2005) rates the landscape of hazard. Second, the morphology (derivative of the age of the development) of subdivisions in the study area is examined as impediments to egress. Third, a GIS network analysis is conducted to egress bottlenecks in the neighborhoods that score the highest and lowest on the egress tests." This study contributes to the scholarship by examining a cross-section of subdivision designs to compare different types of UP neighborhoods with similar levels of wildfire hazard. Bottleneck analysis addresses a research gap on WUI/UP-subdivision evacuations and helps visualize the evacuation hazard in the most egress-deficient neighborhoods in Austin, Texas. It also helps to stress the importance of meeting the occupancy/egress standards.

CHAPTER II

BACKGROUND AND REVIEW OF LITERATURE

Wildfire as Hazard

Wildfires have occurred naturally the world over for millennia. Spatially extensive fire events burn millions of acres and threaten thousands of lives and a great amount of property in the WUI each year (Radeloff et al. 2005). Scholars attribute many civilian casualties from these fires to the inability of residents to safely and quickly evacuate (Church and Sexton, 2002; Cova and Johnson, 2002; Cova, 2005; Wolshon and Marchive, 2007; Cal Fire 2007). Other victims have perished trying to defend their homes from flames (Cal Fire, 2007). Thousands of WUI neighborhoods in the United States exist along road networks designed for rural-activity (Church and Sexton, 2002; Cova, 2005). Studies have examined the role that subdivision design plays in evacuation efficiency in fire-prone areas. Only limited research has considered the interaction of neighborhood structure, housing density and egress capacity to achieve efficient evacuation design of a subdivision (Church and Sexton, 2002; Cova, 2005; Wolshon and Marchive, 2007). This study will explore the application of "maximum occupancy" standards to fire-prone neighborhood to assess neighborhoods' vulnerabilities during emergency evacuation and to evaluate the influence of the conditions of place on subdivision egress.

WUI/UP Hazards

The WUI is simply the boundary between human settlement and wilderness (Liu et al. 2003). The term describes the area where the outer edge of development meets or mixes with areas in which natural processes are more dominant on the landscape. WUI commonly describes a zone of exposure to hazards (Cova and Johnson, 2002). This zone involves three principal elements: people, natural vegetation (or natural ecosystems), and the proximity of each element to another, which enhances the potential for one to influence the other (Stewart, 2007)

In some regions, such as in Central Texas, the WUI can be difficult to discern not only because of the complex pattern of urban "leapfrog" development and rural conditions throughout the region's landscape but also because the majority of less-developed land is privately owned and has been altered by ranching and other economic activities. Describing the less urbanized areas around Austin as "wildland" is thus less appropriate than a more abstract UP. Discerning a distinct boundary between urban and rural land uses in the region is difficult. Both WUI and UP describe the urban fringe, where hazards like large-scale fires are a concern (Figure 1); the former, however, is more appropriate for the boundary between urban development and "wilderness" space such as locations associated with settlements around National Forest land in the western United States.

Rural-urban interaction is greatest just beyond the contiguous urban area (Young, 1990). However, the urban boundary is difficult to delineate, especially

Figure 1. UP Home in Austin above the Balcones Canyonlands.

in terms of hazards (Stewart et al., 2007). For example: a study of wildfire risk perception in Edmonton, Alberta distributed questionnaires to homes within only 50 meters of the urban fringe even though it is clear that fires can threaten a much wider zone (McGee, 2007, Stewart et al., 2007). Radeloff et al. (2005) attempted to define the boundary using housing density and land-cover type at the census-block scale. Because WUI is an abstract space, the number of homes identified in some studies as present in the WUI, does not always match the total number that is in the WUI. There has been a lack of focus on the effects of the mix of urban and rural environments; areas with more dispersed development and a clear urban/rural interface are hard to identify (Cohen, 2000). Theobald and Romme (2007) have attempted to develop methods to predict expansion of the UP as the capacity to anticipate the zone of interface could help with land use planning and emergency management. Their work employed census block-scale housing-density data to identify these areas. The accuracy of projected development cannot, however, be guaranteed as the "projections" are based on forecasted rates of housing development and rely on a number of intervening factors (a deficiency also noted in Stewart (2003) and Radeloff et al. (2005)). Research into residential density patterns in the WUI has been limited. Hammer et al. (2003) employed land-cover maps to classify residential density zones and delineated the UP by emphasizing the region of the most dynamic aspects of human-induced landscape change.

Factors in UP Expansion

Sprawl often "leap-frogs" outward from the urban fringe, with infill development occurring later (Robinson et al., 2005). This characterizes the development history of the Balcones Escarpment region (City of Austin, 2003; Vaughan, 2009). Ninety-five percent of U.S. population growth from 1970-1990 was in suburban areas (Gillham, 2002). The rise of cultural preferences for living “out in the country” and “close to nature” provide much of the rationale behind demand for suburban and exurban homes (Crump, 2003; Kaplan and Austin, 2004). Publicly perceived benefits of suburban living include access to recreation or to scenery and lower land costs (Cova, 2005). The exurban ideal includes a larger home on a large lot in a setting thought of by most to be rural. People who settle along the WUI tend to be of an anti-urban mindset, seeking to rescue themselves and their families from urban problems (Crump, 2003; Davis, 2006). However, low-density exurban development commits large tracts of open space to eventual urbanization (Carruthers and Vias, 2005). Exurban development covers more land-area than suburban development (Theobald, 2008). It also presents expensive challenges, and other residents often bear much of the cost (Sutton et al., 2006).

The highest concentrations of homes in the WUI are in the western and southwestern United States (Stewart et al., 2007). A “growth machine” ideology fuels the exaggerated outward expansion of many metropolitan areas into areas at higher risk for fire and other hazards such as mudslides, floods, and wild animals (Romig, 2004; Busenberg, 2004; Syphard et al. 2007; Wolshon and Marchive, 2007; Vaughan, 2009). Policy makers and conservation groups are reluctant to oppose much WUI development due to inherent political difficulties.

Politics complicates opposition and sprawl continues unabated even though many cities have ample undeveloped space within existing urban boundaries (Martien and Trojnar, 2001) (Figure 2). San Antonio, Texas is a classic example of a sprawling urban system whose urban morphology commonly leapfrogs over expansive tracks of sparsely developed private land so that development occurs in areas farther from the urban zone in areas that are marketed to exclusive markets (Cisneros, 1999; Vaughan, 2009).

Urban-Rural Boundary Dynamics in Central Texas

Western Travis County, Texas has undergone extensive residential development, especially within an area bordered by U.S. Highway 183 on the north, Ranch-to-Market Road (RM) 620 on the west, Texas Highway 71 on the South and Loop 1 (locally referred to as "MoPac") on the east. Within this zone, there are dozens of neighborhoods with high wildfire potential (as defined by the city of Austin (2008)). A sprawling exurban landscape is encroaching on the Balcones Canyonlands in patterns similar to the famously fire-prone hillside and canyon-land residential developments in Southern California. The area's development, topography, invasive vegetation and seasonal drought are also not unlike California's coastal chaparral region. Common characteristics of the most vulnerable neighborhoods are an elongated shape, high ratio of houses to exits (low potential egress), significant topographic relief and large undeveloped parcels of land adjacent to subdivisions.

Wildfire Hazard in Central Texas

Fire hazard is highest where urban areas encroach on more "natural"

Figure 2. “Leapfrog” Sprawl in Travis County, Texas.

wildland areas (Dennison and Cova, 2007). Many factors regularly enhance such hazards in the Balcones Canyonlands area of Texas Hill Country. The potential for drought conditions is especially high during the summer months (Figure 3) (Petersen, 2001; City of Austin, 2008). Relatively warm and dry weather periods occur in non-summer months, as was the case during the disastrous winter 2005-spring 2006 Texas fire season. Significant dry biomass is often present following wetter periods (Figure 4). The overall moisture content of fuel biomass is more critical to fire development than the amount of rain that has fallen in a given year, as live vegetation slows the progress of fires (Yool, 1985; City of Austin, 2008). Fires move more efficiently up slopes (Yool, 1985; Dennison and Cova, 2007), and this is particularly problematic in central Texas as many neighborhoods in the western part of the Austin area are built on top of ridges or on steep sides of hills and canyons (Figure 5). These homes often do not have a clear defensible space around them, which is likely to complicate firefighting response (City of Austin, 2008)

Wildfire is a natural part of the ecology of Central Texas (Figure 6). Rapid development, fire suppression and intensive grazing of ranch lands have interrupted this process, enabling the success of invasive species, such as the ashe juniper, which also alters the overall fire regime of the landscape (Nelle, 2001; Petersen, 2001). An abundance of juniper exists across the Balcones Canyonlands in nature preserves and on grazing lands that surround the suburban/exurban residential developments in the western part of the area (City of Austin, 2008). Junipers possess highly combustible foliage and burn

Figure 3. Arm of Lake Travis Depleted by Extreme Drought in July 2009.

Figure 4. Very Dry Vegetation in Mount Bonnell Park in July 2009.

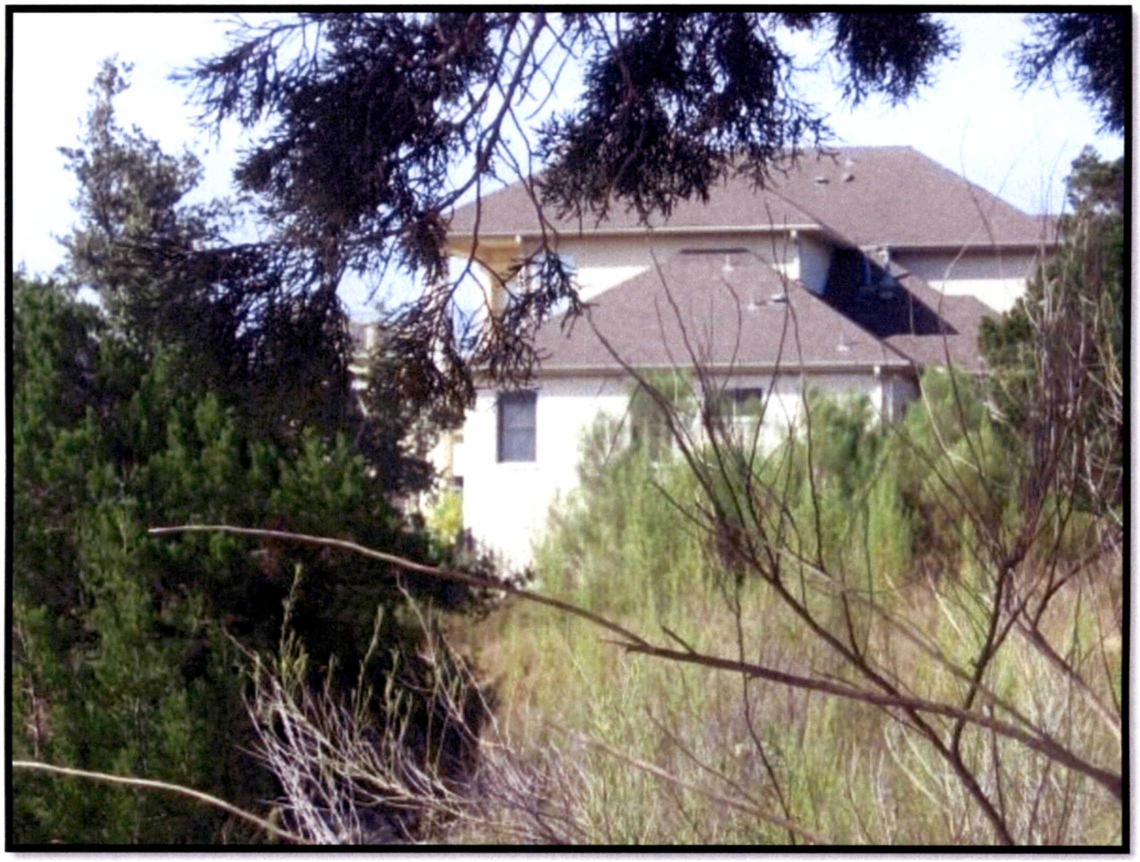

Figure 5. Home in Central Texas UP Surrounded by Dry Brushy Vegetation.

Figure 6. Sign Indicating Elevated Fire-Risk in a Travis County park.

quickly (Barnes et al., 2000, pg. 21). Thus, juniper-dominated landscapes may expose residential developments at greater peril.

Wildfire is a problem throughout Texas (City of Austin, 2008) (Figure 6). More than one million acres in the state burned during the 2005-2006 firestorms. These fires caused twelve deaths. Four occurred in a nine-car pileup in the northwestern part of the state and occurred due to reduced visibility due to smoke. These deaths also highlight the dangers associated with fleeing a fire at the last minute (Centers for Disease Control, 2006).

More recently, a fire ignited by downed power lines, and spread by strong dry winds behind a fast-moving cold front, quickly burned more than 1,500 acres and destroyed twenty-three homes in an exurban area about 40 miles to the east of Austin. Timely calls for evacuation by Bastrop County officials of the neighborhoods downwind of the fire helped to prevent deaths from the firestorm, despite an inactive emergency alert system (Austin American Statesman, 2008). This shows the importance of emergency officials' quick decision making and planning for successful evacuation.

A major reason for the unrelenting pace of residential development in the region is the scenery. Most of the study area is hilly; ridges and canyonlands provide scenic views from most streets and lots. Viewsheds in these developments promote construction of expensive homes (Vaughan, 2009), and many are built as residential islands (or "enclaves") in the sea of wooded lands to promote a marketable sense of exclusion (Romig, 2004). However, the steep slopes and topographic relief of the Balcones Canyonlands increase the fire hazard for its residents (City of Austin, 2008; Texas Forest Service, 2009). The Hill Country also possesses environmental limitations regarding protection of the Edwards Aquifer and water availability limits, particularly during periods of drought. However, environmental concerns have not led to an appreciable decline in the area's residential growth due to legal and structural limits to regulating suburban sprawl in Texas, especially beyond incorporated areas (Vaughan, 2009).

CHAPTER III

THE COMMUNITY EGRESS PROBLEM

Overview of UP Evacuation Issues

A neighborhood is likely to have an evacuation bottleneck if egress-demand overwhelms the transportation infrastructure. "Small area evacuations," such as in an exurban neighborhood threatened by fire, are particularly problematic (Church and Sexton, 2002). Researchers have examined neighborhoods only in a limited number of regions (Cova and Johnson, 2002; Cova, 2005). Suburban development in the context of the physical landscape of western Austin is enhancing the hazard there and the region is emerging as a UP-fire flashpoint (City of Austin, 2008).

Research Methods Applied to Community Evacuation

Scholars have examined the egress issue at a number of scales, from single neighborhoods to entire regions (Cova and Johnson, 2003). At the neighborhood scale, a useful method to determine egress potential is using maximum occupancy standards for buildings (Cova, 2005). Wolshon and Marchive (2007) employed transportation-flow models to determine neighborhood evacuation potential, modeling the relationship between traffic and road networks with a timed-egress model applied to specific neighborhoods. Community-level studies of evacuation triggers in wildfire-prone WUI communities provide another framework for this topic (Dennison and Cova, 2007). Chen and Zhan (2008) employed microscopic simulation (called Paramics) to examine egress dynamics among different theoretical road-structure patterns, and compared their theoretical results to the empirical results from a “real” road network in San Marcos, Texas (located 30 miles south of Austin). This agent-based model attempts to improve prediction of individual evacuation behavior. While this study does not focus on behavior, behavioral studies could benefit neighborhoods that would appear to be primed for evacuation problems by this research. Cova (2009) confronted the technical side of the evacuation problem with a behavioral solution by considering the feasibility of sheltering–in-place (SIP) as an alternative to evacuating. The maximum-occupancy criteria developed by Cova (2005) enable a portion of this study.

I do not specifically attempt to examine individual decision-making relating to evacuation (e.g., whether to stay or go). Instead, I synthesize a method for comparing neighborhoods to identify those types that are most problematic for evacuation. The benefits of evacuation management research, such as that conducted on lane-based modeling (Cova and Johnson, 2003), will be even greater when the most problematic neighborhoods are identified. The neighborhoods found to have evacuation problems could then be targeted with research that examines questions of evacuation vs. SIP, the notion of “defensible-space”, and employing individual evacuation modeling when full-scale evacuation is not the most prudent option.

Wildfire Evacuation Decision-Making

Scholars have debated the question of "to stay or to go" in a UP-fire event. Protecting developments by creating buffer zones and designing subdivisions with fire regimes in mind is one step, but property owners can make their homes less vulnerable to fires on an individual basis (Cohen, 2000; Keeley et al., 2004 Bright and Burtz, 2006). In the context of mandatory and well-enforced home-fire prevention efforts, whether residents should be told to “prepare, stay and defend” their homes rather than evacuate has been explored. This is a common brushfire policy in Australia, for instance (Handmer and Tibbits, 2005). The last-minute nature of evacuations can have unintended consequences for the evacuees as well (Church and Sexton, 2002; Busenburg, 2004; Cova, 2005; Bright and Burtz, 2006; Dennison, 2007; Wolshon and Marchive, 2007). Eleven deaths occurred as WUI residents tried to flee the 2003 Cedar Fire in San Diego County, California (Barnes, 2004; Cal Fire, 2007) and more than twice as many lost their lives trying to flee the Oakland Hills, California Fire in 1991 (Church and Sexton, 2002). The evacuation process can be the most dangerous undertaking during a fast-moving fire (Cova 2005; Cal Fire, 2007; Wolshon and Marchive, 2007). Evacuation procedures and planning can greatly decrease evacuation-related dangers (Cal Fire, 2007). A successful prepare-stay-and-defend policy requires that all homes must be defensible safe-havens. SIP is simply not an option for m any homes along the WUI (Cohen, 2000; Handmer and Tibbits, 2005). However, having SIP as a fall-back plan, particularly in WUI neighborhoods with a high potential for egress congestion, is gaining support among scholars (Cova, 2009).

SIP is most feasible when homes and neighborhoods have "defensible space". The decision to stay or go is one to make cautiously in subdivisions that lack fire-safe elements. Furthermore, SIP requires extensive education of civilians who will likely not have experienced extreme fire conditions before making stay-or-go decisions (Cova et al., 2009).

North American property owners do not universally support proposals to require defensible-space in WUI neighborhoods. Property-rights concerns increase reluctance to accept them (Bright and Burtz, 2006; Mckee, 2007). Experience with fire can affect public perceptions of fire-prevention measures and decisions to evacuate (Jacobson et al., 2007). The improvement of evacuation procedures is an argument against the establishment of an exclusively prepare-stay-and-defend policy (Dennison et al., 2008). However, enforcement of defensible-space policy will be paramount if SIP is to be a viable option (Cova et al., 2009).

Research on neighborhood exits demonstrates that adding a single exit can greatly reduce the time needed to evacuate a subdivision (Cova and Johnson, 2005), and examines larger and more complex development patterns and their potential effect on evacuations (Wolshon and Marchive, 2007). Modeling software tools cannot predict individual choices involving route choice and lane changes (Cova and Johnson, 2002). Hazard-response planning within neighborhoods beyond defensible space and egress requirements is difficult and there is essentially no advantage to ordering staged evacuations in isolated neighborhoods to evacuate one section at a time (Chen and Zhan, 2008). In addition, beyond the challenge of estimating behavioral elements of individual evacuation decisions (Wolshon and Marchive, 2007), there are dynamic and hard-to-predict features of subdivisions themselves that affect the level of hazard within neighborhoods (Cova, 2009). Exits do not guarantee secure egress at all times because wildfire or bottlenecks that form within subdivisions can block them (Church and Sexton, 2002). There is a need for more study of the proper spacing of subdivision exits, conceptually similar to determining the optimal design for emergency exits from buildings. There are potential benefits to studying the application of these methods in regions with different fire regimes (Cova, 2005).

Building Evacuations Compared to Neighborhood Automobile Egress

Determining the maximum capacity for a room or a building is relatively simple. However, devising a method to measure these factors across different buildings is less easy, as structures vary in design and use (Coté and Harrington, 2003). Similarly, urban areas and neighborhoods are not uniform. The number of road exits also restricts people evacuating suburban or exurban neighborhoods, just as egress for building occupants is limited in building fires (Cova 2005; Wolshon and Marchive, 2007). Community egress codes exist, but do not link neighborhood population to minimum egress, road capacity, or exit spacing. Improved standards to address growth in fire-prone areas with infrastructural limitations are needed (Cova, 2005).

Road exits in car-dependent neighborhoods vary in size and egress capacity just as building exits do. Egress flow in buildings is restricted to certain exit pathways, varies in efficiency according to the width of those pathways, and is prone to interior bottlenecks within the building (Chalmet et al., 1982). A major difference, however, is that buildings often have uniform evacuation warning systems (e.g., a standard fire alarm), whereas the egress trigger for housing developments can vary dramatically (Cova, 2005).

Exit Capacity, Spacing and Safety Issues

As with zones of mixed land uses, some neighborhoods exhibit characteristics of both suburban and exurban areas. For example, some neighborhoods have lots that exceed an acre in size. This home spacing means that there is more road space available to handle evacuation traffic. However, this does nothing to alleviate another egress concern; are the exits optimally spaced to reduce evacuation problems? A neighborhood with more than 50 homes and a single exit is categorically vulnerable and adding one exit (identical to the existing exit) would substantially raise egress capacity (Cova, 2005). The impact of doing this however, depends upon the spacing of the exits.

For effective egress, exits should be spaced with a distance of at least 1/n (where n = total number of exits) of the maximum diagonal distance within the subdivision (Cova, 2005). Two closely spaced exits are not much better than one if they are both blocked or impeded. Furthermore, egress bottlenecks are less likely to occur if exit points are nearer to opposite ends of a neighborhood. Moreover, clearing vegetation within 30 meters of each exit will reduce the chance that fire will block them.

CHAPTER IV

STUDY AREA

Overview of Study Area

The wildfire hazard and evacuation capacities of fourteen neighborhoods along and near the Ranch-To-Market Road 2222 (RM 2222), in and northwest of Austin, Texas are studied (Table 1). One of these neighborhoods, Jester Estates, is larger than the others and includes two smaller units for analysis (Figure 9).

Study Area and Neighborhood Selection

The study area possesses a cross-sectional corridor that provides a convenience sample including neighborhoods built during different eras of development. These subdivisions were built under an array of different standards and planning philosophies (Vaughan, 2009), while containing enough distinct limited-egress and a mixture of urban and rural land uses to produce a compelling sample. This research only involves Subdivisions disconnected from the core Austin street grid. Neighborhoods employing the city grid pattern do not have the same egress issues (and they are not in the UP) (Cova, 2005), therefore urban neighborhoods do not serve as a useful comparison to the neighborhoods in the urban-rural interface. A line (denoted as "the northwest Austin urban-intermix boundary") that distinguishes contiguous built-up urban northwest Austin from the city edge was delineated based on the street grid.

Table 1. Neighborhoods in Study Area.

Neighborhood	Homes	Neighborhood	Homes
1 Canyon Creek	862	8. Jester Point	387
2 Comanche Trail	180	9. Long Canyon	316
3. The Courtyard	301	10. Mount Bonnell	281
4. Glenlake	173	11. The Parke	289
5 Great Hills	435	12. River Place	976
6 Jester Estates	1396	13 Steiner Ranch	1655
7. Canyon Ridge	543	14 Westminster Glen	167
		N=	7961

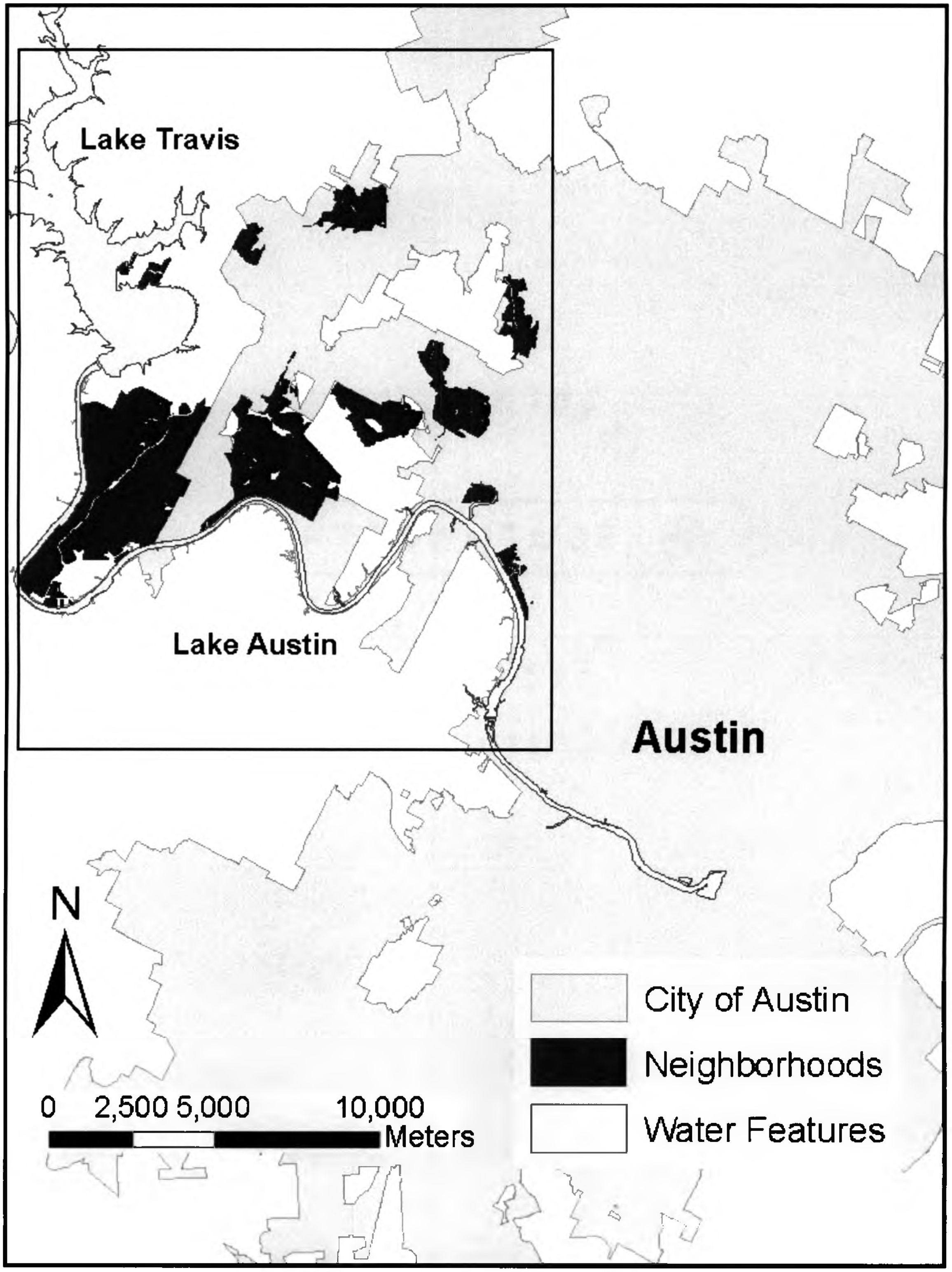

Figure 7. Study Area and Neighborhoods.

and reflects the scholarly definitions of the WUI/UP (Cohen, 2000; Cova and Johnson, 2002; Crump, 2003; Hammer et. al., 2003; Liu et. al. 2003; Stewart, 2003; Busenberg, 2004; Cova, 2005; Radeloff et. al, 2005; Robinson et. al, 2005; Romig, 2004; Sutton et. al, 2006; Stewart, 2007; Syphard et. al 2007; Wolshon and Marchive, 2007).

For comparison, the study focuses on subdivisions with populations large enough to potentially create emergency egress concerns (Cova, 2005). No neighborhoods with fewer than 100 homes examined. This study exposes trends in neighborhood egress capacity, as well as provides a snapshot of the impact of suburban sprawl on the fire hazard in this region.

Each neighborhood is located in an area at high-risk for wildfire (City of Austin, 2008) (Figure 10). The northwest Austin urban-intermix boundary (described above) borders the study area on the north and east by the northwest, with Lake Austin/Lake Travis forming south and west boundaries (Colorado River) and Ranch-to-Market Road 2769 (RM 2769) as the northern boundary (Figure 10). The following are examples of neighborhoods within the study area:

- Long Canyon – a sprawling lower-density neighborhood with exurban characteristics located in an extreme fire-risk area near RM 2222, and has a single egress point.
- Canyon Creek – this neighborhood has more than 1,000 middle- to upper-middle-class homes with three exits. The two northern exits are very closely spaced and a long, looping arterial (Boulder Dr.) is the primary means of egress for both the northern and southern parts of the

neighborhood) located in a high risk WUI area off RM-620 just west of the Lakeline area

- Mt. Bonnell – a neighborhood much closer to the center of Austin than the others in the study area, nestled on a steep grade along and above Lake Austin, narrowly developed and surrounded by ample parkland and a nature preserve and possessing two egress points (one at the north end and one at the south, with Mt. Bonnell Dr., a narrow, winding, two-lane road with steep grades and multiple switchbacks providing both egress points
- Steiner Ranch – A very large (compared to nearby developments), relatively new, sprawling development with two exits onto a highway (RM-620); typical example of recent Hill Country development

Housing developments in the study area are elongated and smaller streets leading to a few small roads that feed onto larger roads and highways. They exist in UP in areas classified as "high" fire-danger zones by the Austin Fire Department (AFD, 2008) (Figure 8). They are classic "leap frog" developments. Lightly developed tracts of land tend to surround most of the neighborhoods in this area, and most are on steeply sloping high fire-risk terrain (City of Austin, 2008). Some developments overlap the boundary between the city limits of Austin, and are partially located in Austin's extra-territorial jurisdiction (ETJ). This further complicates emergency response, as the Austin Fire Department does not directly supervise some areas, although the department has entered into an agreement with Travis County to assist firefighting in ETJ (Figure 11). A weakly cohesive fire response (among fire departments) complicated emergency response in similar WUI subdivisions in San Diego County, California in 2003 (Cal Fire, 2007).

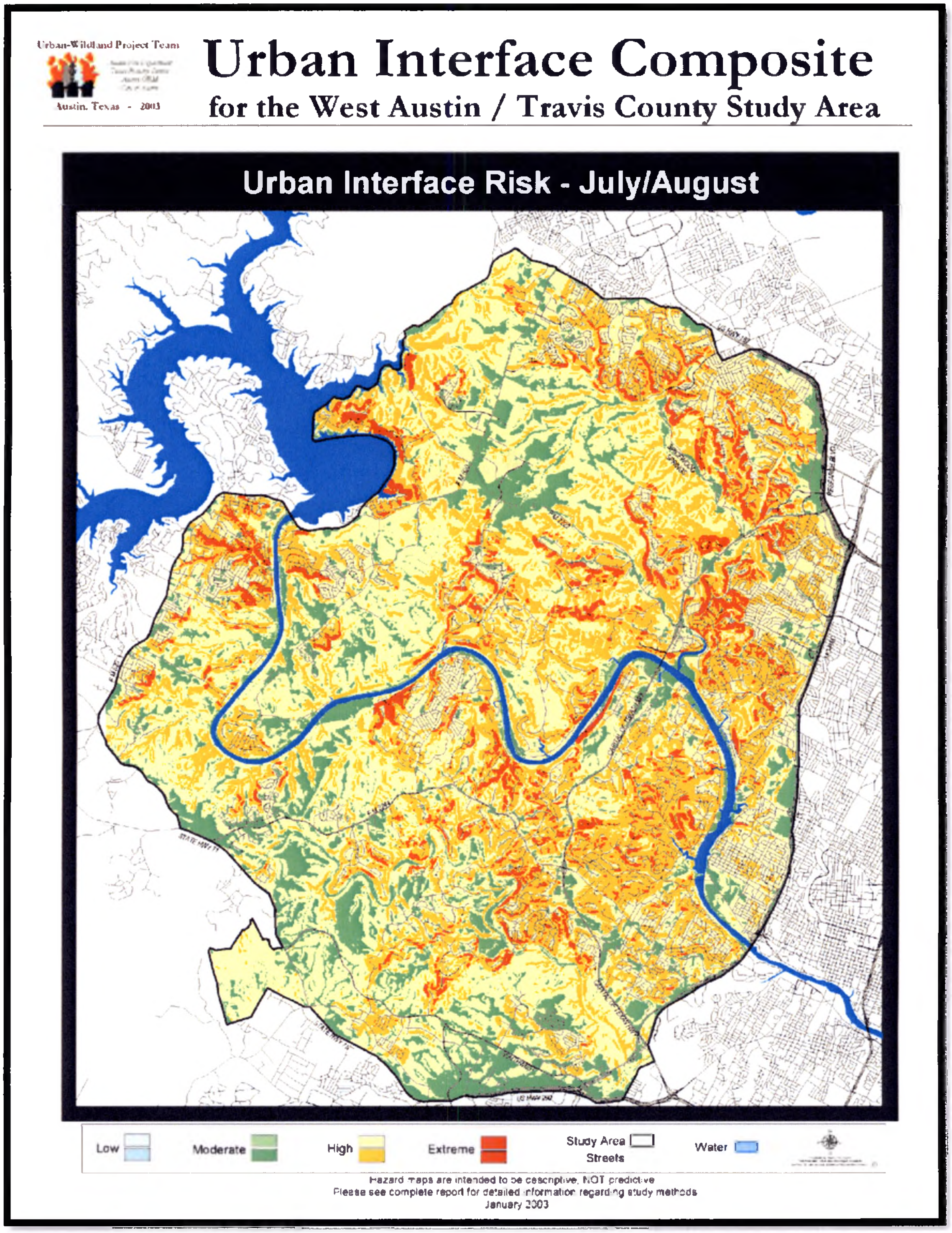

Figure 8. Area Fire-Hazard Level Composite (City of Austin, 2008).

Figure 9. Slope in the UP near Austin, Texas.

CHAPTER V

METHODOLOGY

Overview

The evacuation compliance assessment of the study area employs seven categories including the ratio of households to road length in meters, the number of vehicles per hour (VPH) egress capacity, the potential egress demand after full neighborhood development, the total number of exits, the VPH capacity with the addition of a new exit, exit spacing, and vegetation clearance (Table 2). This assessment enables categorization of sampled neighborhoods according to their relative hazardousness.

Neighborhoods with lower household-to-road (or driveway-to-road) density have less road-space for exiting vehicles, which can exacerbate egress problems. Additionally, neighborhoods with higher fire risk will need lower household-to-road densities to enable rapid mass evacuation. An adequate "load factor" for high-risk subdivisions is a minimum of 20 m per household (Cova, 2005). This standard will be the compliance factor for this study. A neighborhood's road grid is the only space vehicle (and their passengers) can reasonably use in an evacuation. An appropriate minimum egress interval in a high-risk community is 30 minutes (Church and Sexton, 2002; Cova, 2005). A community with 100 homes would require a capacity of at least 400 VPH to allow residents of the 100 homes (with two cars each) to escape in a half-hour or less (Cova, 2005). To calculate this, Cova (2005), using equation 8-3 of the 1997 Highway Capacity Manual (Transportation Research Board, 1997), demonstrates that a single-egress point must have a capacity of approximately 800 VPH. Additionally, a second assessment of VPH-load versus neighborhood capacity measures the egress demand that will exist in a built-out neighborhood. A standard number of exits needed for the number of homes in a neighborhood (Cova, 2005) rewards neighborhoods that have the highest egress capacity. Even if a single-exit neighborhood is not above its population-evacuation capacity, there is still the potential for blockage of the only egress route by wildfire.

An understanding of compliance with community egress standards requires a comparison of projected total egress demand and actual capacity, but egress points must be effectively spaced. This enables a determination of how far beyond the safe egress capacity non-compliant subdivisions are. Determining the potential for a safe mass evacuation involves measuring the distance between exits in each neighborhood (Figure 10). A vegetation clearance must exist within 30 meters of all exits in order for full compliance with egress tests.

<u>Neighborhood Age and Egress Potential</u>

The number of exits (or even the number of homes per exit) is not the only factor that determines whether significant evacuation hazards exist. This study aims to develop a method for comparing newer and older neighborhoods, as well as those that vary in size and morphology, in the same region. Comparing egress-compliance results to the age of each neighborhood shows whether

Table 2. Neighborhood Egress Test Methods.

Egress Test Category	Method of Assessment	Standard for Safe-Egress Compliance	Key Factors in Egress Flow
Road density	The number of homes divided by total road length in meters	Road density no greater than 20 meters per household	A higher value provides increased space for egress
Egress capacity in vehicles per hour (VPH) versus existing demand	VPH potential egress demand (4 per household) versus existing VPH egress capacity (800 per exit)	Existing egress capacity greater than or equal to potential egress demand.	Test of "maximum occupancy" modeled after building evacuation standards.
Egress capacity versus demand after build-out	VPH demand versus capacity if homes are added to empty lots	Existing egress capacity greater than or equal to demand.	Determines effect that a full build-out could have on egress
Total number of Exits	A standard involving number of exits required based on the number of homes	Number of exits equal or above the standard based on occupancy	A test that accounts for the added hazard of limited exit options
Egress capacity with an additional exit	VPH demand versus capacity if a new exit is added	Capacity with an additional exit greater than or equal to demand	Highlights greatest egress hazard
Exit spacing	Linear directional distance (meters) between exits, compared with the standard	Exit spacing greater than 1/n (n= exits) of the length of the neighborhood	Improperly spaced exits are more easily blocked by wildfire
Exit Buffer	Is there a vegetation clearance buffer on all sides of egress points?	A vegetation clearance must exist within 30 meters of exit points	Clearance reduces potential for wildfire to block an exit route

Figure 10. Exit Spacing Buffer Example.

community egress has improved or diminished over time, using plat data collected from the Travis County Appraisal District (TCAD). The date of the first platted section of a neighborhood establishes it's "age" and determines the era in which the neighborhood's planning and morphology originated. The date of the most recently platted section identifies the potential for further neighborhood expansion.

Analysis of Interior Bottlenecks in Selected Neighborhoods

Post-wildfire hazard research finds that bottlenecks, or extended traffic queues, are a danger to emergency egress in suburban and exurban landscapes (Cal Fire, 2007). The role of interior bottlenecks in WUI evacuations needs close examination (Cova, 2005). It is difficult to predict driver decisions during evacuations, and responses to bottlenecks increase the complexity of behaviors, so familiarity of residents with route distance from their homes to the nearest exit.

Emergency responders cannot assist all fire-threatened neighborhoods during evacuations. Identification of the most-hazardous neighborhoods and bottlenecks allows for better emergency evacuation planning. Localized egress vulnerability also highlights how neighborhood fire-safe/emergency councils could enhance readiness and protective action, so that they are not solely reliant on fire crews who can be overwhelmed by large fires (Cal Fire, 2007).

I employ GIS interior-bottleneck network analysis using the Closest Facility Analysis (CFA) tool in the Network Analysis extension of ArcGIS to examine a street-network built using data provided by the City of Austin. I create Nearest-neighbor analysis and evacuation paths with these data. Within this network, the lots on which homes have been built are selected to identify start points for each concurrent “incident,” thus can be created a path to the “closest facility,” or in this case, the egress points of the neighborhood. To make this work, each lot converts to a single point (located at the centroid point of each lot). A manual repositioning of a few outlying points ensures better accuracy, so that egress projections follow correct navigable routes and does not skew the closest-facility egress results.

The Network Analysis tool displays each route and its destination (the closest exit to the points of origin). It is difficult, however, to add them together and display their accumulated impact on a traffic-density map. Therefore, a new category (called rank) exists in the attribute table. Before the closest-facility results are analyzed, Exporting a new data layer that is “intersected” (using ArcToolbox) with the original street file takes place before analyzing closest facility results. Segment selection on the street network now highlights all closest-facility routes passing that point. Because the CFA creates a specific route from each house, segments divide whenever a route intersects with the street network. With the exception of dead ends and cul-de-sacs, the number of sections on each street is nearly as great as the number of homes in the subdivision. This makes the individual selection (and data entry into the rank category) of each segment methodical and time-consuming in the case of large neighborhoods like Jester Estates. However, this detailed, manual analysis is crucial for creating an accurate description of egress flow from a subdivision under optimal conditions, and it is a particularly effective tool for exposing bottlenecks in a clear visual fashion.

CHAPTER VI

RESULTS

Would study area residents be able to evacuate safely and efficiently from their neighborhoods in the event of a rapidly approaching wildfire? The occupancy capacity of each neighborhood benefits from consideration of the role that age and morphology play in egress challenges, and by in-depth analysis of interior bottlenecks in selected neighborhoods. The egress tests and temporal analyses allow comparison of egress among all neighborhoods. GIS egress bottleneck analysis in Westminster Glen and Jester Estates (which received the highest and lowest egress test scores respectively) visualizes the egress problems that result from non-compliance with standards set forth in this research, and the lack of problems in neighborhoods with sufficient means of egress.

Neighborhood 1: Canyon Creek

The Canyon Creek development is within the city limits of Austin (Figure 11). All of streets in the neighborhood feed onto Boulder Drive, a two-lane arterial linking RM-620 to the subdivision. The lower two-thirds of the development are in the UP area and serve as the neighborhood in question. Over 860 homes in this section rely on Boulder Dr. to exit the neighborhood. To the west, south and east, undeveloped juniper-dominated Hill Country brush land abuts Canyon

Table 3. Comparison of Overall Egress Test Results among Neighborhoods.

Neighborhood	Total Points	Road Density	Egress Demand	Build-Out Demand	Number of Exits	Additional Exit	Exit Distance	Fuel Buffer
Canyon Creek	3	Y	N	N	N	N	Y	Y
Comanche Tr.	3	Y	Y	N	N	Y	N	N
Courtyard	6	N	Y	Y	Y	Y	Y	Y
Glenlake	6	Y	Y	Y	Y	Y	Y	N
Great Hills	2	N	N	N	N	Y	Y	N
Jester Estates	0	N	N	N	N	N	N	N
Canyon Ridge	2	N	N	N	N	Y	N	Y
Jester Point	2	N	N	N	N	Y	N	Y
Long Canyon	2	Y	N	N	N	Y	N	N
Mt. Bonnell	6	Y	Y	Y	Y	Y	Y	N
The Parke	5	Y	Y	Y	N	Y	N	Y
River Place	3	Y	N	N	N	N	Y	Y
Steiner Ranch	2	Y	N	N	N	N	N	Y
Westminster Glen	7	Y	Y	Y	Y	Y	Y	Y

Creek (Figure 12.); it is a classic UP subdivision. The semi-circular shape of Boulder Dr. is an advantage for evacuation as it allows for spatial separation between exits. It is not the spacing of these exits that presents a problem, but the egress capacity of the subdivision. There is a large difference in egress VPH demand (3448) and egress capacity (1600). According to the results, it would take Canyon Creek residents twice as long as the minimum recommended time to evacuate if threatened by a wildfire event, as the subdivision is clearly above the capacity allowed by the exits. Even if a third exit were constructed, the neighborhood's egress capacity would still be low. In addition to the excess occupancy already present, the potential development 217 empty lots may increase future egress demand.

There are two areas where Canyon Creek does meet egress compliance standards. Despite the housing density, the 20.1 meters of road per house is above the standard (20 m per house). In addition, it passes the fuel buffer test as satisfactory vegetation clearance exists at the exits (Figure 13).

Neighborhood 2: Comanche Trail

Comanche Trail is the subdivision in the study that is most distant from Austin's continuously urbanized area. The egress problem here is the single long exit road (Figure 14) that winds through an environment of high fire potential (Figure 15). The neighborhood is a mix of older lakeside houses and newer, larger, more expensive homes sitting on top of hills with panoramic vistas and steep slopes and providing a view of Lake Travis (Figure 16). The egress route is compliant with egress potential standards. A single exit is still a problem because, if

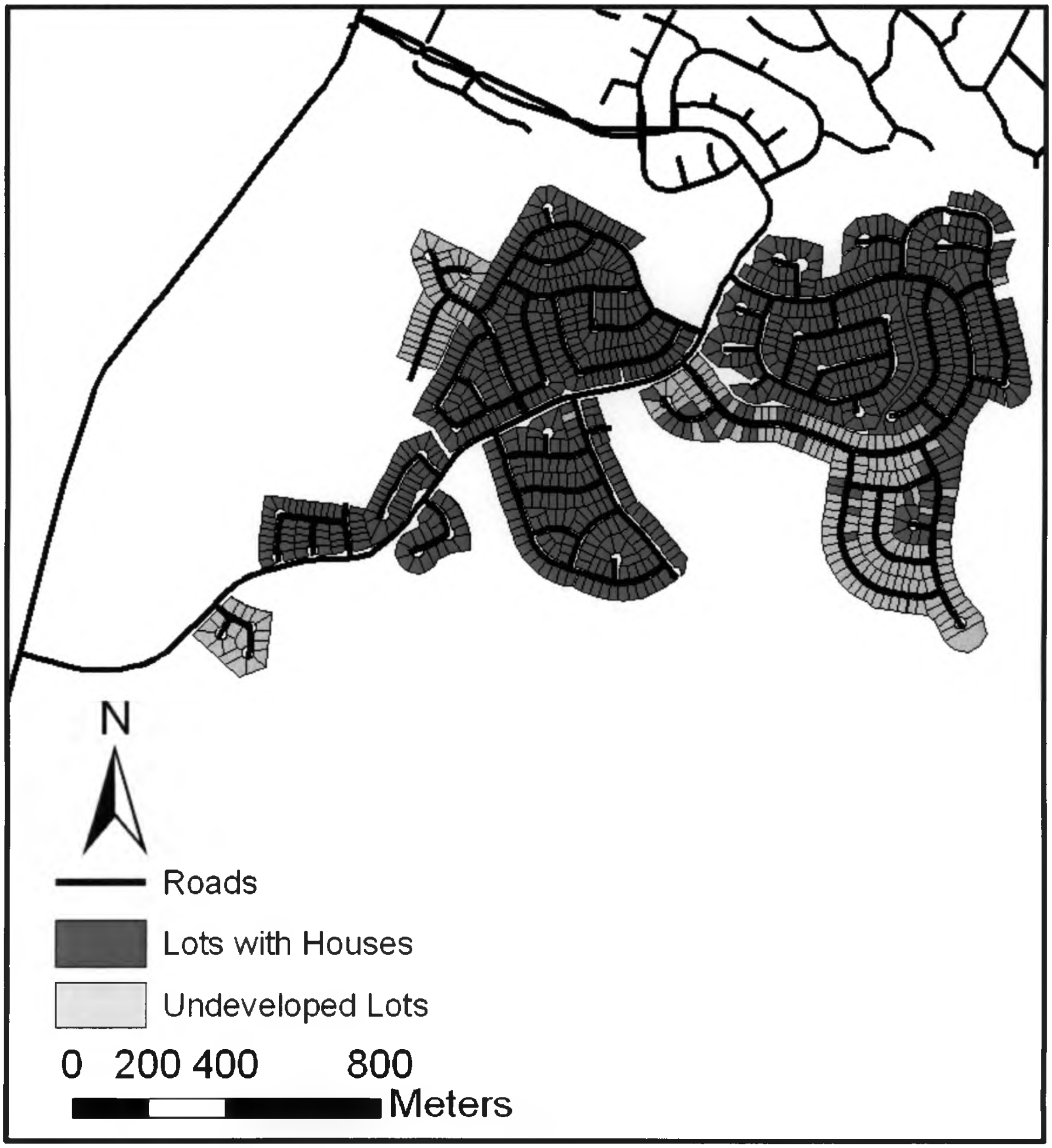

Figure 11. Canyon Creek.

Figure 12. Boulder Dr. in Canyon Creek.

Figure 13. Dry Vegetation near the South Egress Point at RM-620.

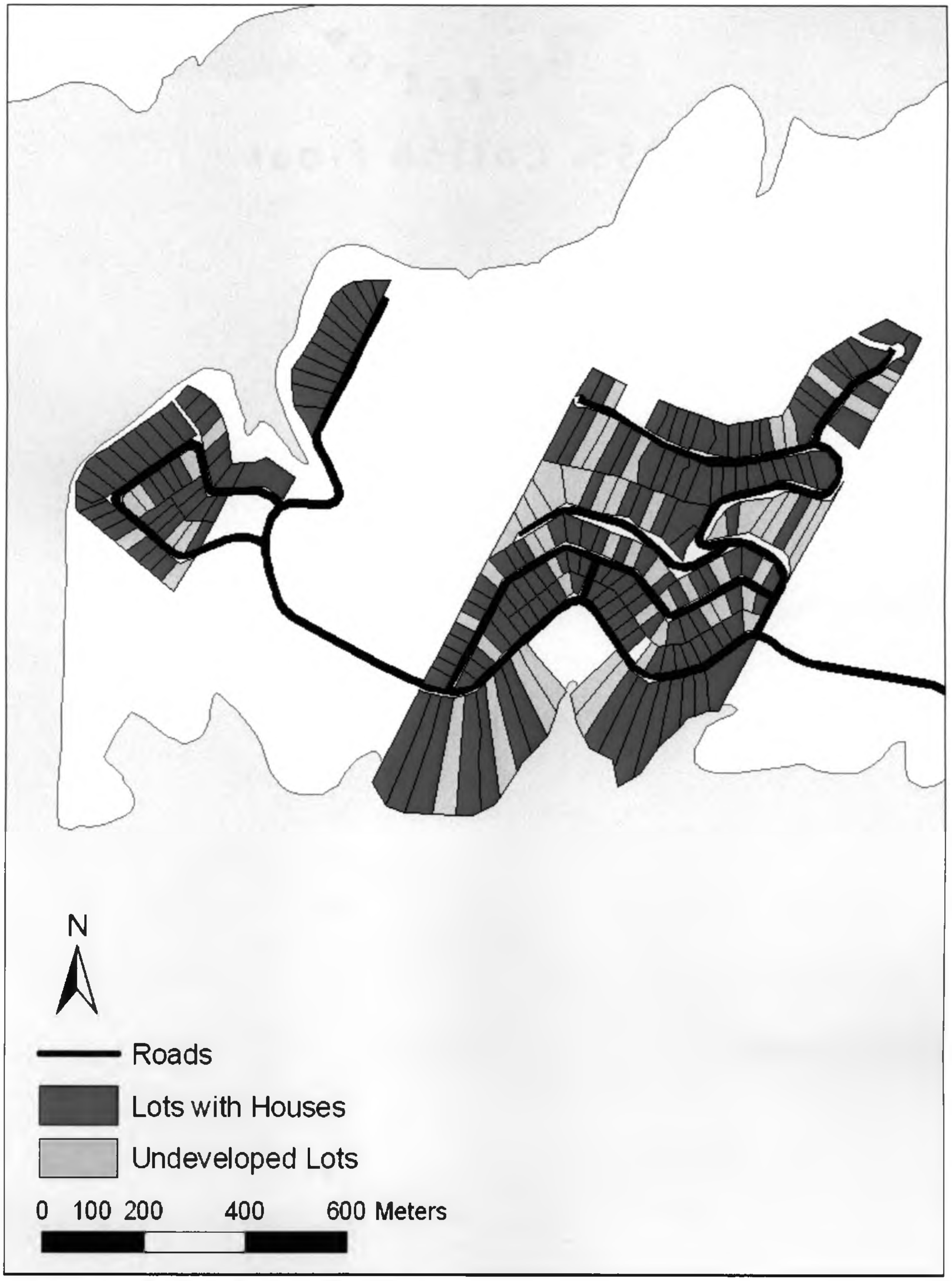

Figure 14. Comanche Trail.

Figure 15. Only Exit for Comanche Trail.

Figure 16. House with a View of Lake Travis in Comanche Trail.

blocked, then there would be no egress. Residents of Comanche Trail would have to shelter in place or evacuate via boats on Lake Travis.

Adding homes to the 60 empty lots would increase projected egress demand beyond single-exit capacity. Furthermore, no vegetation buffer is present along the egress route that winds through steep Hill Country brush. If not obstructed, then the exit should provide residents with safe egress during fire. Safe evacuation is, however, very dependent on an open exit. Comanche Trail demonstrates that evacuation of a neighborhood that is below build-out capacity can still be uncertain because of the single exit.

Neighborhood 3: The Courtyard

The Courtyard, located just inside the UP zone, exemplifies a safer-egress UP neighborhood (Figure 17). The existing road density in the neighborhood, however, does not meet the minimum standard. As in Canyon Creek, a two-lane arc-shaped road bisects the Courtyard and is the primary means of egress (Figure 18). There are fewer homes and streets in this development than in Canyon Creek, allowing the neighborhood to meet occupancy standards with only two exits.

The neighborhood is compliant with the standards of VPH capacity (1204/1600) and capacity if completely built out (only four empty lots remain at present). A single additional exit would enable the subdivision's full compliance with evacuation standards. The main benefit of another exit would be that it would provide an alternate route should an exit be blocked. Existing exits are adequately spaced.

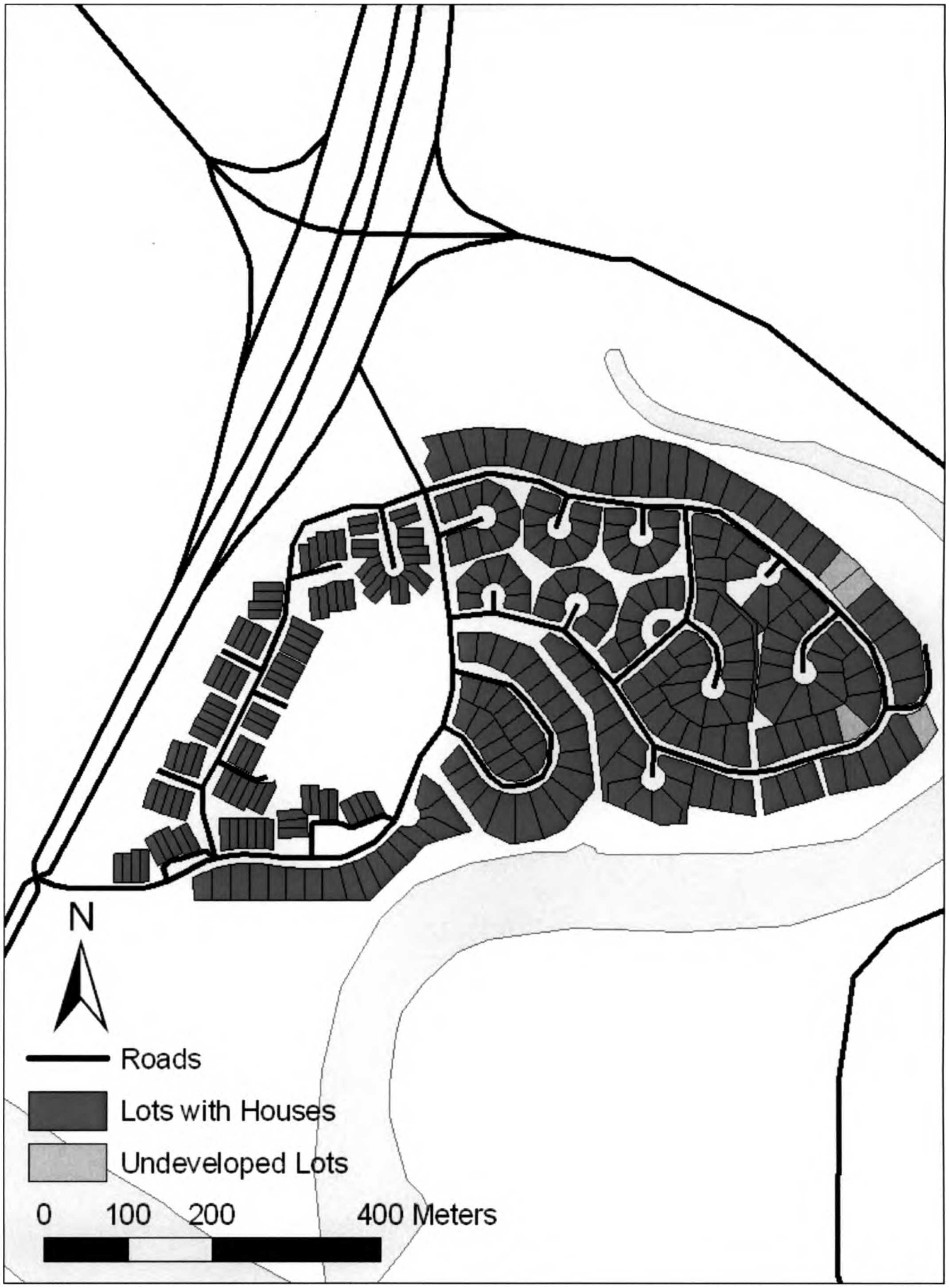

Figure 17. The Courtyard.

Figure 18. South Entrance to The Courtyard along Loop-360.

Neighborhood 4: Glenlake

Glenlake is in an unincorporated area north of a large park located within the City of Austin (Figure 19). The subdivision complies with egress standards. Glenlake possesses an interesting egress feature not found elsewhere in the area. Signage at the main entrance to Glenlake states that there is no other exit in the neighborhood, implying that it is a single-exit neighborhood (Figure 20). However, a drive through the subdivision reveals a second private exit at the west end of the neighborhood (Figure 21). While not marked on a map, the concrete path connecting Glenlake to River Place and Westminster Glen could function as egress and provide access for emergency crews. The second exit is not optimal because landscaped vegetation encroaches on it and there is no vegetation-free buffer (Figure 22). Defensible space improvements around houses are potentially an important step (Figure 23). There is an adequate road-density. The neighborhood is well under the maximum occupancy for two exits. Exits are at opposite ends of the development, which allows for proper spacing (Figure 20).

Neighborhood 5: Great Hills

Great Hills is located within Austin's city limits near the northern edge of the study area, but is within the UP. It is an elongated neighborhood bisected by Yaupon Dr., which provides the only egress (Figure 23). The street leads to exits at the north and south ends of the neighborhood (Figure 24). The neighborhood meets exit-spacing requirements, but it falls short in most other safe-evacuation standards. It almost meets egress needs for the population, so a single additional

Figure 19. Glenlake.

Figure 20. No Outlet Sign near the East Entrance to Glenlake.

Figure 21. Unmarked Second Exit at the West End of Glenlake.

Figure 22. Unsigned Egress Point at the West End of Glenlake.

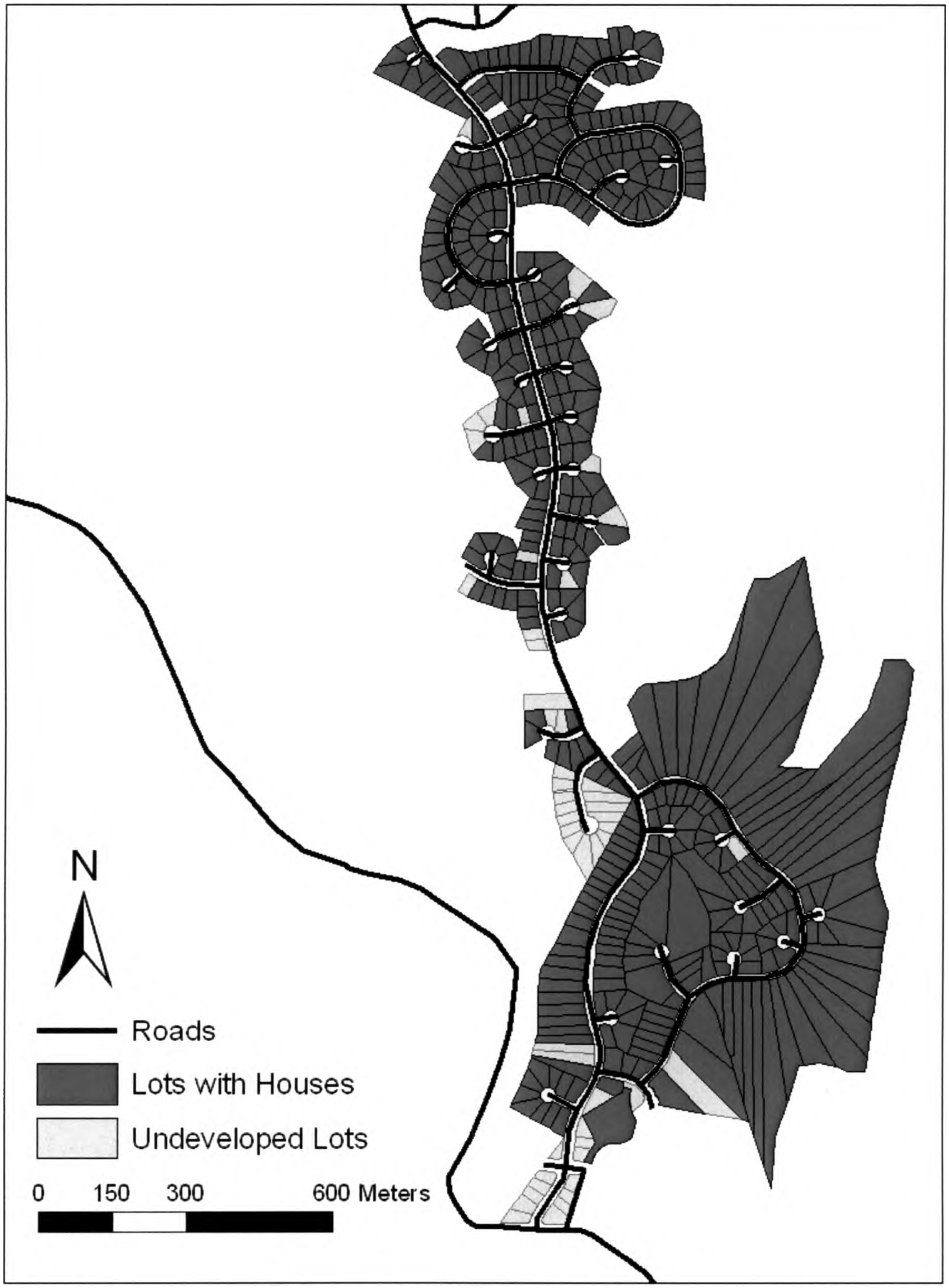

Figure 23. Great Hills.

Figure 24. Yaupon Dr.

exit would meet its needs. But the existing capacity of 1600 VPH falls short of the egress demand of 1735 VPH. More than 50 empty lots exist, so this minor difference could become much greater with the eventual infill. A new exit could connect Great Hills to the adjacent street networks of northwestern Austin or to Spicewood Springs Road to the southwest.

Great Hills does have two positive characteristics that make potential egress improvements possible: it is not far from the existing road network and construction of new egress routes is feasible and the neighborhood is nearly completely built out and it's streets have little space for new construction and future egress demand will be physically limited.

Neighborhood 6: Jester Estates

Jester Estates, the third largest development in this study, is the only neighborhood that fails to earn a single egress test point (Figure 25). The elongated subdivision is has far greater projected egress demand than existing capacity. It's spatial layout, lack of adequate exits, location abutting undeveloped land in all directions and twisting egress routes over areas of sharp topographic relief and are ways in which it is representative of the UP community egress problem (Figure 26). Furthermore, there is inadequate road density and little vegetation clearance along evacuation routes (Figure 27).

The size of this subdivision and layers of egress concerns merit attention given the speed at which wildfire can approach. There is strong concern for residents' ability to evacuate as fire-prone canyonlands surround them with no body of water nearby (Figure 28). The eastern exits travel over sharp topographic

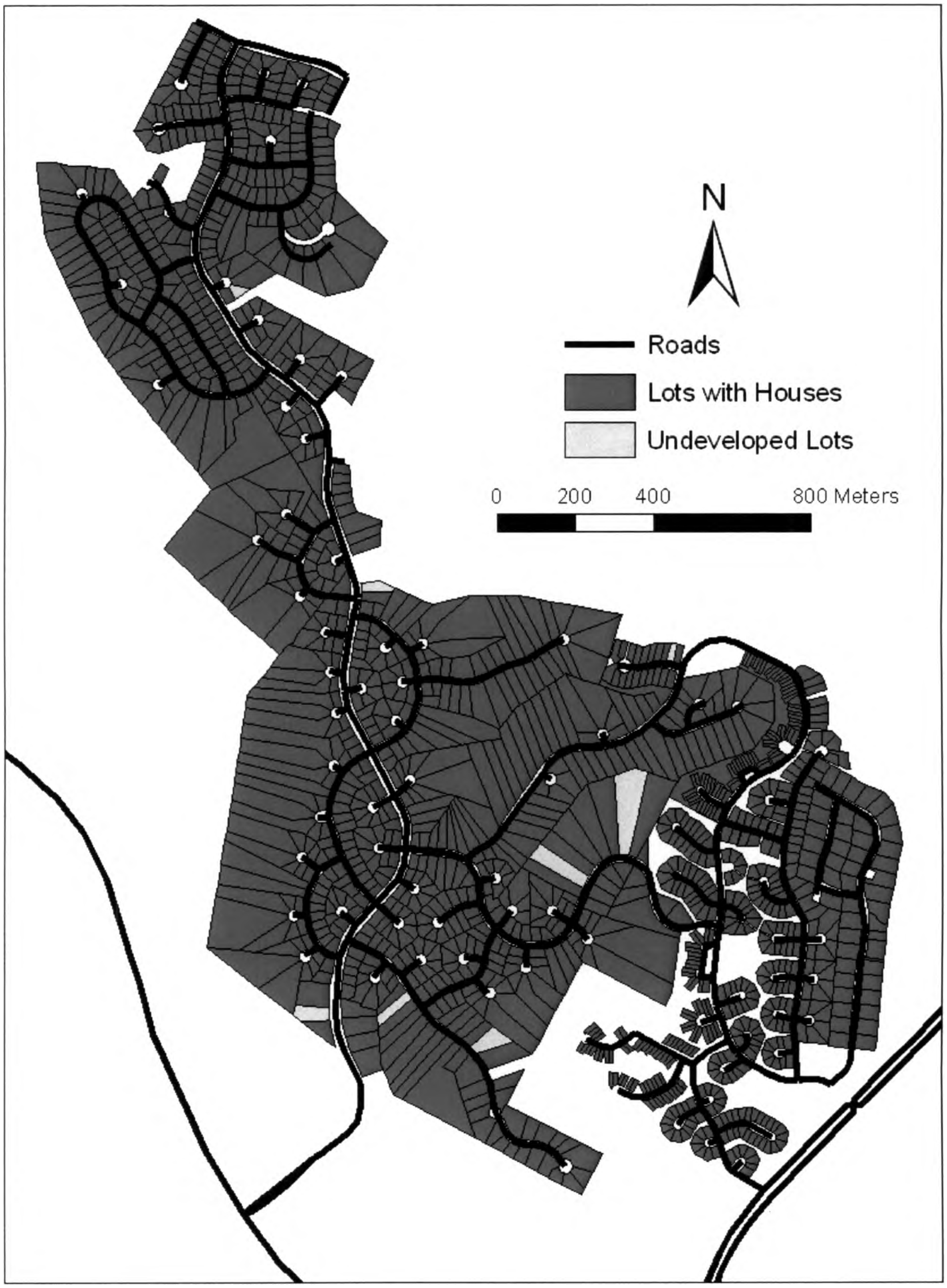

Figure 25. Jester Estates.

Figure 26. Entrance Landscaping along RM-2222.

Figure 27. Steep Grade along Egress Route.

Figure 28. Homes Atop a Steep Fuel-Covered Slope.

relief and through encroaching vegetation. Improving means of egress in the neighborhood requires significant changes.

Neighborhood 7: Jester Estates – Canyon Ridge

Canyon Ridge comprises the middle of Jester Estates. This analysis section also includes Jester Point to the north (Figure 29) due to the necessity of Jester Point residents to egress through Canyon Ridge. Projected egress demand is greater than means of egress afforded by two exits even though it is only part of a larger development (an interior bottleneck). It passes two compliance tests, a fuel buffer at exits and needing a single new exit to have adequate means of egress.

A problem with the exits is how closely they are spaced. The two egress routes cross in a figure-eight fashion, which further complicates egress (Figure 30). Given the existing lack of needed egress capacity in Jester Estates as a whole, a new road connecting Canyon Ridge directly to roads outside of the neighborhood would best support efficient egress. A new exit (if properly separated from exiting ones) would bring this section into compliance and reduce interior bottleneck concerns.

Neighborhood 8: Jester Estates – Jester Point

This section comprises the northern portion of Jester Estates (Figure 31) and a clear interior bottleneck exists with one exit for 387 homes (Figure 32). Furthermore, minimum standards for road density are not met a concern due to Jester Point's place as the distant interior of a neighborhood that fails all egress tests. Standing alone, Jester Point is close enough to compliance that a single

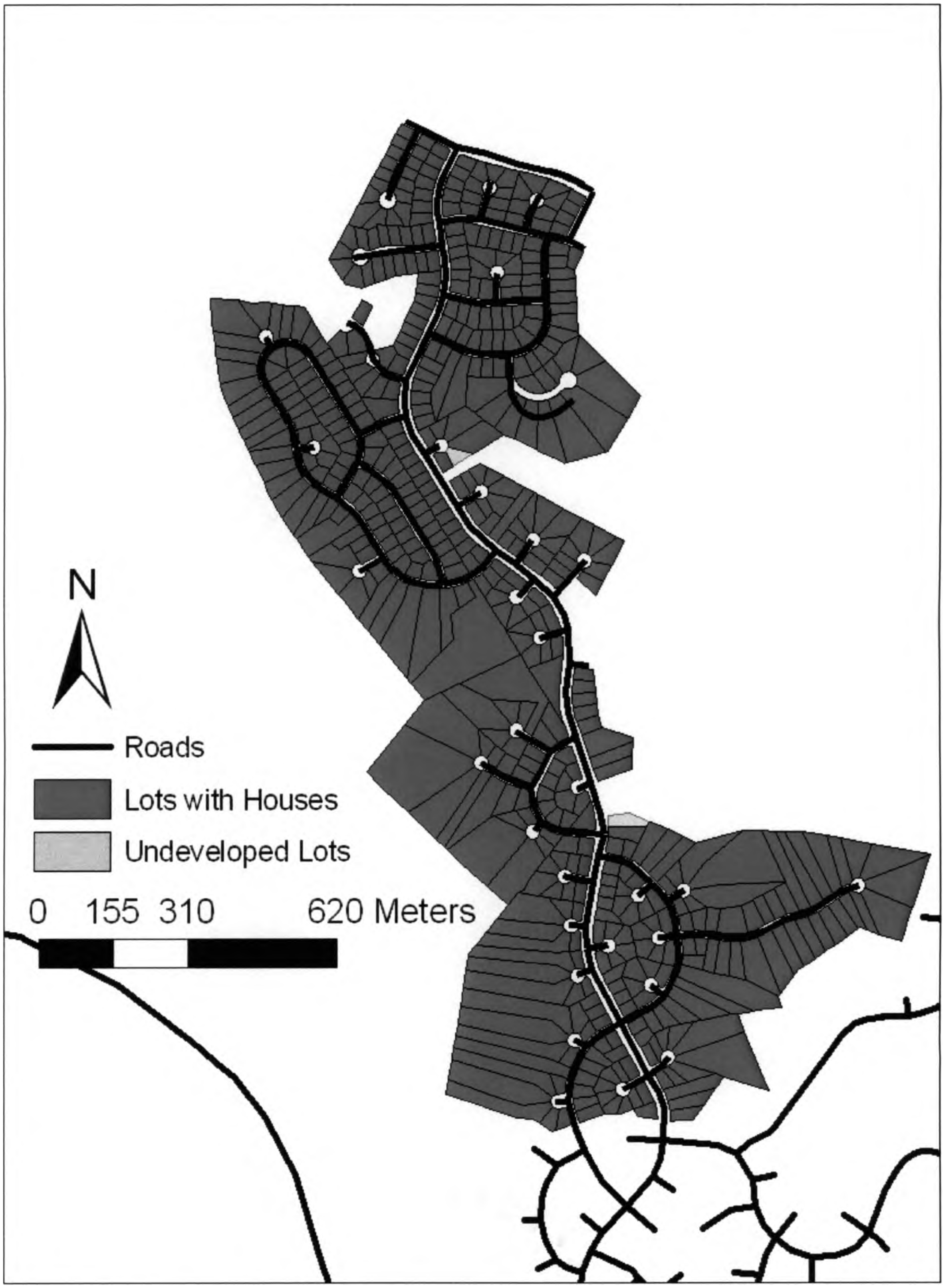

Figure 29. Canyon Ridge.

Figure 30. Egress Routes Cross near Canyon Ridge's South End.

Figure 31. Jester Point.

Figure 32. Dead-End Road at the North End of Jester Point/Jester Estates.

new exit would alleviate evacuation concerns. Connecting to Spicewood Springs Road via an extension of Jester Boulevard or another arterial could accomplish this.

Neighborhood 9: Long Canyon

Long Canyon is a single-exit neighborhood in an unincorporated area off RM-2222. An exurban development with moderate spaced homes on large lots, many of which border open ranch land, it has serious egress concerns that center on having only one egress route (Figure 33). Bell Canyon Dr. collects all egress traffic and there is no suitable vegetation buffer near the exit (Figure 34). A single exit for 316 homes leaves the neighborhood over-occupied in terms of capacity to egress safety. Exurban characteristics of the subdivision allow for passing the road density test, but exacerbate other aspects of evacuation concerns. A high-risk wildfire zone surrounds the neighborhood, which only passes two egress tests. A properly spaced new could alleviate means of egress concerns.

Neighborhood 10: Mount Bonnell

The closest neighborhood to Downtown Austin in this research, parks and an open space preserve separate the Mount Bonnell area from the contiguous urbanized zone. Mount Bonnell Road provides bi-directional egress for all areas (Figure 35). Brushy vegetation surrounds the egress route, which has steep grades and hairpin turns.

A high risk for wildfire exists due to adjacency of open-space containing typical Hill Country vegetation to houses, as well as the topographic relief of

Figure 33. Long Canyon.

Figure 34. Only Automobile Exit for Long Canyon.

Figure 35. Mount Bonnell.

surrounding cliffs and hillsides. Sections within vary in age and value, but all lie to the west of the UP region defined for this research. The area excels in terms of occupancy and means of egress despite its setting. The only test not passed is fuel buffer because the rural nature of Mount Bonnell road provides little vegetation clearance along egress routes (Figure 36). The south end runs alongside a brush covered cliff before reaching the exit (Figure 37), increasing the possibility of blockage by wildfire.

The lack of fuel buffers at exits illustrates egress concerns due to potential exit blockage in neighborhoods that are able to evacuate safely when all exits are open. An egress blockage at one-end forces all residents to egress through the other. For example, a wildfire in adjacent open space that moves into the canyon blocking the south egress route would limit available egress capacity to 800 VPH. An instance of wildfire blocking two of four exits in a very hilly residential contributed to deaths during evacuation from the 1991 Oakland Hills fire (Cova, 2005).

Neighborhood 11: The Parke

The Parke, a single-exit neighborhood (Figure 38), has a four-lane divided arterial with a fuel buffer that serves as its egress. Undeveloped fire-prone land surrounds the neighborhood. It contains two smaller sections, each with a single exit onto the main egress route.

The Parke does not merit the egress-test score that a multiple-exit neighborhood would, although the existing exit can handle more traffic than the typical egress route (Figure 39). "A fuel buffer exists, projected egress demand

Figure 36. Mt. Bonnell Road Leading Away from South Exit.

Figure 37. Fuel Biomass Parched by Drought along Mt. Bonnell Dr.

Figure 38. The Parke.

Figure 39. Egress Point for The Parke on Wilson Parke Dr.

does not exceed exit capacity, and road density is adequate, but the chance that egress could be prevented by blockage of the only exit should be cause for concern. The Parke is not a completely "safe" neighborhood in terms of evacuation even though it meets basic egress criteria. With a second exit, The Parke would exemplify evacuation-safe UP subdivisions given the design of the existing exit. As with other one-exit subdivisions, The Parke does not receive points for exit spacing, because it lacks a second exit.

Neighborhood 12: River Place

This development is the second largest in the study (after Steiner Ranch). Despite its size, there are only two two-lane egress routes, creating serious evacuation concerns. River Place does pass three egress tests: road density, exit separation, and fuel buffer. The potential egress demand of 3904 VPH exceeds capacity (1600) by a factor of two and 175 lots have not yet been developed (Figure 40). Build-out would further strain egress. The neighborhood will still be over-occupied even if another exit were added.

Lake Austin borders this neighborhood to the south and undeveloped land surrounds it on the other three sides (Figure 41). Signs throughout the neighborhood announce it is a "Fire-Wise Community" (Figure 42). Construction and the design of public and private spaces throughout the neighborhood exhibit fire-safety and defensible-space measures. Well-managed vegetation alongside streets and household landscaping is fire-safe compared to other UP neighborhoods (Figure 43). While these attributes may mitigate fire-hazard within the neighborhood, they do not address external fire threat and egress capacity.

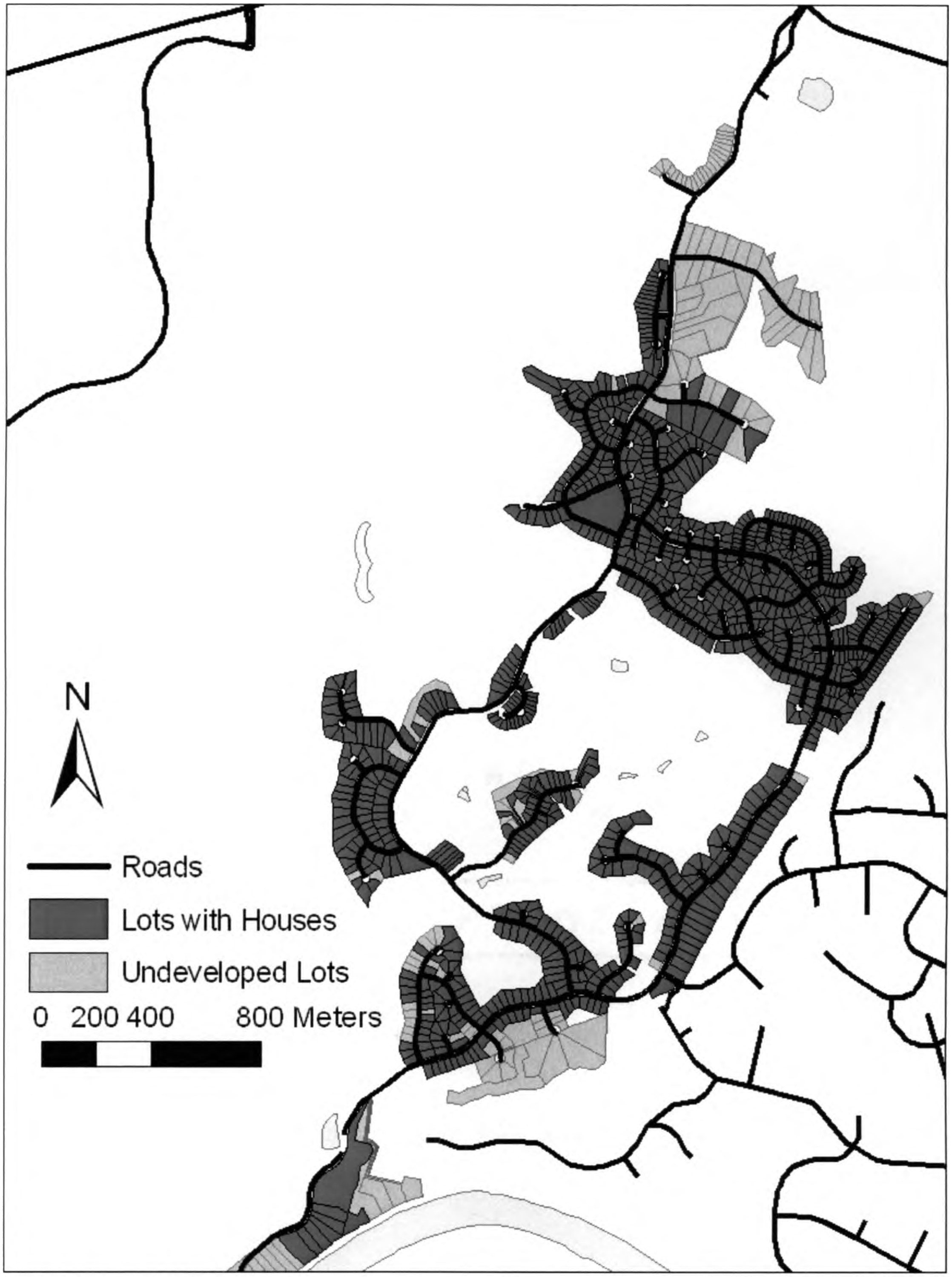

Figure 40. River Place.

Figure 41. View of River Place with Steiner Ranch in the Distance.

Figure 42. Sign Designating River Place as a "Firewise Community."

Figure 43. Street Scene in River Place.

Neighborhood 13: Steiner Ranch

The largest neighborhood of the study area provides a picture of egress problems that exists in larger UP subdivisions. There are 1655 homes and 2800 empty lots in Steiner Ranch and this development currently relies on one four-lane and one two-lane egress route (Figure 44). These exits do not provide sufficient means for a timely escape for residents. Undeveloped land and topographic relief in and around the development contribute to the fire-hazard here (Figure 45). Steiner Ranch also contains commercial and recreational land uses that further complicate evacuation. Neighborhoods that need to cater to a significant non-resident population require greater egress infrastructure in order to be safe (Cova, 2005). Increasing egress really needs to be prioritized at Steiner Ranch in order to accommodate visitors and future residents of the planned build-out of more than 4,000 homes. Furthermore, greater spacing of exits is needed to facilitate community egress. Increasing their spacing at least three-times their current distance is needed to bring the neighborhood into compliance with safety standards.

Neighborhood 14: Westminster Glen

Westminster Glen exemplifies a neighborhood with adequate egress. Exits on opposite ends of the neighborhood connect to River Place and RM-2222 via City Park Road (Figure 46). Both are clearly public roads and serve the subdivision's heavy road density: nearly two-and-a-half times the egress-test minimum. There are fuel buffers at both exits (Figure 47), as well as along the main egress route (Figure 48).

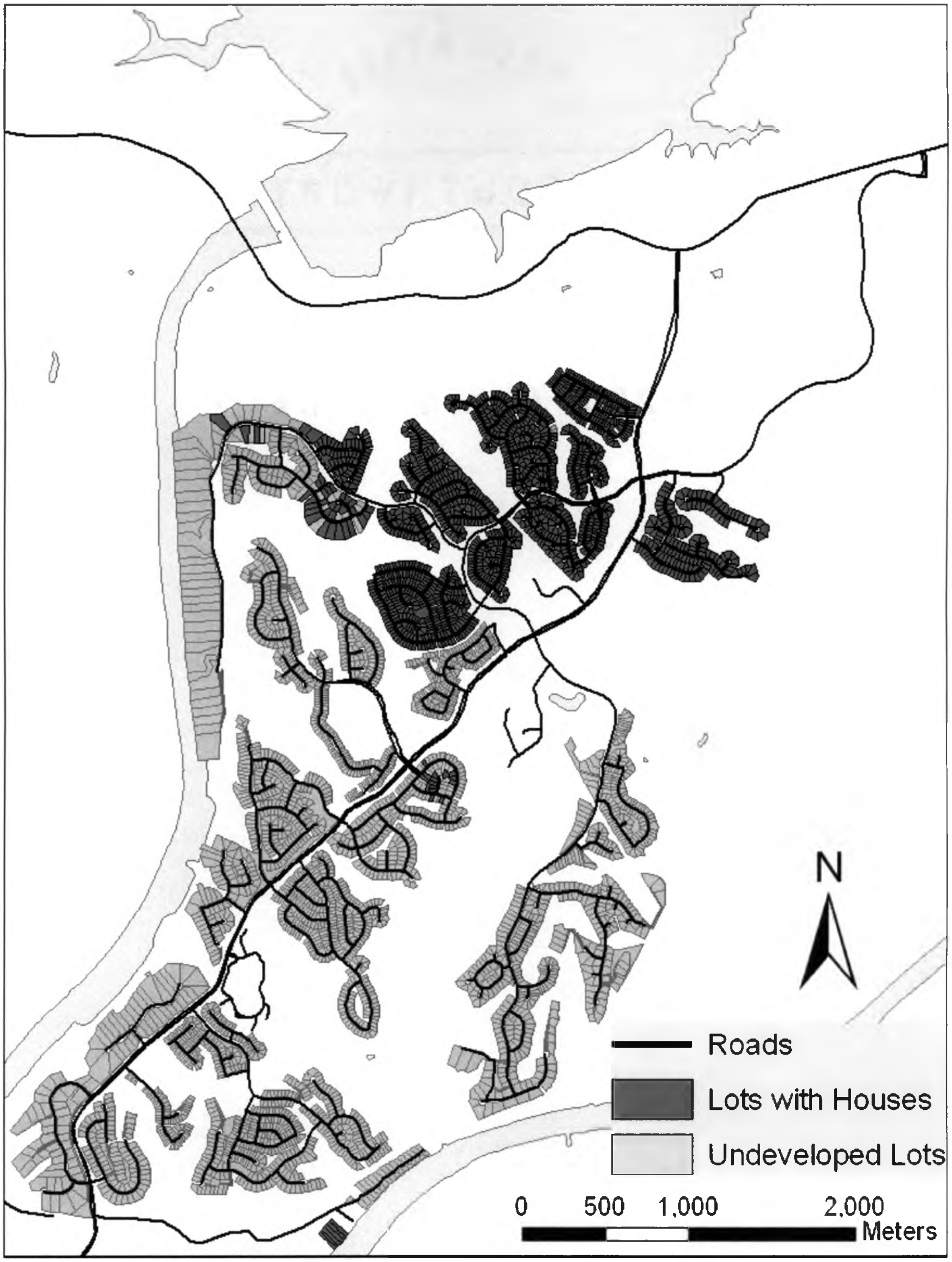

Figure 44. Steiner Ranch.

Figure 45. East Entrance to Steiner Ranch.

Figure 46. Westminster Glen.

Figure 47. Main Route through Westminster Glen.

Figure 48. West Exit.

Westminster Glen is one of only two neighborhoods in the study to earn full marks for means-of-egress versus neighborhood occupancy. If fire were to render one exit impassable, the other would suffice for timely egress (based on a projected demand of less than 800 VPH). The neighborhood needs no additional exits.

Attending to household-level wildfire safety is practical when neighborhood egress is not a problem. Densely landscaped vegetation surrounding homes increases the wildfire threat by providing fuel. Information on defensible spaces around homes should be made available and community education ought to strive to improve fire-safe features throughout UP neighborhoods.

Comparing Neighborhood Egress

There are significant egress problems in the study-area neighborhoods (Figure 49). Nine of the fourteen neighborhoods rate at or below three in terms of compliance points. Only four neighborhoods scored more than five points. Westminster Glen is the only neighborhood that passes all seven tests (Table 4). Better-performing neighborhoods tend to be smaller and closer to the UP line. The three largest neighborhoods: Steiner Ranch, River Place and Jester Estates scored very low. Jester Estates failed all egress tests.

Compliance by Category

Road density was the category with the highest rate of compliance. Nine of the fourteen neighborhoods are density-compliant. Eight of the neighborhoods are compliant in terms of providing fuel buffers. Seven provide sufficient exit separation and six sufficient exit capacity. Only four provide a sufficient number

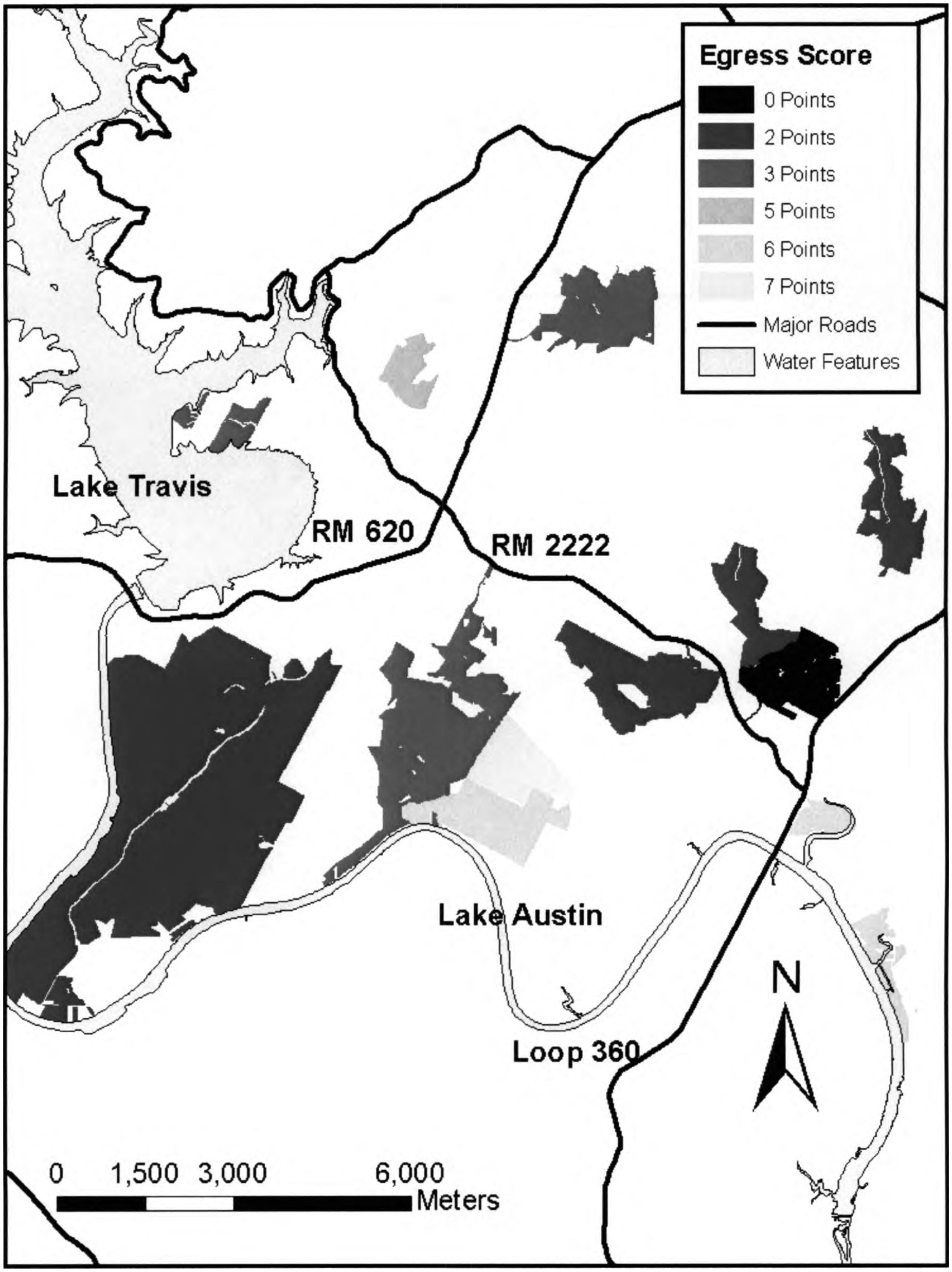

Figure 49. Results.

Table 4. Complete Egress Test Results for all Neighborhoods in Study Area

Neighborhood		Road Density	Egress Demand	Build-Out Demand	Num. of Exits	+ 1 Exit	Exit Separation	Fuel Buffer
	Homes	M / Home	VPH(Max)	VPH(Max)	N(Max)	N+1(Max)	1/2 Max Dist.	30m
Canyon Creek	862	20.1(20)	3448(1600)	4136(1600)	2(4)	3448(2400)	2270m(1370)	Yes
Comanche Trail	180	37.6(20)	720(800)	960(800)	1(2)	960(1600)	One exit	No
Courtyard	301	5.6(20)	1204(1600)	1220(1600)	2(3)	1204(2400)	715m(520)	Yes
Glenlake	173	48.3(20)	692(1600)	792(1600)	2(2)	692(2400)	1882m(1363)	Yes
Great Hills	435	18.6(20)	1735(1600)	1944(1600)	2(2)	1735(2400)	2446m(625)	No
Jester Estates	1396	16.1(20)	5584(2400)	5616(2400)	3(4)	5584(3200)	1336m(1650)	No
Canyon Ridge	543	17.2(20)	2172(1600)	2180(1600)	2(3)	2172(2400)	172m(1043)	Yes
Jester Point	387	18(20)	1548(800)	1552(800)	1(3)	1548(1600)	One exit	Yes
Long Canyon	316	35.1(20)	1264(800)	1372(800)	1(3)	1264(1600)	One exit	No
Mount Bonnell	281	27.9(20)	1028(1600)	1124(1600)	2(2)	1028(2400)	2032m(522)	No
The Parke	289	27.8(20)	1156(1600)	1440(1600)	1(2)	1156(2400)	One exit	Yes
River Place	976	23.6(20)	3904(1600)	4564(1600)	2(4)	3904(2400)	3635m(2782)	Yes
Steiner Ranch	1655	23.6(20)	6620(2400)	17908(2400)	2(4)	6620(3200)	1630m(4740)	Yes
Westminster Glen	167	44.2(20)	668(1600)	674(1600)	2(2)	668(2400)	1945m(825)	Yes

of exits, however (Table 5). Four of the eight neighborhoods that lack sufficient egress capacity versus demand (Exit Capacity) require multiple additional exits to meet exit standards (Table 4). Three of the seven neighborhoods with sufficiently spaced exits are over-occupied in terms of egress. Only four have adequate number and spacing of exits. Single-exit subdivisions automatically fail the exit-spacing tests because they offer no serviceable alternative for when that exit is blocked by wildfire or another obstruction, even when there is safe means of egress when under normal road conditions.

Five of the eight neighborhoods that pass the Fuel Buffer test have adequate means of egress. Of these, four have properly spaced exits. Regarding Road Density, Five of the nine neighborhoods earning points road density category also pass the Egress Capacity test, leaving four neighborhoods that are not over-occupied but lack the recommended space for egress flow on their road networks (Table 5).

Restricted Egress Corridor

"Five of the eight neighborhoods with sufficient fuel-buffering have adequate egress. Of these, four also have adequately spaced exits. Five of the nine neighborhoods with adequate road densities also meet the standards of egress capacity, leaving four neighborhoods that are below occupancy capacity but lack the recommended egress (Table 5).

Restricted Egress Corridor

Egress problems are prominent along a west-to-east restricted egress corridor (REC) of five developments. RM-2222 bisects the REC about a mile

Table 5. Overall Success by Compliance Category.

Egress Test Category	Rank	Compliant Neighborhoods	Non-Compliant Neighborhoods
Exit Capacity +1 Exit	1	10	4
Road Density	2	9	5
Fuel Buffer	3	8	6
Exit Separation	4	7	7
Egress Capacity	5	6	8
Capacity if Built Out	6	4	10
Number of Exits	7	4	10

west of Loop-360 (Figure 50). All neighborhoods in the REC fail to meet at least five egress tests, and this includes the three main egress capacity standards. In some developments, the primary means of egress is a road that was built to serve fewer people. The physical features that attract new residents to the area also magnify wildfires and limit avenues of escape. The neighborhoods that comprise the REC include Steiner Ranch, River Place, Long Canyon, Jester Estates and Great Hills. Each neighborhood is disconnected from the surrounding developments, and this further enhances the problem.

Ranch lands, preserves and parkland surrounding the REC neighborhoods add to the wildfire risk (City of Austin, 2008). Several REC neighborhoods abut sections of the Balcones Canyonlands Preserve. Proximity to preserved land satisfies homeowners that they won't gain neighbors, but it increases the potential for wildfires. Road density is also an issue due to the size of the developments. The enclave design of REC subdivisions is a catalyst for limited egress and for concurrent occupancy problems. For example: Steiner Ranch is a large, disconnected residential island lacking road connections to the neighboring River Place development (less than 1,000 meters away). While detachment promotes exclusivity, it also complicates evacuation.

Egress from REC neighborhoods is onto three major roads: RM-620 (Figure 51), RM-2222 and Loop-360. Traffic on these routes, particularly RM-620 and Loop-360, requires long traffic-light cycles for smaller intersecting roads. Bottlenecks occur under normal conditions. The random timing of wildfires could further complicate evacuation, especially at times when either most residents are

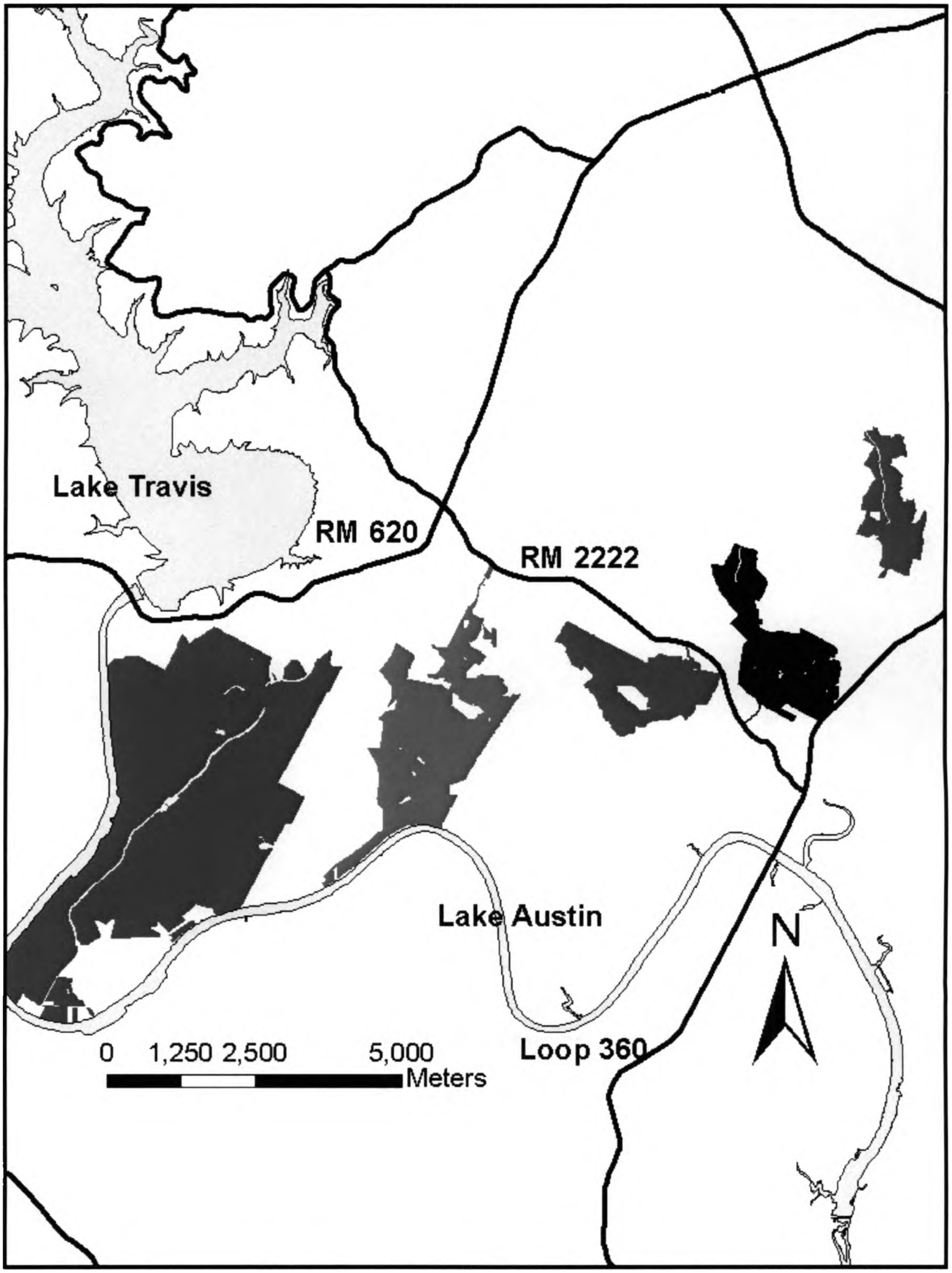

Figure 50. Restricted Egress Corridor.

Figure 51. RM-620 near Steiner Ranch.

at home or during the start of morning commutes. Loop-360, with a 60 mile-per-hour speed limit and traffic lights, functions as a hybrid major street and freeway, and RM-620 and RM-2222 have 55 to 60 MPH speed limits through the study area. The hierarchies within the road networks need to be reexamined in order to remedy the mismatch of neighborhood egress routes and the highways with which they intersect.

Subdivision Age and Egress Safety

With the most problematic neighborhoods identified, a neighborhood's age has an influence on the degree of egress. Plat records show that more than half of the subdivisions were platted in the 1980s. At that time, the Texas legislature passed a law that allowed Municipal Utility Districts (MUDs) in unincorporated areas. These are legal entities, incorporated by referendum, with authority to provide water and other utilities for land development. They can be formed by a single person, if they are the only voter in an unincorporated area and if that voter is the primary stakeholder in a planned development. Property owners near a proposed MUD have little (to no) say in the matter. The MUD process was a key factor in Austin's inability to maintain a "preferred growth corridor" that was intended to limit urban sprawl (Vaughan, 2009).

All of the neighborhoods examined in this study were platted before 1997; most were designed in the 1970s and 1980s. Comanche Point was first platted in 1946, making it the oldest neighborhood, but it was expanded in 1998 (Table 6). Canyon Creek added a new section in 2008 and is only one of two neighborhoods founded after 1990. While five neighborhoods have added

Table 6. Compliance Results and Plat Dates.

Neighborhood	Compliance Pts.	First Plat Date	Newest Plat Date
Canyon Creek	3	1996	2008
Comanche Trail	3	1946	1998
The Courtyard	6	1977	1995
Glenlake	6	1978	1997
Great Hills	2	1993	2006
Jester Estates	0	1979	1998
Canyon Ridge	2	1986	1998
Jester Point	2	1982	1998
Long Canyon	2	1981	1997
Mount Bonnell	6	1981	2007
The Parke	5	1988	1997
River Place	3	1984	2008
Steiner Ranch	2	1988	2008
Westminster Glen	7	1985	2002

sections since 2006, eight have had no significant additions since the 1990s (Table 6). One group is actively expanding and the other is not (Table 6 and Table 7). The age of a neighborhood appears to have little bearing on egress, however.

Lower-scoring neighborhoods (on the egress tests) exist across the age spectrum. The age analysis does show that the most rapid pace of new development has not occurred quite as recently in the study area as was perhaps expected. Conversely, many of these neighborhoods have been built out over a period of 20-30 years or longer. It is clear that some neighborhoods are still rapidly expanding. Steiner Ranch, in particular, has with multiple sections of empty lots planned for development.

<u>Egress Test Breakdown: Older and Newer Neighborhoods</u>

The median neighborhood first plat date (FPD) is 1984. The egress test points (ETP) total for the pre-1984 neighborhoods is 25, with the newer half totaling 24. The CP average for the earlier FPD group is actually slightly higher (3.57) than the more recent FPD group (3.43) (Table 8). There is little difference between newer and older groups of neighborhoods and how well they collectively perform on the egress test. Means of egress is not better in the newest group of neighborhoods.

Another aspect of age-egress analysis involves recently expanded neighborhoods and the community exit problem. Use of the most recent plat date (MRPD) allows for delineation of older and newer groups. There is clearly defined group with recent additions and ETP added for each. There is a clear

Table 7. Temporal Egress Safety Comparison

First Plat Date (FPD) Neighborhood	Date	Points	Most Recent Plat Date (MRPD) Neighborhood	Date	Points
Comanche Trail	1946	3	The Courtyard	1995	6
The Courtyard	1977	6	Glenlake	1997	6
Glenlake	1978	6	Long Canyon	1997	2
Jester Estates	1979	0	The Parke	1997	5
Long Canyon	1981	2	Comanche Trail	1998	3
Mount Bonnell	1981	6	Canyon Ridge	1998	2
Jester Point	1982	2	Jester Estates	1998	0
River Place	1984	3	Jester Point	1998	2
Westminster Glen	1985	7	Westminster Glen	2002	7
Canyon Ridge	1986	2	Great Hills	2006	2
The Parke	1988	5	Mount Bonnell	2007	6
Steiner Ranch	1988	2	Canyon Creek	2008	2
Great Hills	1993	2	River Place	2008	2
Canyon Creek	1996	3	Steiner Ranch	2008	3

Table 8. Egress Safety Comparison, Older and Newer Neighborhood Groups.

First Plat Date (FPD)				Most Recent Plat Date (MRPD)			
	Neigh-borhooods	Points	Avg		Neigh-borhooods	Points	Avg
Pre-1984	7	25	3.57	Pre-2000	8	27	3 37
1984-Pres	7	24	3.43	2006-Pres	6	22	3 67
N=	14	49	3.5	N=	14	49	3.5
				Pre-2006	9	34	3 78
				2006-Pres	5	15	3
				N=	14	49	3.5
				Pre-2000			
				2006-	8	27	3 37
				Pres.	5	15	3
				N=	13	42	3.23

group of neighborhoods that have expanded before 2000, and another group after. The pre-2000 group has eight neighborhoods, with six in the latter group (2000-present). The older MRPD group has an average ETP of 3.37 and the newer one an average of 3.78 (Table 8). Mean ETP for all neighborhoods is 3.5.

These results appear to show marginal improvement since 2000. If Westminster Glen were removed from the analysis as an outlier (it is the only neighborhood with 7 ETP), it is less evident that egress has been improved. Westminster Glen is also an outlier in the respect that only it has an MRPD (2002) between 2000 and 2006. Including Westminster Glen in the first group instead changes the CP average. The pre-2006 group has an average of 3.78, and the post-2006 group has an average of 3.0. This suggests that recently expanded neighborhoods are worsening wildfire-evacuation problems.

Removing Westminster Glen entirely leaves two distinct groups of older and newer MRPD neighborhoods. The older MRPD group has an average ETP score of 3.38 and the newer has an average of 3.0. This also shows no improvement of evacuation capacity. Mount Bonnell is the only neighborhood with a section platted since 2006 that did well in egress tests. There is otherwise no improvement in egress options from newer developments in the study. The exit problem continues in most recently expanded neighborhoods. Great Hills, Canyon Creek and River Place each passed only two egress tests (Table 5) and River Place and Steiner Ranch (compliant in 3 tests) are the largest neighborhoods in this research.

Results of Interior Bottleneck Analysis

A spatial bottleneck analysis was performed with the ArcGIS network analysis tool to identify the locations where bottlenecks might occur. The highest and lowest scoring neighborhoods from earlier egress tests were selected for closer analysis. Westminster Glen, the only neighborhood to meet the requirements of all 7 categories, and Jester Estates, the only neighborhood to pass none of them, were examined for bottleneck problems. These neighborhoods clearly contrast with each other. Jester Estates is larger, but Westminster Glen has better spaced exits. By comparison, they demonstrate the difference between egress-compliant and non-compliant subdivisions.

Interior Bottleneck Analysis: Westminster Glen

The map of closest facility analysis (CFA) egress volume shows routes splitting near the middle (a zero traffic value can be seen) of the neighborhood (Figure 53). The color scale on the map measures potential volume of CFA egress with interior bottlenecks (if they exist) highlighted in the color scale. In this case, analysis projects the highest traffic volumes within the neighborhood occurring at exit points. Egress-volume on interior streets is much lower, which shows safe and efficient means of egress (Figure 52). CFA demonstrates how well spaced exits effectively distribute egress traffic (Table 9). CFA can indicate the better route for residents based on their home's location, the locations of exits and the balance of traffic being generated during an evacuation (for instance, residents on the west side of the neighborhood would know to exit to the west instead of taking other paths). This analysis confirms that Westminster

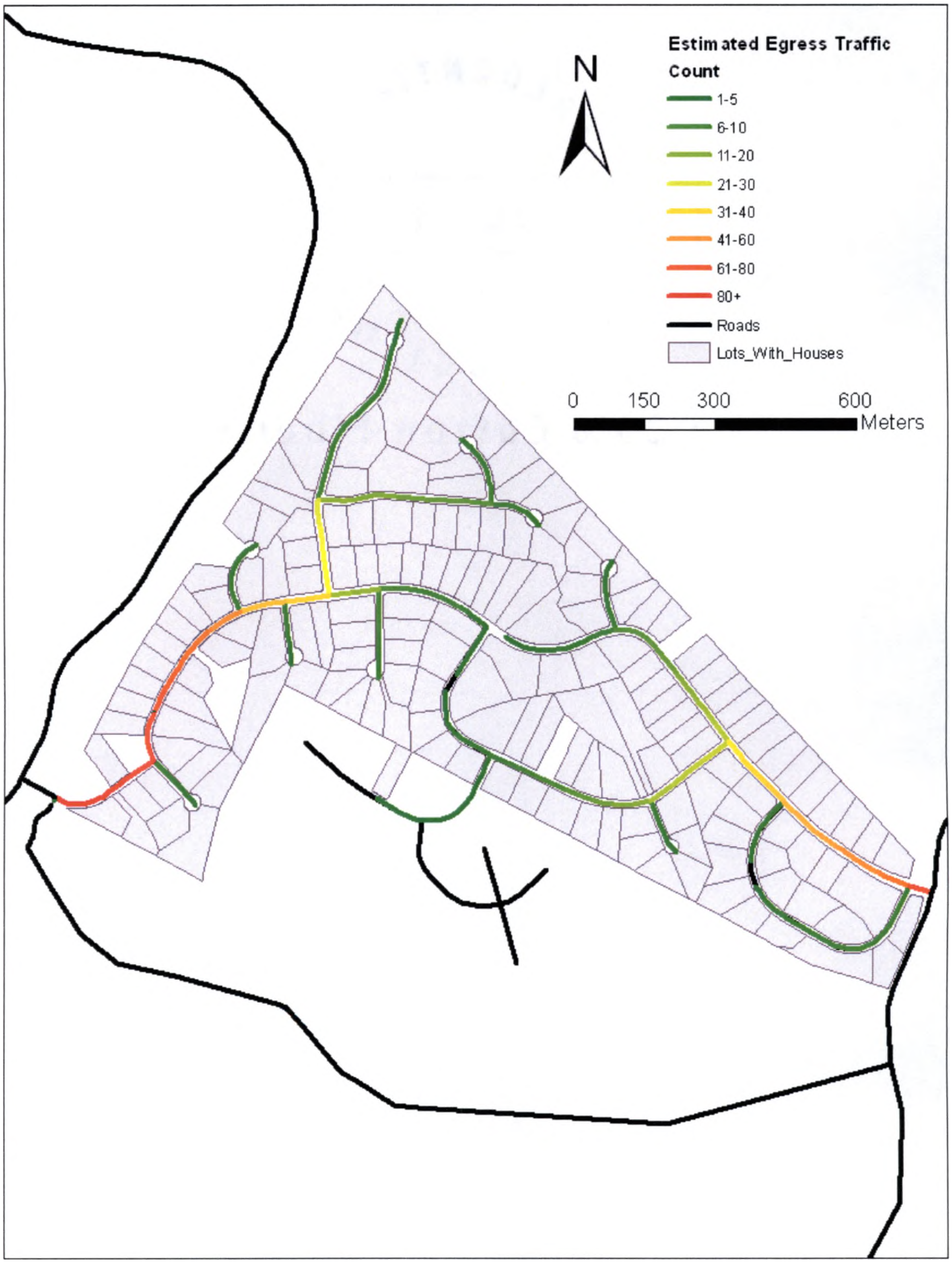

Figure 52. Network Analysis Closest Facility Map for Westminster Glen.

Table 9. Predicted Egress Traffic in Jester Estates and Westminster Glen.

Neighborhood	Routes	Percent of N
Jester Estates	N=1388	
Exit 1	819	58.6
Exit 2	114	08.2
Exit 3	463	33.2
Westminster Glen	N=167	
Exit 1	88	52.7
Exit 2	79	47.3

Glen complies with egress standards and should not have evacuation problems assuming road conditions are normal. The benefits of designing neighborhoods in accordance with egress-test categories are reflected in the fact that neither exit would be overwhelmed during egress (Figure 52).

Interior Bottleneck Analysis: Jester Estates

Jester Estates CFA map shows a large potential for interior bottlenecks in several places (Figure 53), and contrasts sharply with the spatial distribution of exits in Westminster Glen (Figure 54). The map displays the implications of Jester Estates' failure of all egress tests. Bottlenecking is likely to occur on sections of Jester Blvd., far from any egress point, and also near one of the exits (Table 9) (Figure 55).

CFA results also show that there are likely to be problems in Canyon Ridge and Jester Point, two sections of Jester Estates described above in the discussion of the egress tests. Even these sub-sections failed most tests. The CFA demonstrates the inefficiency of closely spaced exits.

Network analysis results for simulated nearest exit paths for each home in Jester Estates graphically exhibits the results of the egress tests. In fact they demonstrate the evacuation problems inherent in any UP subdivision with poor egress. Jester Estates and Westminster Glen are very different neighborhoods, but network analysis can display the strengths and weaknesses of different road network designs.

Earlier capacity test results for Jester Estates subsections Canyon Ridge and Jester Point (Table 4) provide a platform for examination of bottlenecks.

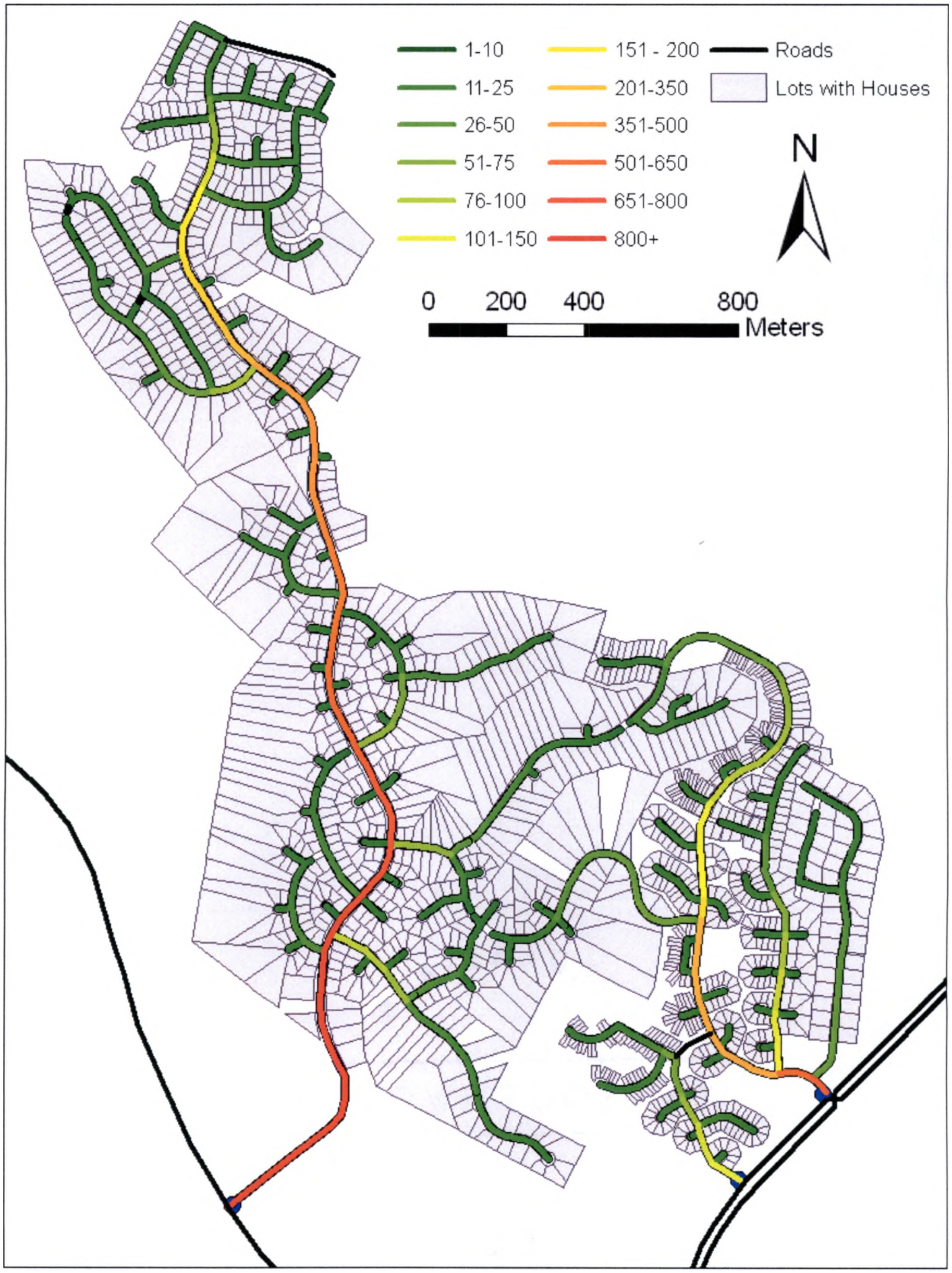

Figure 53. CFA Projected Egress Traffic Distribution: Jester Estates.

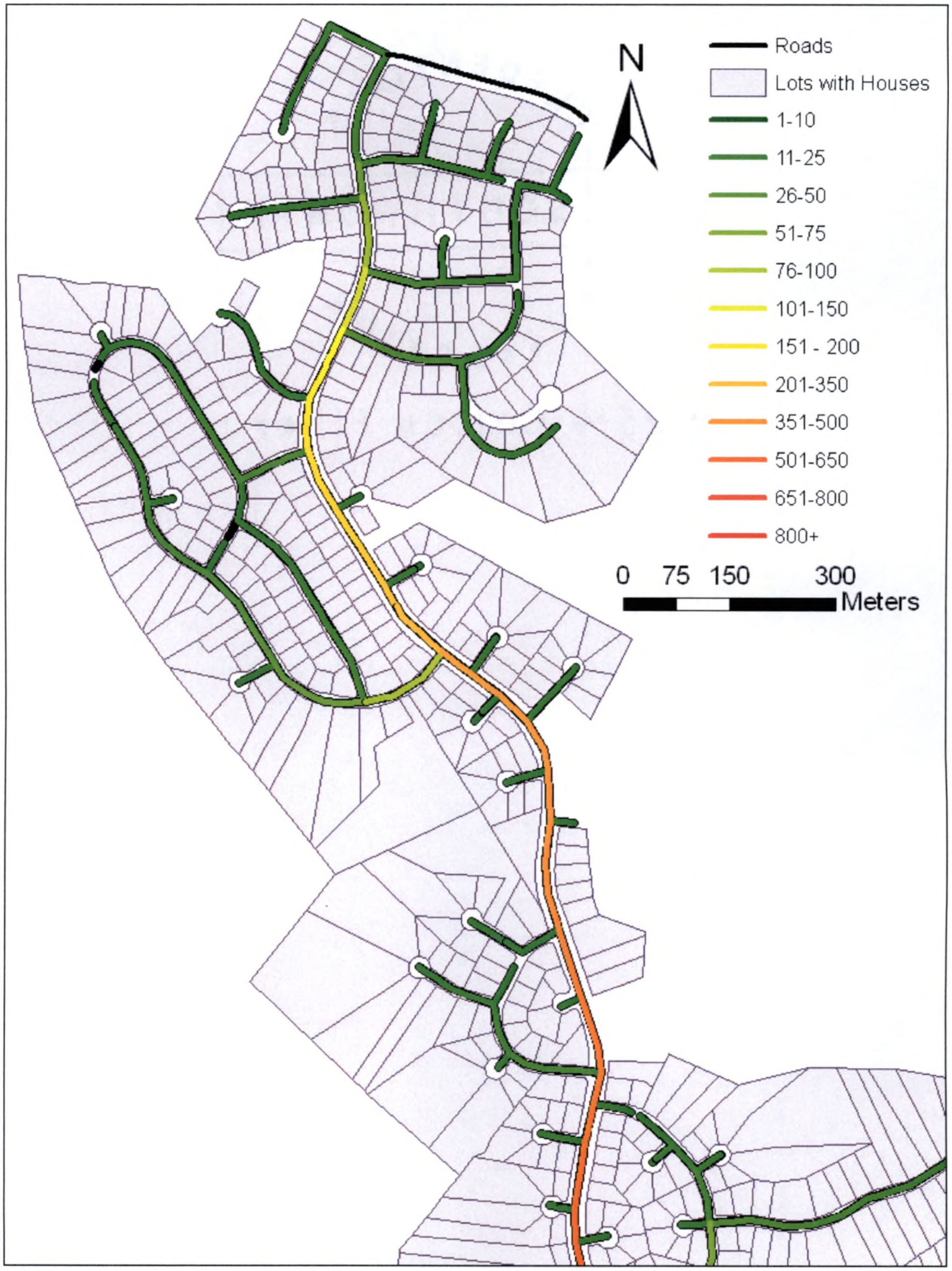

Figure 54. Close up Network Analysis of Jester Point/Canyon Ridge.

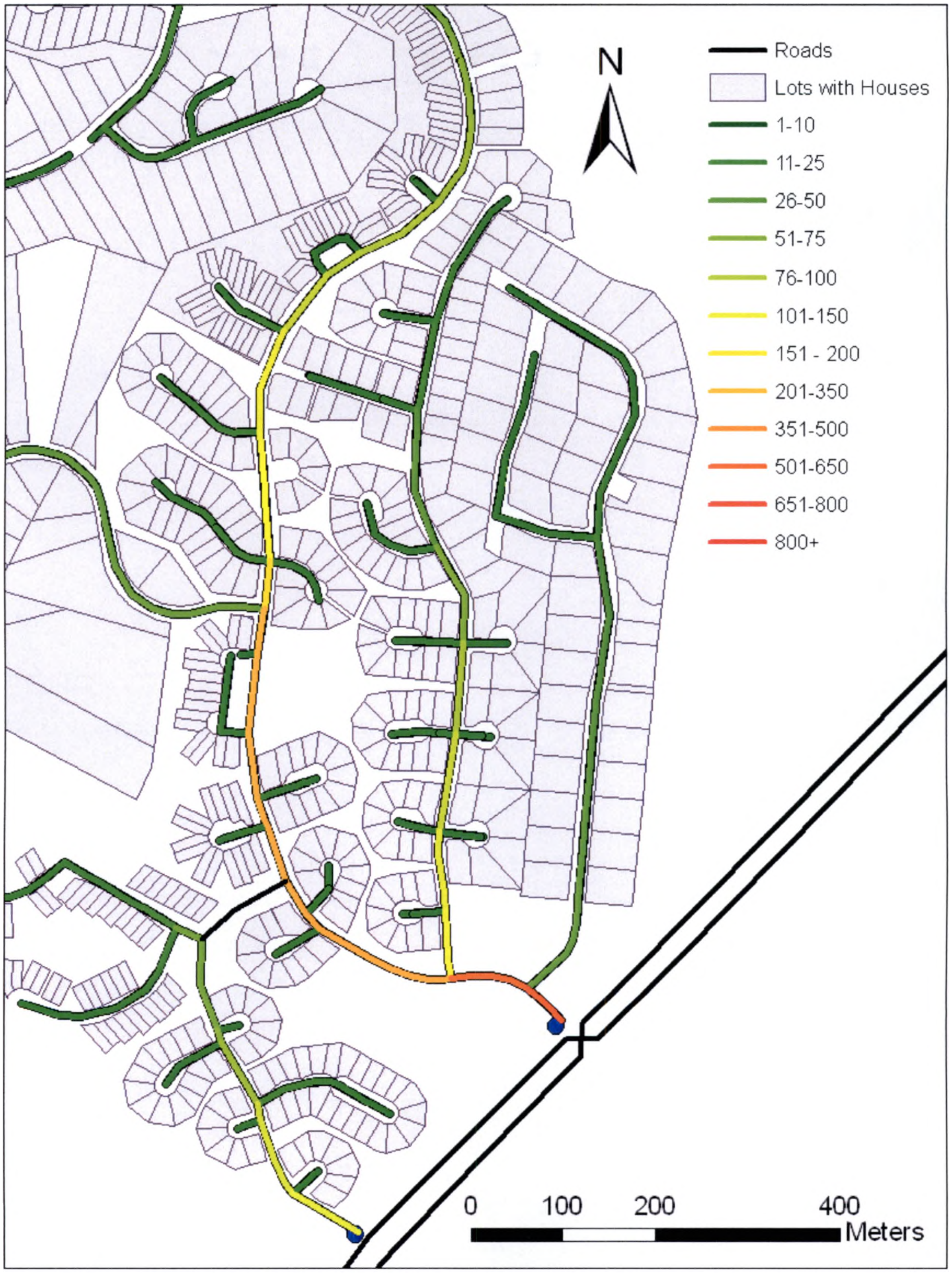

Figure 55. Close Up Map of Jester East.

Given the egress test results that indicate that both sub-sections exceed capacity standards based on the number of households and the number of exits, a closer look at bottleneck formation might be helpful.

All homes in Jester Point must rely on a single exit. CFA results confirm that residents would be stuck in bottlenecks and could not escape quickly. Automobiles are limited to roadways during evacuations. Eventually all cars must manage to move through navigable exits to escape neighborhoods. Egress demand overwhelming capacity will impede evacuation and residents would either be stranded or would be forced to flee on foot. Eleven of the thirteen deaths in Cedar Fire in San Diego County, California resulted from bottlenecks (Cal Fire, 2007).

Almost as many vehicles must exit through Jester Point's single exit as are projected to pass through exit 3 and three times as many as the number that would use exit 2. It is a pronounced and obvious interior bottleneck.

Road Network Inefficiency and Exit Spacing

So far, discussion of exit spacing has focused mainly on the potential for obstruction by wildfire. But exit spacing also affects the distribution and location of exits. Analysis of Westminster Glen's road network shows that the closest "facility" routes diverge near the neighborhood's center. An equal number of households are closest to the east exit as to the west exit. Jester Estates' traffic flows toward the south as all three exits, some of which are very distant from northern sections, are on the same side.

More than half of the CFA paths travel through the west exit. Exits 2 and 3 are closely spaced and farther from most of the homes in the neighborhood. Exit 1 must take the brunt of the traffic, and would result in unbalanced evacuation demand.

An inefficient distribution of exits also exists within eastern Jester Estates. Road network design forces most traffic onto a single street in this part of the neighborhood. A major bottleneck exists and would emerge even if individuals decided to redistribute traffic in response to the congestion. The spacing of exits distributes traffic only slightly better than if there were only one exit in this part of the neighborhood. Better spacing of the third exit allows for better egress.

CHAPTER VII

DISCUSSION AND CONCLUSION

Egress Analysis

There is a need to apply research on the community exit problem in understudied areas due to the multiregional scope of WUI hazards. The analytical approach demonstrated in this research demonstrates a framework for comparing different subdivisions and developments threatened by a similar hazard.

An important discovery of this study is that the largest neighborhoods in the study area failed most egress tests. The study area is at high-risk for wildfires and the neighborhoods examined here are comprised of moderate to high-end housing. The spatial designs and types of road networks of the studied neighborhoods vary considerably. The analysis, however, provides a rational means of comparing egress. Subdivisions with numerous exits promote egress capacity when exits are adequately spaced, but other factors influence the degree to which egress capacity would affect a neighborhood. Jester Estates has the most exits (three), but fails to pass a single egress test. Exits are more widely spaced in the neighborhoods that are elongated, and in neighborhoods where egress is a single road exiting at opposite ends of the development. Neighborhoods, such as Steiner Ranch and Jester Estates are more compact and have poorly spaced exits Steiner Ranch and Jester Estates, tend to have poorly-spaced exits.

Study-area neighborhoods vary by age and development standards and there are factors beyond the simple number of exits and traffic that merit consideration. These include: road density (meters of road per home) and ratio of homes per exit. Road width and length also influence traffic density (Church and Sexton, 2002). Logically, egress is likely to be less constricted in neighborhoods with homes that are widely spaced (with more road length per home or car), but less densely developed (i.e. sprawling) neighborhoods require more space and more emergency personnel to defend (Cal Fire, 2007). The safety of the exits themselves should be factored in as well (i.e. if they are made more hazardous by failure to properly clear vegetation clearance or parked vehicles) (Church and Sexton, 2002; Cova and Johnson, 2005).

Analysis of the relationship between compliance and the age of the developments shows that newer subdivisions have not necessarily improved wildfire evacuation potential. Newer and recently expanded developments exhibit some progress in some categories (such as vegetation clearance along egress routes, fire-safe construction and wildfire resistant landscaping around homes). Nevertheless, the egress problem, not individual defensible space measures, is the focus here. The lack of progress in egress safety among newer neighborhoods means that the community-exit problem is not being attended to. A serious matter is the over-occupancy (based on egress capacity) of the largest neighborhoods. Egress in the study area has not improved even after the hazard has become well known.

Other Notes on the Research

This study has dealt with the topic of neighborhood wildfire evacuation and community exits at the neighborhood scale. It has not examined the issues of emergency response or evacuation timing. The methods employed demonstrate the evaluation of the best-case levels of egress under normal road conditions. Comparing projected evacuation efficiency among neighborhoods of the study are was the primary goal. The dynamics of wildfire response, timely provision of information and community education are important, but they are not the issues this research examined.

This study has not considered important factors like housing type, property value or demographics. The socio-economic resources neighborhoods or households may affect citizens' hazard awareness levels and preparedness, but these things are complex and are beyond the scope of this study. To be able to identify neighborhoods with egress problems could be valuable for prioritization of problem areas by emergency managers. Furthermore, identification of subdivisions in need of fire-safe and defensible-space features can help clarify where sheltering-in-place might be a necessary and viable fallback plan (Cal Fire, 2007; Cova et. al, 2009). Timely warnings are crucial in vulnerable neighborhoods (Dennison and Cova, 2007). Coordinating responses can be made more difficult by wildfires that cross jurisdictions. The relationship between wildfire distribution and recommended action needs much more research (Keeley et al., 2003; Kim et al., 2006; Cal Fire, 2007). Establishing neighborhood-based "fire safety councils" in the Austin metropolitan area would help fire-preparedness education. Similar councils have advanced fire safety, prevention and evacuation success in other places (California Governor's Office of Emergency Services, 2004; Cal Fire, 2007). Community education normalizes behavioral response within neighborhoods and this can be important because decision-making seems to be more erratic and panicky in neighborhood evacuations than it seems to be in other fire-escape scenarios (such as within buildings during structure-fires) (Cova, 2005). Even community awareness of simple measures, such as backing into driveways when fire risk is high so that those vehicles can pull onto roadways more efficiently, can take on life-or-death importance in evacuations (Church and Sexton, 2002). Clearing vegetation near roads reduces the likelihood of blocked exits (Cova, 2005) (Figure 56).

Multi-Family UP Developments and Egress

The development trend toward large multi-family residential complexes in Central Texas UP zones raises questions that could focus future research on community egress. These developments sometimes sit atop hills above traditional single-family neighborhoods (Figure 57). The same factors that drive suburban sprawl also promote development of "luxury" apartments where renters live in scenic exurban settings within commuting distances of urban employment. Evacuation from these complexes should be studied. These complexes represent the schizophrenia of U.S. land use: urban-living "in the country." As a result, both urban and rural hazard issues exist. They are urban building-evacuation challenges as well as wildfire hazards stemming from the "wildlands" of the automobile-dependent world. Egress is restricted by roads that are

Figure 56. Vegetation Buffer along Entrance/Exit to River Place.

Figure 57. Multi-Family Development Viewed from Long Canyon.

avalible to them as well, just as in the single-family spaces of UP neighborhoods. Hundreds of units sometimes rely on a single exit (Figure 58).

Exit Strategy

Urban growth in Central Texas will put more people into contact with the hazards normally associated with rural areas. Planners must account for wildfire evacuation potential in automobile-dependent neighborhoods. The capacity to safely exit a neighborhood should be a key concern. Residents should also be schooled on the creation of defensible spaces to protect themselves and their neighbors.

The exceptional droughts of recent times have promoted greater attention to the wildfire hazard in Central Texas, as climatic conditions since 2008 in particular have increased wildfire activity in the region. Strong winds and dry vegetation fueled the 1,500-acre Wilderness Ridge Fire near Bastrop (east of Austin) in March 2009. High winds downed power lines, sparking dry vegetation. Winds propelled the fire as it destroyed 26 homes in about two-hours, forcing evacuation of a wide rural/exurban area (Texas Forest Service, 2009).

That wildfire occurred on the mostly level terrain of the Blackland Prairie to the east of the Balcones Escarpment, but research shows that a similar fire in the Hill Country might have a more catastrophic effect on the built landscape (City of Austin, 2008). Topographic relief combined with the infrastructural development of the region complicates neighborhood defenses. Central Texas has recently seen wet winters (that effectively increase fuel biomass) followed by prolonged dry summers (that desiccate the abundant biofuels). Changing climate may be

Figure 58. Only Visible Automobile Exit for Multi-Family Development.

thus increasing wildfire probabilities throughout the region as well (Texas Forest Service, 2009).

Increases in anthropogenic wildfires are also a concern. The UP areas in Central Texas could surely benefit from both improved neighborhood egress and greater regulation of neighborhood design to combat wildfire. Additionally, creating defensible space should be of concern for UP homeowners.

The dramatic relief of the Hill Country is the only significant barrier to improving egress in the study area. There is limited development around these neighborhoods to block new road construction, but exits must be properly spaced to improve egress. Research on the relationship between neighborhood design and street networks and egress safety would greatly further the search for solutions to egress problems. Furthermore, creation of a visualization tool for GIS network analysis of bottlenecks (based on the manual closest facility method employed here) would be very beneficial.

Developers, land-use planners and conservation interests vie for control of the UP landscape. Conservationists and some planners advocate preserving open space among UP development. While this has environmental benefits, it may also complicate wildfire hazard management. More open space near development expands the UP and increases the need for UP wildfire management. The creation of a "climate" favorable to UP development combined with the push to preserve open space and the heightening probability of wildfire means that the community exit problem will increasingly require the attention of government entities, emergency planners, and UP residents.

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VITA

Jordan Ryan Stewart was born in Colorado Springs, Colorado on January 7, 1983, the son of Jack Albert Stewart and Eva Marie Stewart. His family relocated to Belton, Texas in 1985 and he spent most his entire childhood in Bell County, Texas. After doing basic coursework at Temple College, he transferred to Texas State University-San Marcos, where he received a Bachelor of Arts degree in Mass Communication-Electronic Media, with a minor in Geography, from the Texas State School of Journalism and Mass Communication in 2006. He returned to Texas State in 2007 to pursue a Master of Science degree in Geography. During May-June, 2008 he went to Hannover, Germany as a member of the Geography Department's Texas State/Hannover Exchange Program. For the past three years, he has been employed as a Stormwater Permitting Specialist as a Graduate Intern in the San Marcos, Texas office of the Texas State University-Texas Commission on Environmental Quality Government Partnership Program.

Permanent address: 19999 FM 2268

Holland, TX 76534

This thesis was typed by Jordan Ryan Stewart, B.A.