Single-Access Subdivisions Assessment Project:

Developing a Planning Tool for Evaluating Proposed Developments Accessible by Dead-End Roads

Prepared for

CAL FIRE and the California Board of Forestry and Fire Protection

By

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February 2016

Executive Summary

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When a wildfire threatens a single-access subdivision, potentially life-threatening problems may arise when occupants seek to evacuate to a safe location while fire and other responders try to manage the emergency. Even when access is not disrupted by fire or smoke, factors such as inadequate road widths, steep grades, traffic congestion, and obstacles in the road can interfere with safe and timely in- and out-movement, possibly causing entrapment of occupants and preventing responders from gaining access to do their job.

Under California's Subdivision Map Act (known as the "Map Act"), authority is given to cities and counties to regulate and control the subdivision of real property. Under the provisions of recent legislation[1], the agency having jurisdiction must find (among other things) that the design and location of a proposed subdivision must be consistent with applicable regulations adopted by the State Board of Forestry and Fire Protection (the "Board") pursuant to Sections 4290 and 4291 of the Public Resources Code (PRC). Under PRC 4290, standards established in 1991 govern the maximum length of dead-end roads, including all additional dead-end roads accessed from the initial dead-end road. The intent of the standards is to **provide for safe egress and ingress of occupants and fire personnel/equipment during a wildfire.**

Table 1-1: Dead-End Road Maximum Lengths (Current Standards)

Parcel Size Allowed by Zoning	Maximum Dead-End Road Length
Less than 1 acre	800 feet
1 acre to 4.99 acres	1,320 feet
5 acres to 19.99 acres	2,640 feet
20 acres or larger	5,280 feet

[1] Senate Bill 1241 (2012), which amends Sections 65302 and 65302.5 and adds Sections 65040.20 and 66474.02 to the Government Code and adds Section 21083.01 to the PRC.

The standards stipulate that dead-end roads shall not exceed the cumulative lengths shown in Table 1-1, **regardless of the numbers of parcels served**. Exceptions to the standards are permitted when it can be demonstrated that "the same practical effect" can be achieved, that is, if **alternative practices effectively meet the regulatory intent**. [2]

The maximum dead-end road lengths permitted by the standards depend ***only*** on parcel sizes allowed by zoning and do not take into account other factors affecting egress and ingress, such as:

- Land use (e.g., maximum allowable residential density under the general plan, square feet of commercial space, sizes of facilities such as schools, hospitals, etc. -- all determining the number of people potentially needing to exit the subdivision in the event of a fire)
- Demographics (e.g., proportions of youth, adults, seniors)
- Road system (e.g., roadway width, grade, condition, connections to other roads, etc.)
- Fire hazard (e.g., presence and type of hazardous fuels, potential for extreme weather, adverse topography, etc.)
- The location of, and conditions at, the intersection where occupants exit from the dead-end road, which itself may not be safe in the event of a fire

Because they do not take into account these other factors, the current standards in many instances may not adequately provide for safe egress and ingress of occupants and fire personnel/equipment in the event of a fire. Furthermore, in situations where proposed dead-end roads would exceed the maximum lengths specified in the standard, the standards give no guidance on how to determine whether "the same practical effect" might be achieved by mitigation (e.g., by controlling the mix of residential and commercial land uses, adjusting the roadway characteristics, etc.).

It should be noted that the current standards make no explicit reference to the time needed for safe egress or ingress. However, **implicit** assumptions about time are built in to the standards. For example, by specifying a maximum dead-end road length of 800 feet in a single-access subdivision zoned for parcels below 1 acre in size, the implicit assumption is made that the occupants could be evacuated along a road of this length in less time than it would take for a fire to overtake them. The standards also make no reference to where a fire might start, nor to the conditions (e.g., vegetation, topography, wind speed, moisture level, etc.,) that affect fire behavior once ignition has occurred.

The present study was intended to assess the current standards, to provide a defensible foundation for establishing new standards if needed, and to develop a simple-to-use planning tool based on computer modeling that can be applied by jurisdictions, developers, and others to (1) judge whether a project proposal is likely to satisfy the "same practical effect" criterion meant to meet the regulatory intent of assuring "safe egress and ingress of occupants and fire personnel/equipment during a wildfire," and (2) assist them in identifying mitigation options that will enable this criterion to be met.

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[2] Ibid. 1270.07 *Exceptions to Standards.*

For this purpose, we attempted to model how long it takes, in the event of a fire, for:

- Occupants of a single-access subdivision to reach an intersection with a through road that gives a choice of two or more directions in which to travel from that intersection; and
- Fire personnel/equipment to reach where they need to be in order to fight the fire.

Our modeling led to the development of a user-friendly tool that estimates how quickly occupants can leave a subdivision as a function of:

- Intensity of development or number of people to evacuate (expressed in number of vehicles);
- Physical size of development or distance to traverse;
- Potential travel speed for the given design speed of segments in the road network; and
- Design speed of roadway segments.

As it turned out, despite having response time data from around the state (as reported to CAL FIRE), it was not possible to model with adequate confidence the time taken for fire personnel/equipment to reach a fire (as opposed to occupants evacuating).

Also, we initially had hoped to incorporate fire behavior as a variable directly into our access model and the resulting tool. Without having a fire behavior expert involved in each application of the tool, this did not prove possible. However, we were able to develop a simplified fire behavior model allowing planners and others to consider evacuation time information (from applying the tool) in light of information about the likely rate of spread and intensity of a wildfire.

Application of the tool to various hypothetical subdivision configurations falling into the zoned parcel size categories listed in the present standards led to the following findings:

- In relatively good conditions (e.g., no congestion or no visibility constraints), egress time was sometimes but not always less than 10 minutes.
- Subdivision configurations with the smallest and largest parcels showed the greatest potential for problems with evacuation. In subdivisions with the smallest parcels, assuming that developers will typically construct as many residential units as possible in a bid to maximize return on investment, large numbers of residents potentially will have to be evacuated. In subdivisions with the largest parcels, residential units will be spread out, creating long traverse distances during evacuation. These results illustrate the flaw in the language of the existing standards ("regardless of the number of parcels served") that permits the size of development and the number of occupants to be ignored.
- Scenarios involving unconstrained conditions depicted the best possible results, but these conditions are not thought likely to occur under emergency conditions. Scenarios involving congested conditions depicted more likely results, but even these scenarios still assumed that there would be no obstruction (bottleneck) where the single-access road exits on to a through road. The existing standards do not address the potential for bottlenecks.
- The problems are likely to be most severe when land use is not limited to single-family residential. Condominiums, mobile home parks, campgrounds, retail-commercial, schools, and churches are among the other, more intense forms of development that can occur. In these

types of development, many more people may need to be evacuated in a fire emergency, for example if a school is in session or a church service is being held. This observation illustrates a further flaw in the existing standards, which ignore the type of development that is being proposed as well as the possibility that the intensity of land use will change over time..

The tool was subsequently applied to 14 case studies representing a variety of access situations in the wildland-urban interface, including subdivisions with single or multiple access, residential or other land uses (such as schools and churches), and/or problematic connections to arterials or other through roads. One case allowed us to explore the potential effect of smoke from a wildland fire.

The results of applying the tool to case studies were consistent with those of applying it to hypothetical configurations, and led to the following preliminary conclusions:

- The type and intensity of land use in single-access subdivisions should not be ignored.
- Simply providing two entrances for a development of uncontrolled size may not be sufficient to ensure safe evacuation of occupants in the event of an emergency.
- Potential effects of fire on visibility can add significantly to clearance times.
- Potential effects of perennial delays at a primary through road intersection can add significantly to clearance times
- Simply adding an additional lane to the primary single access road for evacuation does not appear to improve evacuation times. Adding a true second access that is independent of the first (meaning the two exits are neither close together nor access the same through road) offers a significant reduction in clearance time. In developments with high intensities of land use, however, clearance time can remain high. In these developments, multiple entrances (not just one or two) could offer the highest potential for timely evacuation.

The findings of the study led to the following recommendations:

1. **Amend the existing dead-end road standards**

We recommend that the existing standards be amended for the following reasons:

a) Maximum dead-end road lengths are based solely on parcel size.
b) The standards assume that subdivisions are only for single-family residential uses.
c) The standards place no limit on the number of lots in subdivisions.
d) The standards allow for stacking of multiple roadways within maximum length limits.
e) The standards do not provide for reasonable evacuation times for all road length categories.
f) The standards do not consider other land uses such as commercial uses, apartments, or schools.
g) The standards do not take into account potential long-term land use intensification.
h) There is no clearly stated enforcement mechanism or penalty for non-compliance.

To eliminate existing flaws and loopholes, and to provide informed guidance to jurisdictions, developers, and other stakeholders, we recommend that the standards be amended with the following considerations in mind:

a) The existing table of maximum road lengths for dead-end roads should be eliminated.
b) Other factors in addition to lot size should be addressed, including potential land uses, with attention paid to likely occupancy, now and in the future.
c) Open-ended loophole wording, such as "regardless of number of lots," should be eliminated.
d) The stacking of multiple roadways within maximum road length limits should be limited.
e) The maximum evacuation traffic generation potential of all land uses, including commercial uses, apartments, and schools, should be taken into account.
f) Potential long-term land use intensification should be addressed.

2. **Require application of the tool and appropriate mitigation measures**

We recommend that any proposal for a single-access subdivision in an SRA (or in a Local Responsibility Area [LRA] if the local jurisdiction has adopted the state's recommendation of a very high fire hazard severity zone) should trigger analysis by means of the tool developed in this study. Even when secondary access is available, we recommend requiring analysis by means of the tool in any SRA that is categorized as a high or very high Fire Hazard Severity Zone. We recommend this because, depending on the size of the subdivision, secondary access does not necessarily guarantee adequate exiting capacity. Exiting capacity is relevant for all wildland-urban interface subdivisions, not just single-access subdivisions.

Use of the planning tool would permit agencies having jurisdiction to estimate the time required to evacuate the occupants of a proposed subdivision in the event of a fire or other emergency. It would then be up to the agency to decide whether the time is likely to exceed that needed for occupants to be evacuated safely. If the intent of the regulation is to be met, the agency cannot avoid deciding on an evacuation time considered to be safe, if not explicitly then implicitly.

The agency might be helped in deciding on a safe evacuation time by results from application of the fire behavior model. However, the model cannot tell us with precision how quickly occupants would be overtaken by a fire, both because of our inability to predict where a fire might start and the conditions under which it would burn, and because the model was intentionally designed to be overly simplified in order to allow its application by those who are not experts in fire behavior. Potentially, as part of the regulation, the state could specify an upper limit to this time, to ensure that an agency stays within reasonable boundaries.

If the agency decides that the egress time from a proposed subdivision is likely to be too long for occupants to be evacuated safely in the event of a fire, an option would be for the analysis to be repeated with additional mitigation measures incorporated into the proposal[3]. These measures may include, for example, changes in the capacity of access roads in order to speed up evacuation and/or fuel modification techniques to slow the spread of fire. The analysis might show that, with these

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[3] "Additional" reflects the assumption that some mitigation measures would have been included in the proposal as originally submitted and analyzed.

mitigation measures required as a condition of approval by the agency and put in place, the intent of the regulation would now likely be met.

3. **Tie in the preceding recommendations with Senate Bill 1241 (2012)**
General plans govern land use intensification and are especially relevant to single-access subdivision land use capacity and occupancy considerations. Approval for a new subdivision is contingent on the proposal being consistent with the general plan. Legislation enacted in 2012 requires that additional mandatory findings be made before approval can be granted to a proposed subdivision in an area located within an SRA or a locally adopted very high fire hazard severity zone, specifically (1) that the design and location of the subdivision are consistent with applicable regulations adopted by the State Board of Forestry and Fire Protection pursuant to PRC Sections 4290 and 4291, (2) that structural fire protection and suppression services will be available for the subdivision, and (3) that, to the extent practicable, ingress and egress for the subdivision meet the regulations regarding road standards for fire equipment access adopted pursuant to PRC Section 4290 and any applicable local ordinance. We recommend that special attention be given to implementing these requirements for additional mandatory findings under Senate Bill 1241.

4. **Explore potential opportunities and challenges related to strengthening enforcement of the modified dead-end road standards**
We recommend giving attention to possible mechanisms to bring about more uniform compliance, addressing non-compliance situations and seeking options (such as fines and other penalties) at the local level that go beyond case law. We further recommend the establishment of a mandatory appeal process to a higher authority such as the State Board of Forestry and Fire Protection.

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ACKNOWLEDGMENTS

The Cal Poly team thanks Jana Luis, who served initially as the Project Officer for CAL FIRE and continued to provide valued input after a promotion caused her to relinquish this formal role. Thanks are also due to CAL FIRE officials Pete Munoa, who took over as Project Officer, and Matt Damon. Edith Hannigan is thanked for her comments and suggestions as a consultant to the Board of Forestry and Fire Protection.

Assistance in our efforts to model fire behavior was kindly provided by David Sapsis, David Passovoy, and Tadashi Moody, all of CAL FIRE's Fire and Resource Assessment Program.

The Cal Poly team also wishes to acknowledge contributions over the course of this project from several graduate student assistants and a few undergraduate students, all in City & Regional Planning at Cal Poly. The assistants and their contributions were as follows:

Student Name	*Contributions*
Lance Knox	For technical assistance with GIS mapping and formatting of worksheets during development of the access model.
Ben Rady	For graphics support and data entry during applications of the access model and preparation of study documentation.
Ricky Williams Jana Schwartz Evelyn Garcia Jose Palma Kip Morais	For initial literature search on previous fires in California, search for documentary data on fires, field visits, and review of related legislation. They also contributed to the location of available GIS data.
Kissila Santos Julia Marques Felipe Schuckar	Brazilian undergraduate student interns who enthusiastically learned the SPSS statistical package and applied it in the exploration and analysis of CAL FIRE data on response times.

Meg Henry kindly provided assistance as Project Research Analyst early in the project and subsequently helped to format the final report. Natalie Macris is thanked for copy editing the final report.

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1.0 THE PROJECT

Background

Subdivision Map Approval Process

Standard land subdivision practice normally includes provision of at least two points of vehicle access to allow for safe egress of occupants and efficient ingress by responders in case one point is blocked in an emergency. Where terrain, property ownerships, or other constraints make only a single access feasible, with all parties using one dead-end road, it is important to take special precautions to minimize risk in an emergency.

When a wildfire threatens a single-access subdivision, potentially life-threatening problems may arise when occupants seek to evacuate to a safe location while fire and other responders try to manage the emergency. Even when access is not disrupted by fire or smoke, factors such as inadequate road widths, steep grades, traffic congestion, and obstacles in the road can interfere with safe and timely in- and out-movement, possibly causing entrapment of occupants and preventing responders from gaining access to do their job.

Under California's Subdivision Map Act (known as the "Map Act"), authority is given to cities and counties to regulate and control the subdivision of real property. The statute specifies two steps for the approval of a new subdivision: (1) tentative map approval, which determines the overall subdivision design and improvements; and (2) final map approval. The second step is a purely ministerial process, meaning that the final map is automatically approved once stated terms and conditions have been met.

In the first step, the tentative map is reviewed by the locally designated "advisory agency," which can be at any level as determined by the governing body. Many localities delegate this process primarily to staff, so the review is conducted by a committee composed of representatives of planning, engineering, fire, and other interested departments. Staff determinations are generally subject to review at a higher level such as the planning commission and/or board of supervisors or city council.

Under the Map Act, tentative map approval requires that certain mandatory findings be made for the record. One of these mandatory findings is that the tentative map, including its design and improvements, is consistent with the general plan.[4] Tentative map approval is a discretionary action under the California Environmental Quality Act (CEQA), requiring a Mitigated Negative Declaration (MND) or an Environmental Impact Report (EIR), depending on size and impact of the proposed subdivision. Tentative map conditions are the primary means used to ensure the implementation of mitigation measures identified in the MND or EIR before the final map is recorded.

[4] Government Code Section 66473.5.

Under the provisions of recent legislation,[5] for tentative map approval to be granted to a proposed subdivision in an area located within a State Responsibility Area (SRA)[6] or a locally adopted Very High Fire Hazard Severity Zone (FHSZ), the following findings beyond those required by the Map Act must be made: (1) that the design and location of the subdivision are consistent with applicable regulations adopted by the State Board of Forestry and Fire Protection (the "Board") pursuant to Sections 4290 and 4291 of the Public Resources Code (PRC), (2) that structural fire protection and suppression services will be available for the subdivision, and (3) that, to the extent practicable, ingress and egress for the subdivision meet the regulations regarding road standards for fire equipment access adopted pursuant to PRC Section 4290 and any applicable local ordinance.

Existing Fire Safe Standards

PRC Section 4290 requires the Board to adopt minimum fire safe standards applicable to SRA lands under the fire protection authority of the Department of Forestry and Fire Protection (CAL FIRE). Standards established in 1991 on the basis of practical experience of firefighting and planning professionals at that time[7] presently govern the maximum length of dead-end roads, including all additional dead-end roads accessed from the initial dead-end road. The intent of the standards is to ***provide for safe egress and ingress of occupants and fire personnel/equipment during a wildfire.***

Table 1-1: Dead-End Road Maximum Lengths (Current Standards)

Parcel Size Allowed by Zoning	Maximum Dead-End Road Length
Less than 1 acre	800 feet
1 acre to 4.99 acres	1,320 feet
5 acres to 19.99 acres	2,640 feet
20 acres or larger	5,280 feet

The standards stipulate that dead-end roads shall not exceed the cumulative lengths shown in Table 1-1, regardless of the numbers of parcels served. Exceptions to the standards are permitted when it can be demonstrated that "the same practical effect" can be achieved, that is, if ***alternative practices effectively meet the regulatory intent***.[8] As will become apparent in this report, this study concludes that the current standards themselves do not meet the declared intent of the regulation.

[5] Senate Bill 1241 (2012), which amends Sections 65302 and 65302.5 and adds Sections 65040.20 and 66474.02 to the Government Code and adds Section 21083.01 to the Public Resources Code

[6] PRC Section 4102 defines SRAs as "areas of the state in which the financial responsibility of preventing and suppressing fires" is "primarily the responsibility of the state."

[7] California Code of Regulations Title 14, 1270, Fire Safe Regulations, Section 1273.09 Dead-*end Roads.*

[8] Ibid. 1270.07 *Exceptions to Standards.*

The maximum dead-end road lengths permitted by the standards depend ***only*** on parcel sizes allowed by zoning and do not take into account other factors affecting egress and ingress, such as:

1. Land use (e.g., maximum allowable residential density under the general plan, square feet of commercial space, sizes of facilities such as schools, hospitals, etc. – all determining the number of people potentially needing to exit the subdivision in the event of a fire)
2. Demographics (e.g., proportions of youth, adults, seniors)
3. Road system (e.g., roadway width, grade, condition, connections to other roads, etc.)
4. Fire hazard (e.g., presence and type of hazardous fuels, potential for extreme weather, adverse topography, etc.)
5. The location of, and conditions at, the intersection where occupants exit from the dead-end road, which itself may not be safe in the event of a fire

Because they do not take into account these other factors, the current standards may not adequately provide for safe egress and ingress of occupants and fire personnel/equipment, respectively, in the event of a fire. Furthermore, in situations where proposed dead-end roads would exceed the maximum lengths specified in the standard, the standards give no guidance on how to determine whether "the same practical effect" might be achieved by mitigation (e.g., by controlling the mix of residential and commercial land uses, adjusting the roadway characteristics, etc.).

It should be noted that the current standards make no explicit reference to the time needed for safe egress or ingress. However, ***implicit*** assumptions about time are built in to the standards. For example, by specifying a maximum dead-end road length of 800 feet in a single-access subdivision zoned for parcels below 1 acre in size, the implicit assumption is made that the occupants could be evacuated along a road of this length in less time than it would take for a fire to overtake them. The standards also make no reference to where a fire might start, nor to the conditions (e.g., vegetation, topography, wind speed, moisture level, etc.,) that affect fire behavior once ignited.

Purpose of Study

This study is intended to assess the current standards, to provide a defensible foundation for establishing new standards if needed, and to develop a simple-to-use planning tool based on computer modeling that can be applied by jurisdictions, developers, and others to (1) judge whether a project proposal is likely to satisfy the "same practical effect" criterion meant to meet the regulatory intent of assuring "safe egress and ingress of occupants and fire personnel/equipment during a wildfire," and (2) assist them in identifying mitigation options that will enable this criterion to be met.

Because of the nature of the tentative map approval process described above, we designed the planning tool so that informed non-technical participants (such as members of the public, the planning commission, the board of supervisors, or the city council) would be able to use it without having to seek the advice of an expert. The non-technical user would be able to enter relevant information and receive understandable results, with the calculations proceeding in the background. By changing the inputs, the user would be able to test different scenarios (e.g., alternative mitigation strategies).

For this purpose, we attempted to model how long it takes, in the event of a fire, for:

- Occupants of a single-access subdivision to reach an ***intersection with a through road**.* For the purpose of this study, we defined a through road as one that gives a choice of two or more directions in which to travel from the intersection.[9]
- Fire personnel/equipment to reach where they need to be in order to fight the fire.

Overall Methodology

In the context of a wildfire occurrence, access involves four phases of activity: discovery, notification, reaction, and travel. In this project we focused only on the travel phase. The other three phases are highly variable and would typically precede the fourth phase. In a worst case, all four phases could occur in quick succession, but the travel phase would always be at the tail end of the activities.

We set out to develop a prototypical access planning and evaluation tool ("the tool") that would allow the user to estimate the time (T) needed for evacuation of occupants from a single- access subdivision threatened by a fire to an intersection with a through road,[10] and/or ingress of emergency response personnel/equipment to the fire's location, as a function of key variables or combinations thereof ($KV_{1,}$ KV_2, KV_3, etc.).

$$T = f(KV_{1,}\ KV_2,\ KV_3,\ \ldots)$$

Initially, the key variables to be included in the underlying model were to be drawn from the following four groups of factors or combinations thereof:

- Proposed land use
- Demographic composition of proposed development
- Road system characteristics
- Fire behavior

As it turned out, we were unable to incorporate fire behavior as a variable directly into a model that could be applied by those who are not themselves fire behavior experts. Nevertheless, as discussed later in this report, we were able to develop a means by which planners and others may choose to combine the results of applying the tool with information about the likely rate of spread and intensity of a wildfire.

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[9] Note that the regulation's intent is not necessarily met by occupants reaching an intersection with a through road, since the intersection might not be safe and the through road might not lead to a safe location.

[10] The structural fire protection engineering equivalent of this time is the Actual Safe Egress Time (ASET). ASET is the actual time for occupants to reach a "safe place."

Egress

As ultimately developed, the tool estimates how quickly occupants can leave a subdivision as a function of:

- Intensity of development or number of people to evacuate (expressed in number of vehicles);
- Physical size of development or distance to traverse;
- Potential travel speed for the given design speed of segments in the road network; and
- Design speed of roadway segments.

The tool is designed to handle up to 250 roadway segments in one application.

The tool's input screen is designed to be user-friendly, allowing the entry of simple information such as the proportion of different land use types being proposed (e.g., single-family residential, multi-family residential, school, commercial, etc.). The tool estimates the number of persons associated with the land use types and sizes, based on default values. However, each agency having jurisdiction can enter its own values.

Ingress

We also explored the possibility of incorporating into the tool the time needed for emergency response personnel/equipment to reach the fire's location. We intended to use data for response times of emergency responders that were supplied by CAL FIRE for the past 5 years.

However, ultimately we decided not to incorporate response times into the tool in its present iteration, in part because of a lack of confidence that the currently available data accurately reflect what we were trying to measure. One of the problems is the uncertainty about the location of CAL FIRE vehicles when response time measurements are initiated (i.e., the vehicles may not start out from a fire station and/or they may already be on their way to a fire when they report that they are responding). Furthermore, for the purpose of this study, we assumed that the safe evacuation of occupants is typically the first priority.

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2.0 ACCESS MODELING

Methodology for Applying the Tool

Input Data

The application of the access model requires the conversion of a subdivision (whether existing or proposed) into a schematic of links (or roadway segments) and nodes (or intersections). At a minimum, the information needed along each link includes:

1. Length of link (feet)
2. Number of directional lanes
3. Posted speed limit ***or*** design speed (in miles per hour [mph])
4. Number of houses and other land uses (existing or proposed)

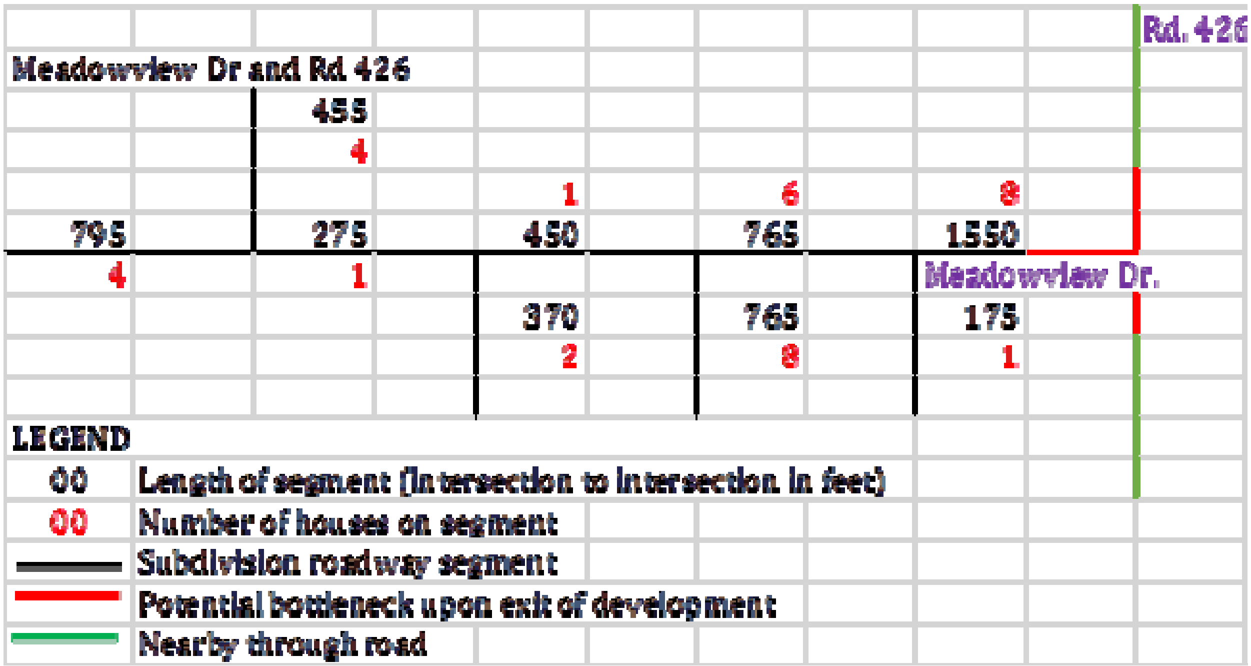
Figure 2-1 illustrates a sample subdivision network, with its application schematic shown in Figure 2-2. Appendix 1 (Additional Details on Access Modeling) includes additional examples of applications.

Figure 2-1: Sample Subdivision Network

LEGEND

(black line)	Subdivision roadway segment
(red line)	Potential bottleneck upon exit of development
(green line)	Nearby through road

Figure 2-2: Application Schematic for Sample Subdivision Network



Additional information required for background calculations of ***roadway capacity*** includes:

1. Lane width (feet)
2. Shoulder width (feet)
3. Access-point density (that is, number of intersections on one side of the street per mile)
4. Terrain (level, rolling)
5. Percent no-passing zone (20%, 40%, 80%)
6. Length of passing lane (if present)

Capacity Calculation

The calculation of roadway capacity is a multi-step process involving Highway Capacity Methods of the 2010 Highway Capacity Manual (HCM).[11] Procedures are adapted from Chapter 15 of the 2010 HCM. Appendix 1 (Additional Details on Access Modeling) includes details.

Speed and Travel Time Calculation

The calculation of vehicle speed and travel time is a multi-step process involving Highway Capacity Methods of the 2010 HCM. Procedures are adapted from Chapter 16 of the 2010 HCM. Appendix 1 (Additional Details on Access Modeling) includes details.

[11] The HCM is a publication of the Transportation Research Board of the National Academies of Science. Engineers and planners use the HCM to assess the traffic and environmental effects of highway projects.

Total Travel Time

The total travel time involved in evacuating occupants in vehicles from a single-access subdivision on to a through road[12] is made up of:

1. The nominal time to clear all vehicles out of the development (Clearance Time); ***plus***
2. The sum of any delays encountered by individual vehicles as they approach the intersection with the through road (estimated using HCM methods).

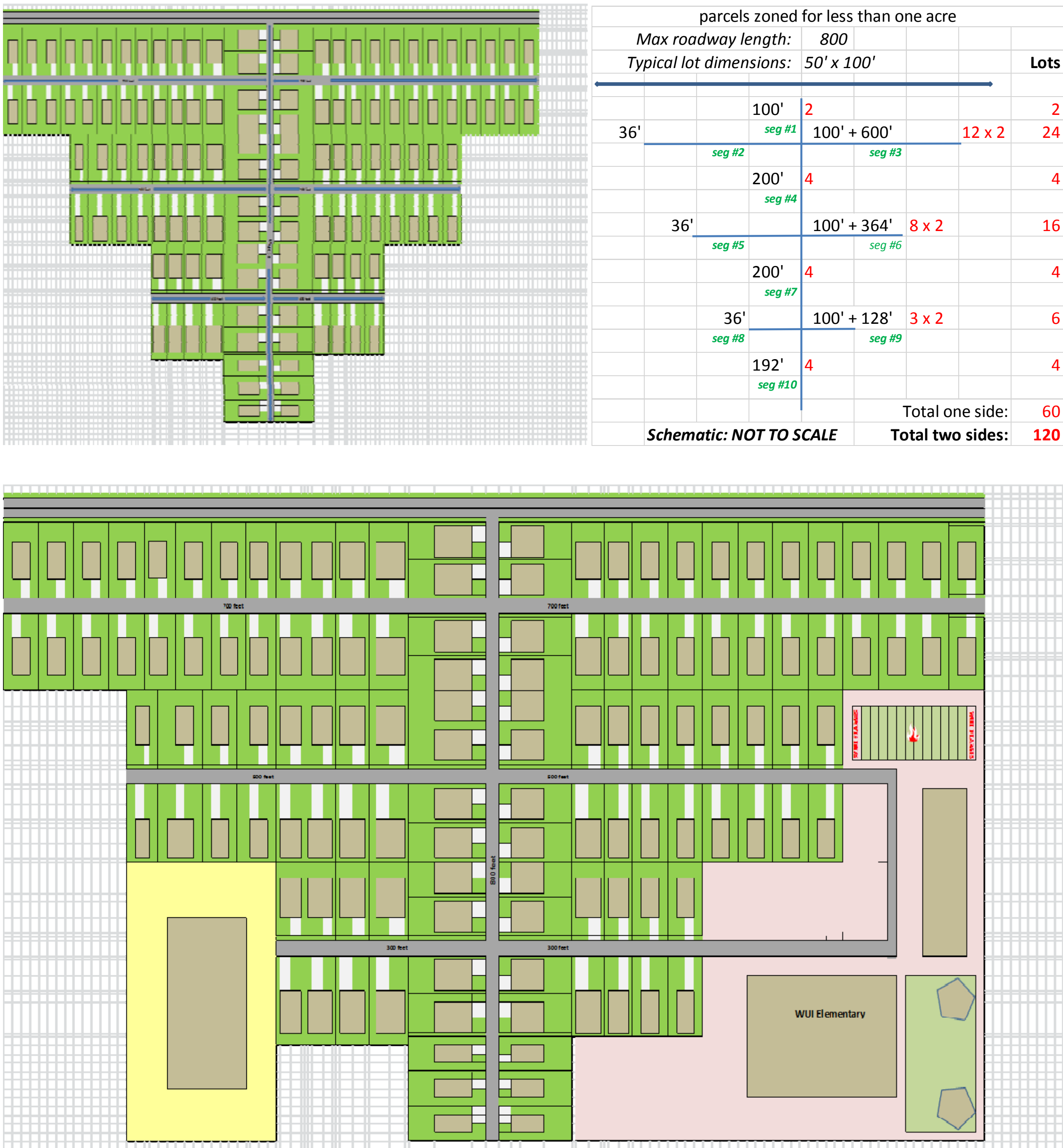
Initial Assessment of Existing Standards

Hypothetical Configurations

We first considered how many parcels within a particular size category (less than 1 acre, 1 to 4.99 acres, etc.) can fit along the prescribed dead-end road maximum lengths, using various plausible but hypothetical configurations. For example, where zoning allows parcels of less than 1 acre, the standards allow a dead-end road to reach a maximum of 800 feet ***including cumulative lengths of dead-end roads accessed from the main dead-end road***. In other words, the standards allow one or more forks along the dead-end road and along the forks themselves (a condition known as "stacking"), provided that the length of the road from the far end of ***any*** fork does not exceed the prescribed maximum. Using the configurations illustrated in Figure 2-3 for a subdivision with parcels of less than 1 acre, it would be possible to comply with the standards with as many as 120 parcels in such a subdivision. For subdivisions with parcels between 1 acre and 5 acres, Figure 2-4 illustrates that it would be possible to comply with the standards with as many as 46 parcels. For subdivisions with parcels between 5 acres and 20 acres, it would be possible to comply with the standards with as many as 34 parcels, as illustrated in Figure 2-5. For subdivisions with parcels greater than 20 acres, it would be possible to comply with the standards with as many as 36 parcels, as shown in Figure 2-6.

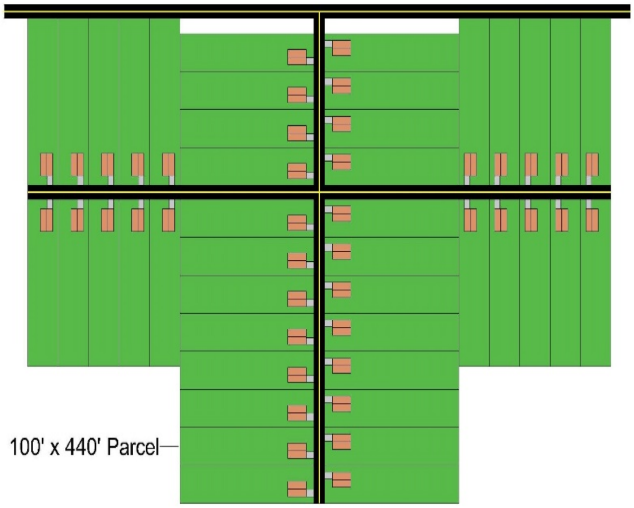
[12] As previously noted in footnote 7, the evacuation of occupants on to a through road may not by itself ensure their safety.

Figure 2-3: Sample Subdivision Network with Parcel Size of Less than 1 Acre

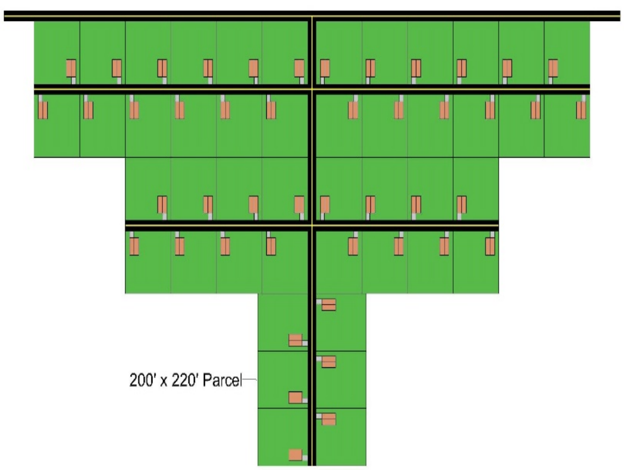


Maximum of 800 feet including cumulative lengths of dead-end roads accessed from main dead-end road. Upper image includes housing only; lower image includes housing and a school.

Figure 2-4: Sample Subdivision Network with Parcel Size of 1 to 5 Acres



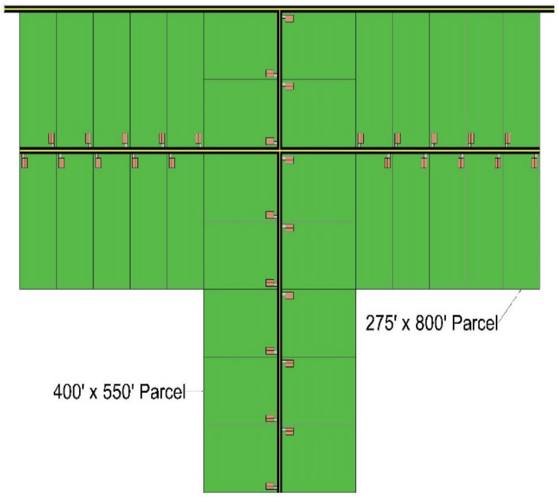
parcels zoned for 1 acre to 4.99 acres				
Max roadway length:	*1320*			
Typical lot dimensions:	*100' x 440'*			**Lots**
440'	4			4
36'		440' + 440'	5 x 2	10
440'	4			4
404'	4			4
			Total one side:	22
Schematic: NOT TO SCALE			**Total two sides:**	**44**



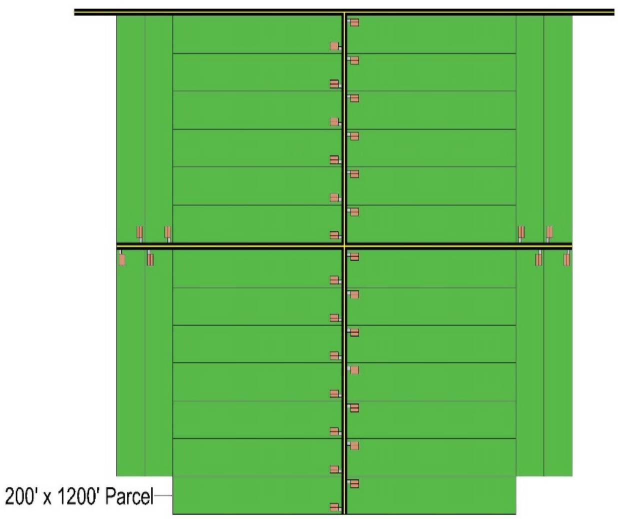
parcels zoned for 1 acre to 4.99 acres				
Max roadway length:	*1320*			
Typical lot dimensions:	*200' x 220'*			**Lots**
220'	0			0
36'		200' + 900'	6 x 2	12
440'	0			0
36'		200' + 424'	4 x 2	8
588'	3			3
				0
			Total one side:	23
Schematic: NOT TO SCALE			**Total two sides:**	**46**

Maximum of 1,320 feet including cumulative lengths of dead-end roads accessed from main dead-end road.

Figure 2-5: Sample Subdivision Network with Parcel Size of 5 to 20 Acres



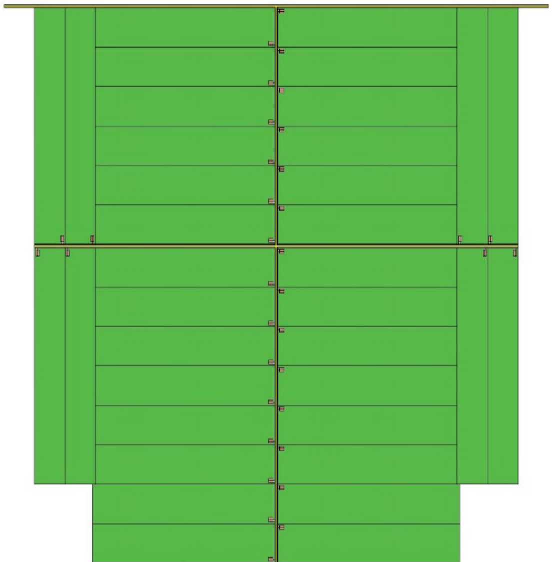
parcels zoned for 5 acres to 19.99 acres				
Max roadway length:	*2640*			
Typical lot dimensions:	*400' x 550' & 275' x 800'*			**Lots**
	800'	2		2
36'		550' + 1290'	5 x 2	10
	800'	2		2
	800'	2		2
	204'	1		1
			Total one side:	17
Schematic: NOT TO SCALE			**Total two sides:**	**34**



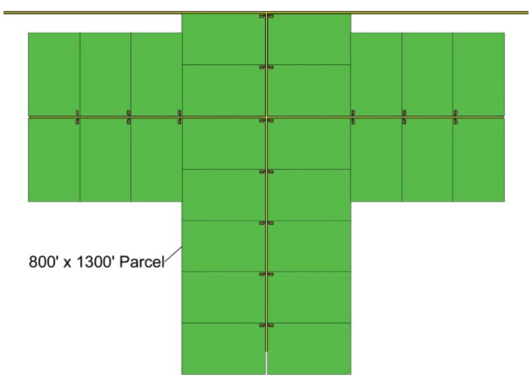
parcels zoned for 5 acres to 19.99 acres				
Max roadway length:	*2640*			
Typical lot dimensions:	*200' x 1200'*			**Lots**
	1200'	6		6
36'		1200' + 240'	2 x 2	4
	1200'	6		6
	204'	1		1
			Total one side:	17
Schematic: NOT TO SCALE			**Total two sides:**	**34**

Maximum of 2,640 feet including cumulative lengths of dead-end roads accessed from main dead-end road.

Figure 2-6: Sample Subdivision Network with Parcel Size of 20 Acres or Larger



parcels zoned for 20 acres or larger				
Max roadway length:	*5280*			
Typical lot dimensions:	*400' x 2400'*			**Lots**
	2400'	6		6
36'		2400' + 480'	2 x 2	4
	2400'	6		6
	444'	2		2
			Total one side:	18
Schematic: NOT TO SCALE			**Total two sides:**	**36**



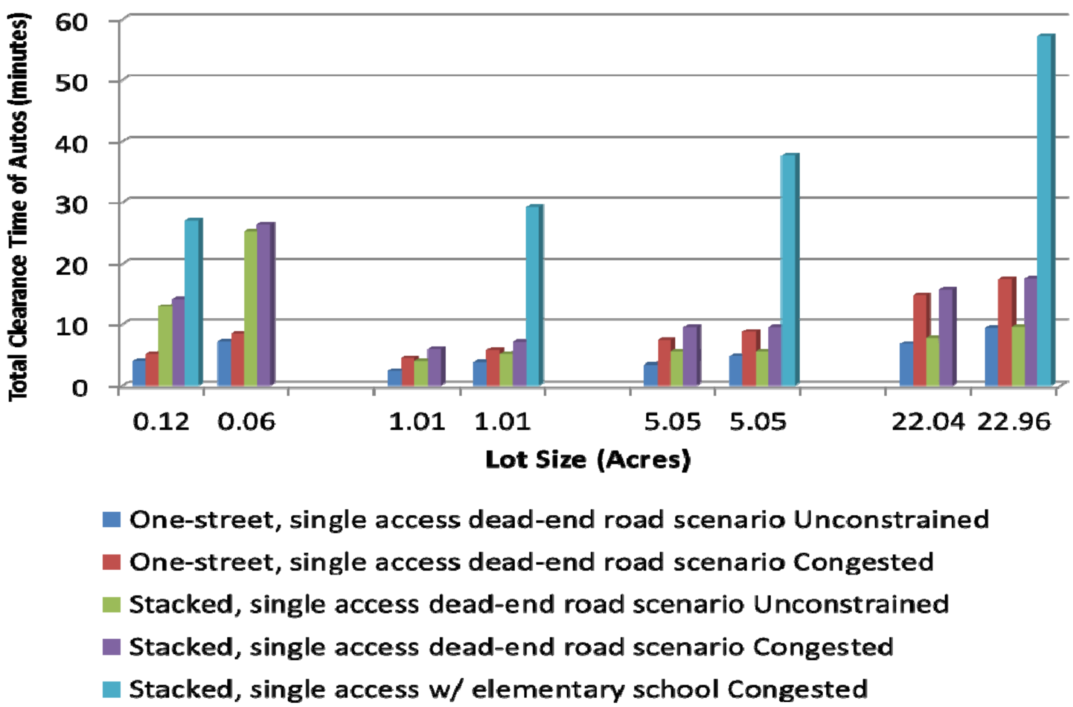
parcels zoned for 20 acres or larger				
Max roadway length:	*5280*			
Typical lot dimensions:	*800' x 1300'*			**Lots**
	1600'	2		2
36'		1300' + 2380'	3 x 2	6
	3200'	4		4
	444'	1		1
			Total one side:	13
Schematic: NOT TO SCALE			**Total two sides:**	**26**

Maximum of 5,280 feet including cumulative lengths of dead-end roads accessed from main dead-end road.

Results of Quick-Response Analyses

We next examined hypothetical scenarios conforming to parcel-size categories and estimated the time for clearing all vehicles from a subdivision (egress time - T). Figure 2-7 presents a graphical comparison of the results, along with the associated data table.

Figure 2-7: Comparative Times to Clear Occupants under Various Lot Configurations



Lot Size (acres)	Land Use	Zoned (acres per DU)	Private Auto Clearance Times (mins): One-street, single access dead-end road scenario		Stacked, single access dead-end road scenario		Stacked, single access w/ elementary school
			Unconstrained	Congested	Unconstrained	Congested	Congested
0.12	SFR (50' x 100')	< 1	4	5	13	14	27
0.06	SFR (25' x 100')	< 1	7	8	25	26	
1.01	SFR (200' x 220')	1 to 4.99	2	4	4	6	
1.01	SFR (100' x 440')	1 to 4.99	4	6	5	7	29
5.05	SFR (400' x 550')	5 to19.99	3	7	6	10	
5.05	SFR (200' x 1100')	5 to19.99	5	9	6	10	38
22.04	SFR (400' x 2400')	20+	7	15	8	16	
22.96	SFR (200' x 5000')	20+	9	17	10	18	57

DU= dwelling unit

Times in excess of 10 minutes are written in red.

In Figure 2-7, "unconstrained" situations indicate no additional travel delay from network congestion or poor visibility. "Congested" situations indicate drastic reduction in average network speed as a result of capacity and visibility constraints on movement.

The findings were as follows:

- In relatively good conditions (e.g., no congestion or no visibility constraints), egress time was sometimes but not always less than 10 minutes.

- Subdivision configurations with the smallest and largest parcels showed the greatest potential for problems with evacuation. In subdivisions with the smallest parcels, assuming that developers will typically construct as many residential units as possible in a bid to maximize return on investment, large numbers of residents potentially will have to be evacuated. In subdivisions with the largest parcels, residential units will be spread out, creating long traverse distances during evacuation. These results illustrate the flaw in the language of the existing standards ("*regardless of the number of parcels served*") that permits the size of development and the number of occupants to be ignored.

- Scenarios involving unconstrained conditions depicted the best possible results, but these conditions are not thought likely to occur under emergency conditions. Scenarios involving congested conditions depicted more likely results, but even these scenarios still assumed that there would be no obstruction (bottleneck) where the single-access road exits on to a through road. The existing standards do not address the potential for bottlenecks.

- The problems are likely to be most severe when land use is not limited to single-family residential. Condominiums, mobile home parks, campgrounds, retail commercial, schools, and churches are among the other, more intense forms of development that can occur. In these types of development, many more people may need to be evacuated in a fire emergency, for example if a school is in session or a church service is being held. This observation illustrates a further flaw in the existing standards, which ignore the type of development that is being proposed as well as the possibility that the intensity of land use will change over time.

Case Studies

The tool was applied in 14 case studies including 1 hypothetical case, 12 existing cases, and 1 proposed case. The cases were selected to enable assessment of a variety of access situations in the wildland-urban interface, including subdivisions with single or multiple access, residential or other land uses (such as schools and churches), and/or problematic connections to arterials or other through roads. One case allowed us to explore the potential effect of smoke from a wildland fire. Prior familiarity with locations ultimately dictated the case selections, which resulted in the following geographic distribution: three cases in Santa Barbara County, seven cases in San Luis Obispo County, one case in Madera County, one case in Contra Costa County, and one case in Placer County. Figure 2-8 identifies the geographic locations of the case studies.

Table 2-1 provides a summary of results from applications of the tool. The figures that follow show the road networks (in light-colored lines) within the case study subdivisions and demarcate the exit points, which are potential bottlenecks (shown in red). The figures also show the through roads for evacuation (in green). A subsequent section provides an overview of the results.

Figure 2-8: Geographic Locations of Case Studies

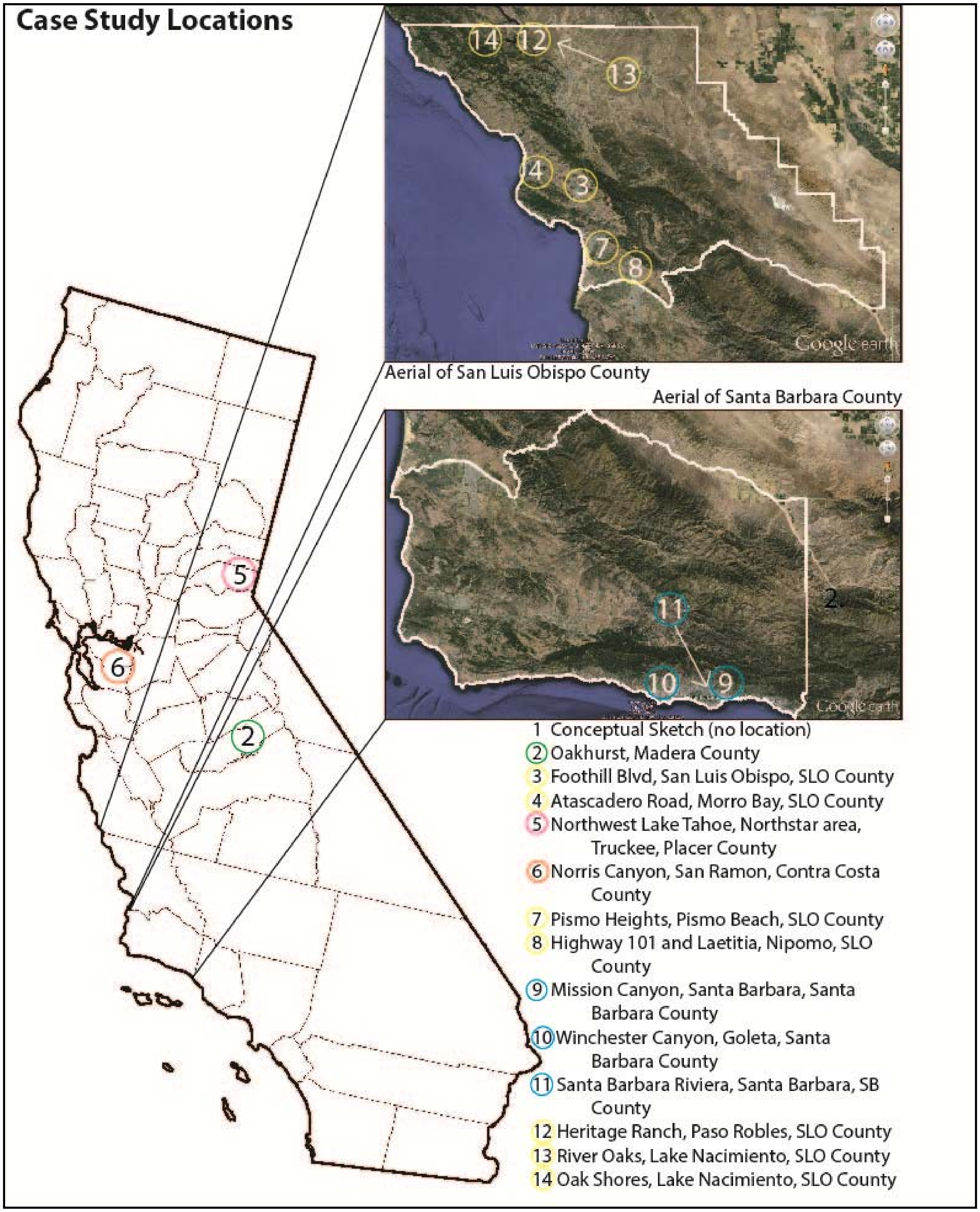


Table 2-1: Application of Tool to Case Studies – Summary of Results

Case	Case Study *(Residential Developments except as otherwise noted)*	Farthest Vehicle Time (seconds)	Farthest Vehicle Delay (seconds)	Total Farthest Time (seconds)	Vehicles to Clear Out	Average Network/Facility Operating Speed (mph)	Total Clearance Time (minutes)
1	Stacked Single-Access – conceptual sketch only	22	47	68	293	7	13
2	Oakhurst: Meadowview Drive and Road 426, Madera County	105	33	138	86	12	6
3	Foothill Boulevard and O'Connor Way, San Luis Obispo County (*Mixed use development: Homes, School , Churches*)	367	248	615	466	8	30
4	Atascadero Road and Mission Drive, Morro Bay, San Luis Obispo County	33	33	66	315	5	14
5	Northwest Lake Tahoe, Truckee, Placer County	730	8	738	1,621	8	80
6	Norris Canyon Estates, San Ramon, Contra Costa County	323	200	523		9	42
7	Pismo Heights, Pismo Beach, San Luis Obispo County	217	200	417	1,149	6	55
8	Highway 101 and Laetitia Vineyard Drive, Nipomo, San Luis Obispo County (*Proposed development*)	376	27	402	247	15	17
9	Mission Canyon, Santa Barbara, Santa Barbara County	190	23	214	853	13	39
10	Westchester Canyon, Goleta, Santa Barbara County	475	17	492	369	16	24
11	Santa Barbara Riviera, Santa Barbara, Santa Barbara County	340	0	340	848	14	41
12.1	Heritage Ranch – Western Entrance, Paso Robles, San Luis Obispo County	255	0	255	1,435	4	64
12.2	Heritage Ranch – Eastern Entrance, Paso Robles, San Luis Obispo County	765	33	799	2,476	6	117
13	River Oaks, Lake Nacimiento, San Luis Obispo County	122	37	159	264	17	14
14	Oak Shores, Lake Nacimiento, San Luis Obispo County	44	50	94	1,569	9	67

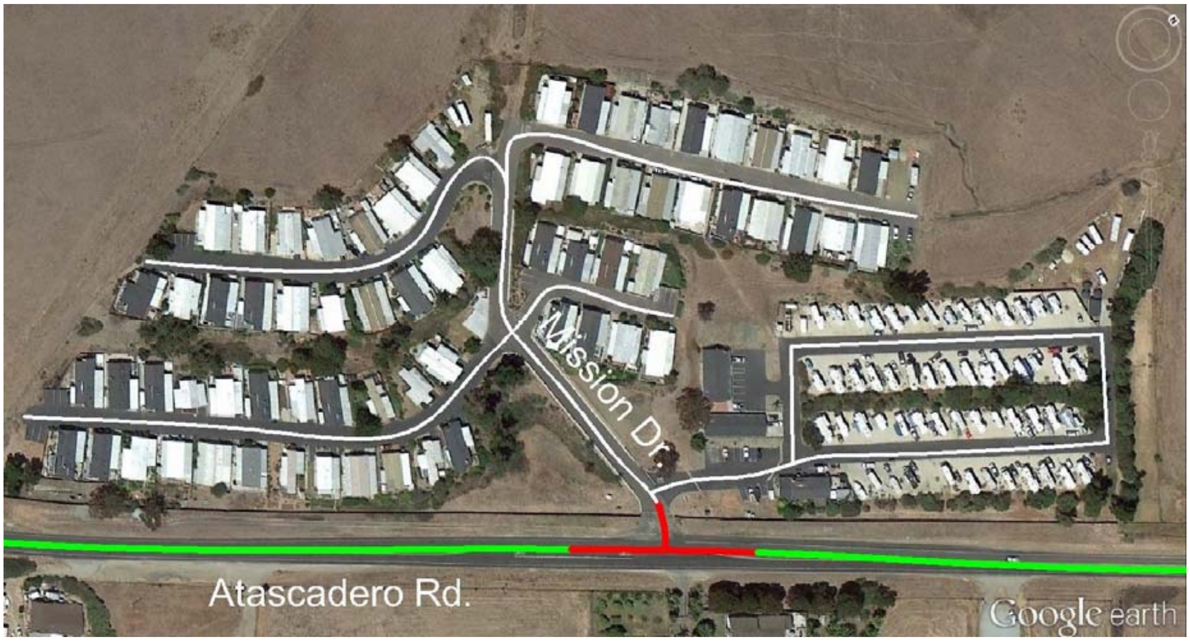
Oakhurst: Meadowview Drive and Road 426

***Oakhurst, Meadowview Drive and Road 426, Madera County** – A single-access subdivision with a few short branches from the primary spine road (Meadowview Drive).*

Foothill Boulevard and O'Connor Way – Mixed Use

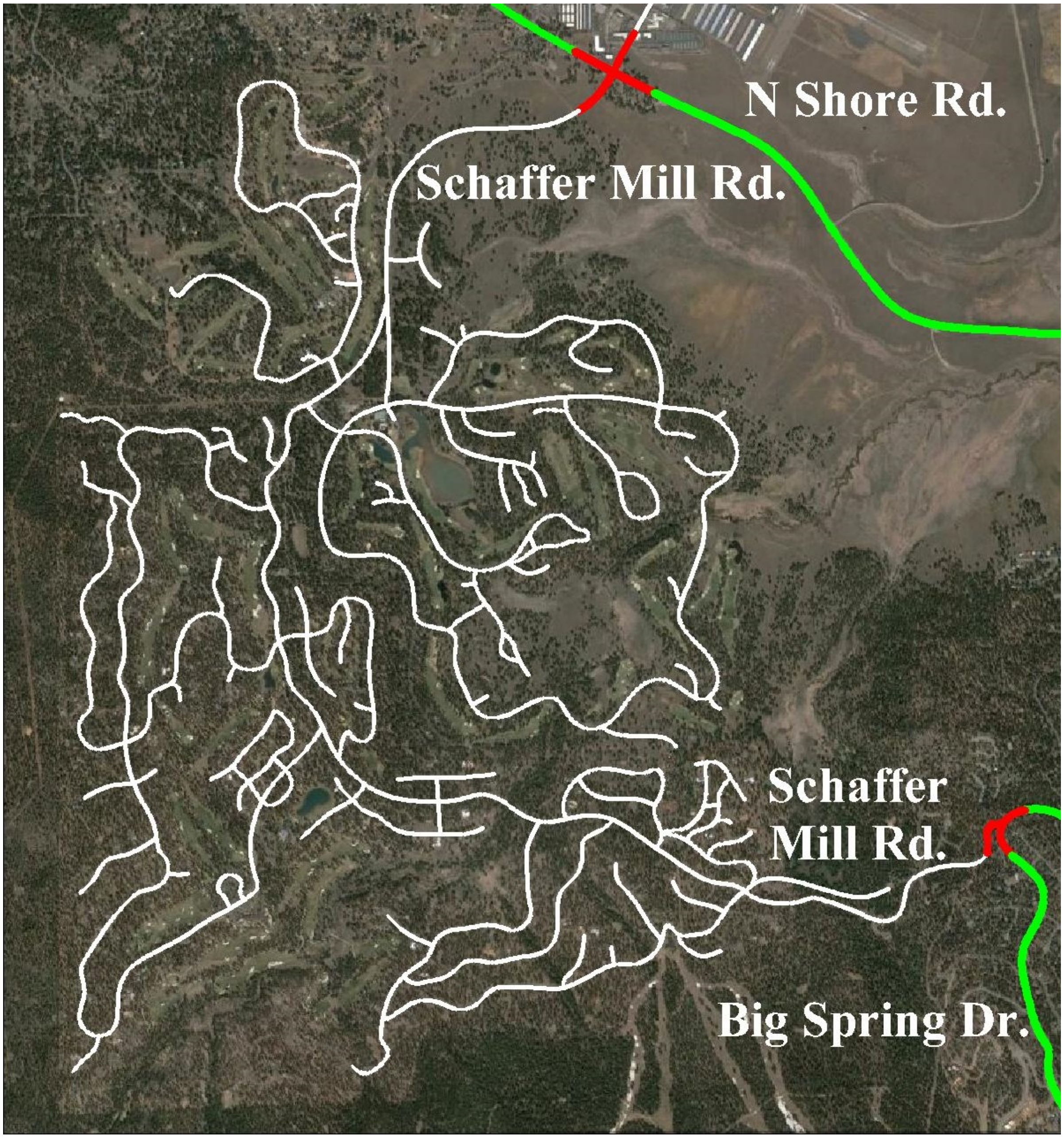
***Foothill Boulevard and O'Connor Way, San Luis Obispo County** – A mixed-use single-access subdivision with several short branches from the primary spine road (O'Connor Way). Land uses include homes,* *schools, and churches: The Agape Church with a congregation of 400 to 440 people, Temple Ner Shalom, and the Laureate School with a population of 120.*

Atascadero Road and Mission Drive – Mobile Home Park



Atascadero Road and Mission Drive, Morro Bay, San Luis Obispo County *– A tightly packed mobile home park with a single access via Mission Drive. The largest parcel size is 110 feet by 90 feet, and the smallest parcel size is 45 feet by 60 feet.*

Northwest Lake Tahoe

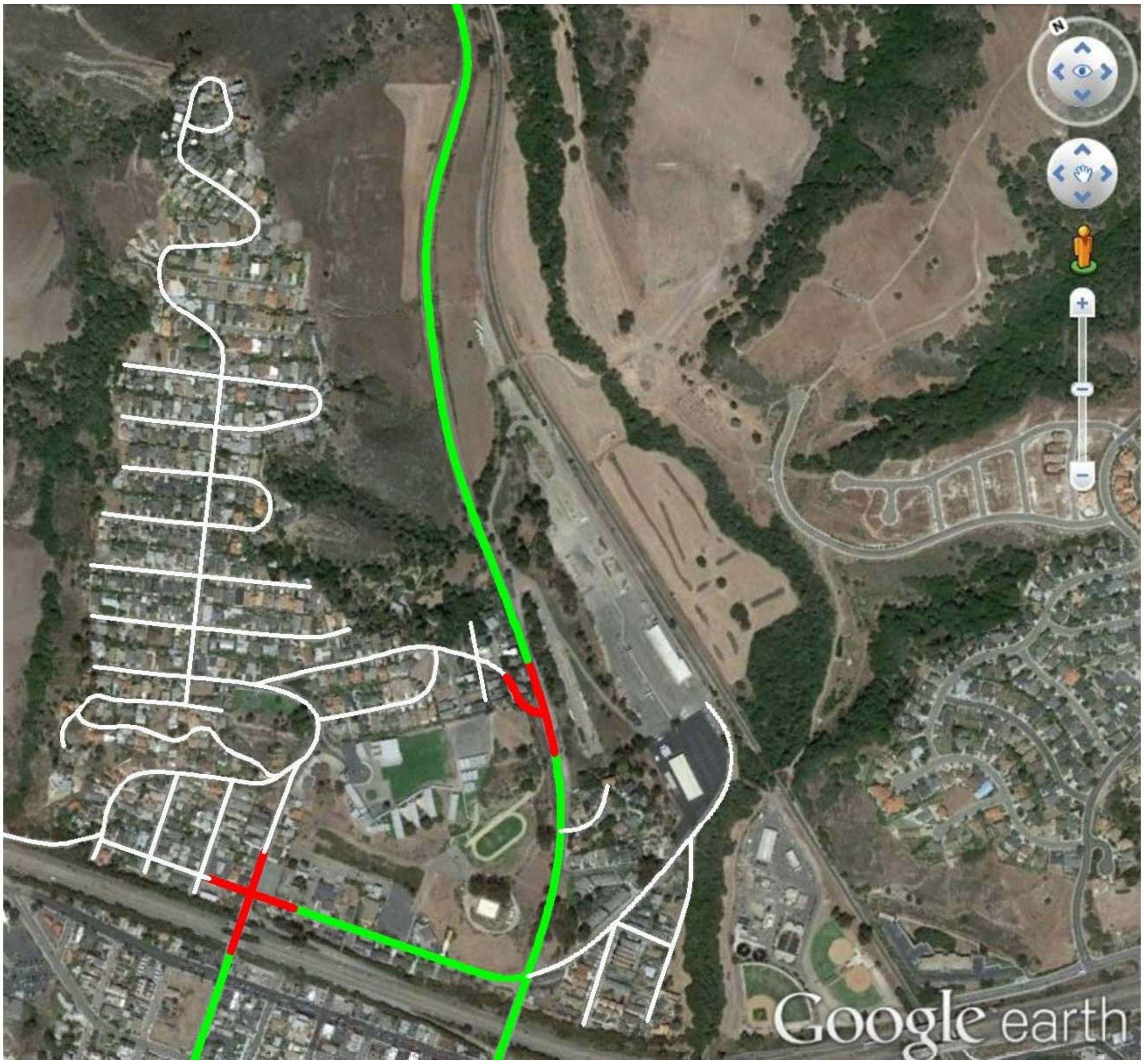


Northwest Lake Tahoe, Truckee, Placer County *– A development in the Northstar area, with secondary access enabling so much land use that the two exits become major bottlenecks with very long evacuation times.*

Norris Canyon Estates

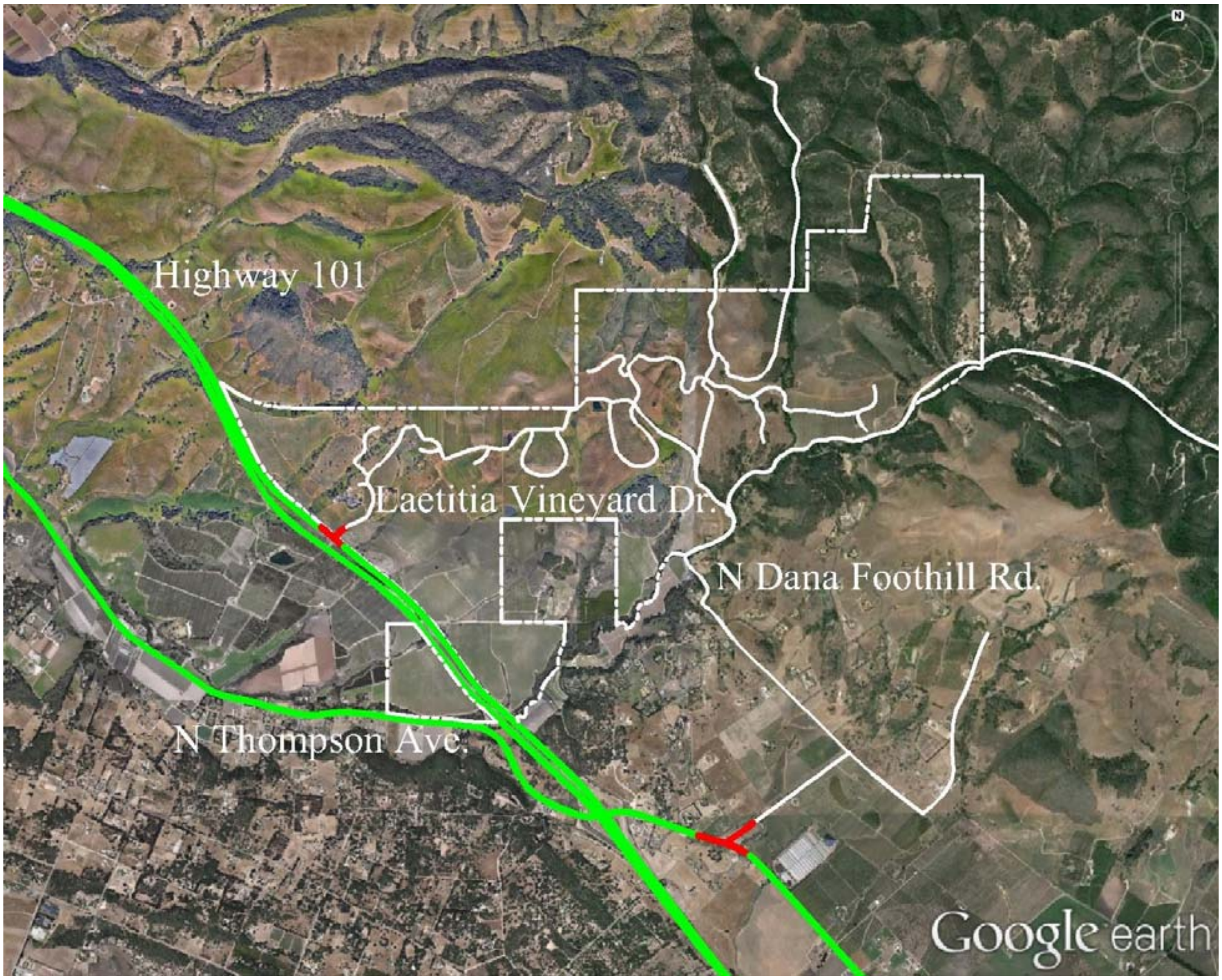
Norris Canyon Estates, San Ramon, Contra Costa County *– A single-access subdivision with several branches from the primary spine road (Ashborne Drive). While the subdivision appears to have two access points, they are close enough to each other that they will effectively function as one exit during emergency evacuation.*

Pismo Heights



***Pismo Heights, Pismo Beach, San Luis Obispo County** – A highly stacked single-access subdivision with several branches from the primary spine road (Longview Avenue), with two access points that are both toward one end of the development, restricting the evacuation path for most residents in the upper portion of Longview Avenue.*

Highway 101 and Laetitia Vineyard Drive – Proposed Development



Highway 101 and Laetitia Vineyard Drive, Nipomo, San Luis Obispo County *– A proposed subdivision with several branches from the primary spine road. The subdivision has two exits at opposite ends of the development, but the secondary access (Laetitia Vineyard Drive) connects to the heavily traveled, high-speed Highway 101, creating a very dangerous situation when used. The proposed subdivision is in reality a single-access development.*

Mission Canyon

***Mission Canyon, Santa Barbara, Santa Barbara County** – A stacked single-access development in hilly terrain with residences that are not reachable by large emergency vehicles.*

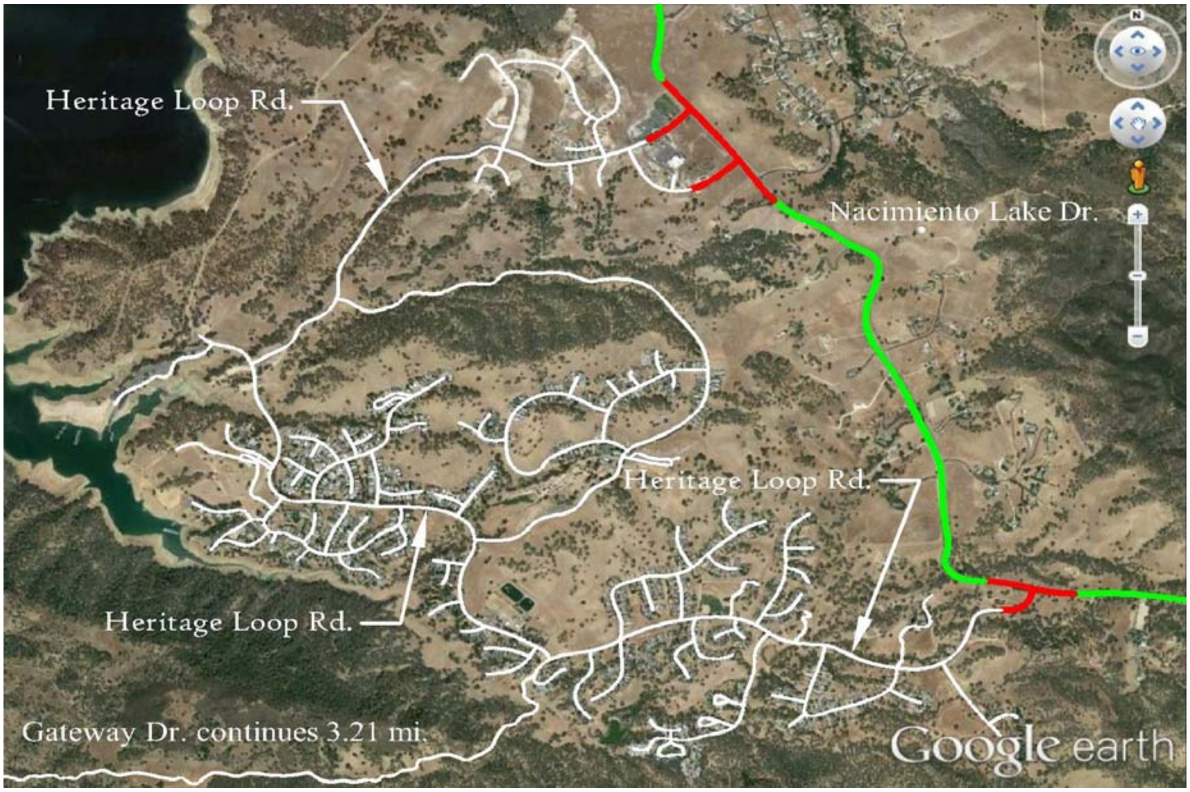
Westchester Canyon

***Westchester Canyon, Goleta, Santa Barbara County** – A single-access development with most subdivision roads connecting by a single access to the primary single-access spine (Westchester Canyon Road).*

Santa Barbara Riviera

***Santa Barbara Riviera, Santa Barbara, Santa Barbara County** – A development in hilly terrain, with multiple entrances that open onto the same surrounding arterial streets, effectively turning escape routes into potential problem routes during emergency evacuation.*

Heritage Ranch

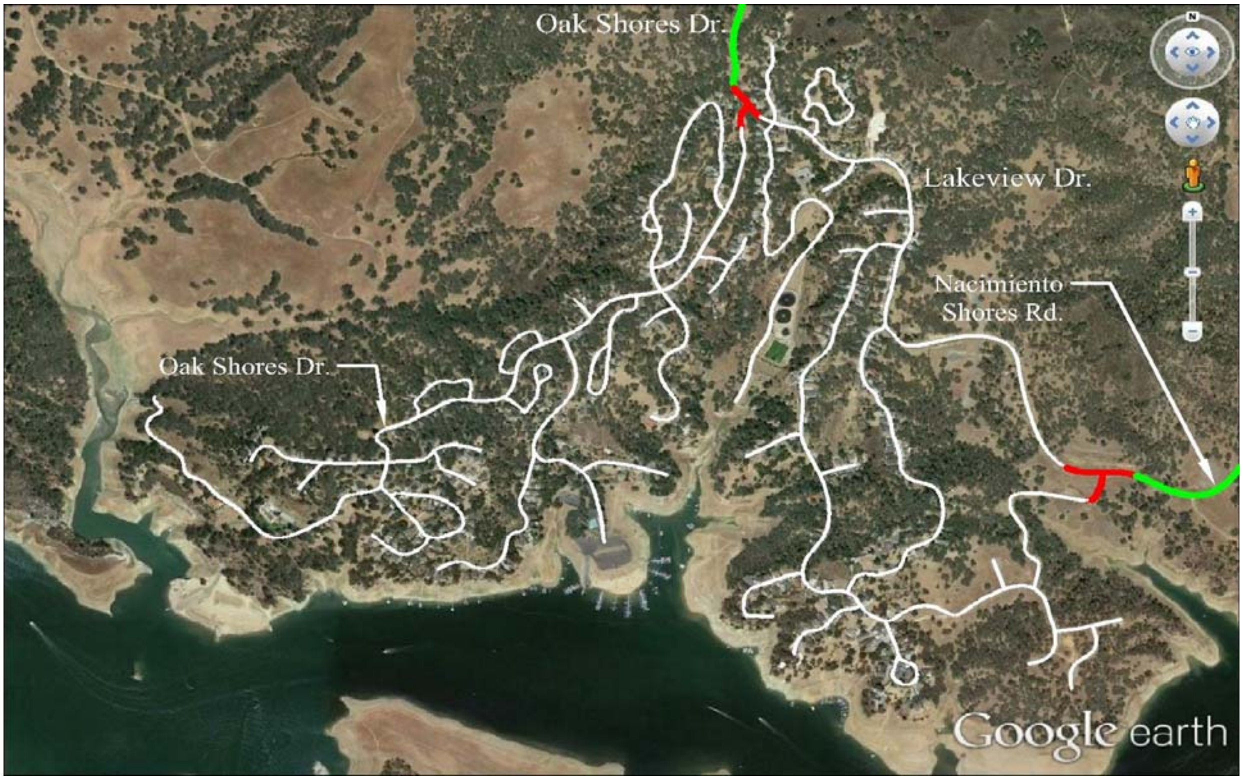


Heritage Ranch, Paso Robles, San Luis Obispo County *– A development with secondary access serving so many parcels that the two exits become major bottlenecks with very long evacuation times.*

River Oaks

***River Oaks, Lake Nacimiento, San Luis Obispo County** – A development with secondary access but a limited number of homes, enabling the two exits to work during evacuation.*

Oak Shores



Oak Shores, Lake Nacimiento, San Luis Obispo County *– A development with secondary access serving so many parcels that the two exits become major bottlenecks with very long evacuation times.*

Results of Applying the Tool to Case Studies

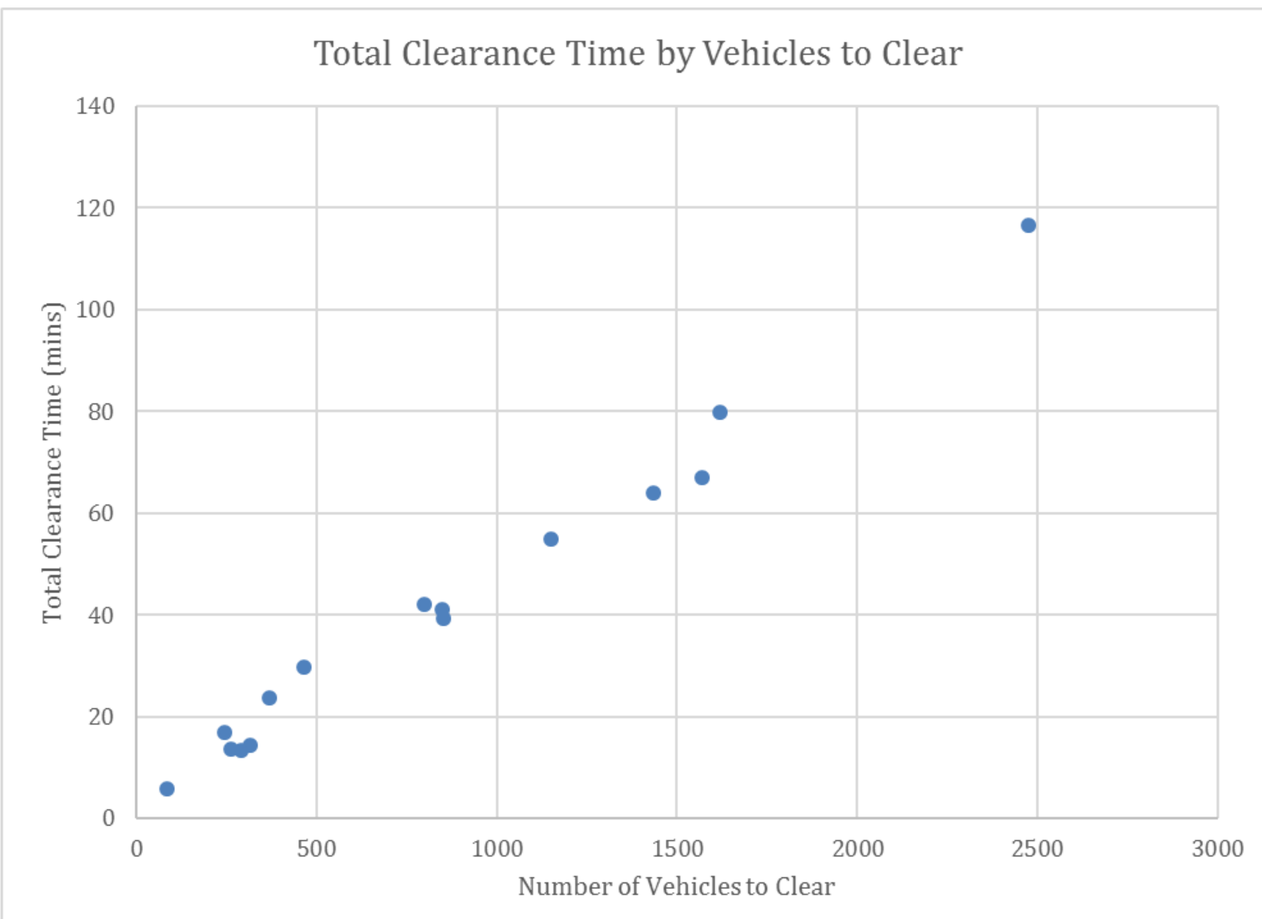
General Observations

Table 2-1, which was previously presented, shows a summary of the results. Examination of case study results led to certain general observations that may be outlined as follows:

1. In 8 of the 14 cases, evacuation was estimated to take more than 30 minutes. This is quite a long time threshold, considering that recent wild fires took much less time than that to burn through major portions of communities.
2. In 13 of the 14 cases, evacuation was estimated to take more than 10 minutes to clear.
3. As expected, there was a strong, positive association between the size of development and the time to clear, even in cases that have secondary access. In other words, evacuation was estimated to take longer in larger developments. Figure 2-9 illustrates the association.

The next subsection includes deliberate comparisons of varying situations. Each comparison leads to a preliminary conclusion.

Figure 2-9: Total Clearance Time by Size of Development (Number of Vehicles to Clear)



Comparisons of Varying Situations Reflected in Case Studies

Single vs. Mixed Use – Foothill Boulevard at O'Connor Way, San Luis Obispo County

This subdivision has almost 50 homes, which equated to persons in 105 passenger cars that were estimated to be cleared within 10 minutes; this scenario assumes that the school, church, and synagogue were not in operation at the time of the incident. Assuming all the uses are operational during emergency evacuation, persons in approximately 466 vehicles would need to be evacuated over an estimated period of nearly 30 minutes. In other words, mixed use would require three times more clearance time than residential single use. Table 2-2 shows comparative results that led to the following conclusion:

The type and intensity of land use in single-access subdivisions should not be ignored.

Table 2-2: Single vs. Mixed Use Clearance Times

	Normal Travel Time of Farthest Vehicle (seconds)	Delay to Farthest Vehicle (seconds)	Total Travel Time for Farthest Vehicle Time (seconds)	Number of Vehicles to Clear	Average Network/Facility Operating Speed (mph)	Total Clearance Time (minutes)
Single Land Use (residential)	305	0	305	105		**9.5**
Mixed Land Use (homes, school, church, and synagogue)	367	248	615	466	**8.4**	**29.7**

Single vs. Multiple Entrances – Heritage Ranch, Paso Robles, San Luis Obispo County

This subdivision is vast, with two widely separated access points on the same through road. In applying the tool, it was assumed that residents would be directed to the nearest exit based on ***distance to the nearest exit.*** The application produced highly varied clearance times: 64 minutes for the western entrance (which would serve fewer vehicles) and 117 minutes for the eastern entrance (which would serve many more vehicles). Even if, with constant communications, residents were able to switch routes to balance exit times, the average clearance time for each exit would be approximately 90 minutes. The results of this application led to the following conclusion:

Simply providing two entrances for a development of uncontrolled size may not be sufficient to ensure safe evacuation of occupants in the event of an emergency.

Potential Effects of Fire – Smoke Limiting Visibility in Northwest Lake Tahoe, Truckee, Placer County

This comparison used studies of fog as a surrogate for the thick smoke that may arise during a wildland fire. The studies suggest increases of 10% to 50% in travel time when visibility is limited.[13] Assuming a 50% increase in travel time due to thick smoke, the clearance time for the Northwest Lake Tahoe development would worsen from 80 minutes on a normal severe fire weather day to 92 minutes. This equates to a 24% reduction in network travel speed (from 7.6 mph to 5.8 mph) and a 15% increase in clearance time. Table 2-3 shows comparative results that led to the following conclusion:

Potential effects of fire on visibility can add significantly to clearance times.

Table 2-3: Potential Effects of Fire on Clearance Times

	Normal Travel Time of Farthest Vehicle (seconds)	**Delay to Farthest Vehicle (seconds)**	**Total Travel Time for Farthest Vehicle Time (seconds)**	**Number of Vehicles to Clear**	**Average Network/Facility Operating Speed (mph)**	**Total Clearance Time (minutes)**
Normally severe fire weather day	730	8	738	1621	**7.6**	**79.9**
Smoke-engulfed day	1459	17	1476	1621	**5.8**	**92.2**

Potential Effects of Delay at Through Road Intersection – Pismo Heights, Pismo Beach, San Luis Obispo County

Pismo Heights is a single-access subdivision along Longview Avenue in Pismo Beach. Longview Avenue ends at its intersection with Wadsworth Street. Just below that intersection, residents have two route choices for exit:

- East on Lemoore Avenue to Price Canyon Road
- South on Wadsworth Street with three choices at Bello Street:
    - Left on Bello Street to Price Canyon Road
    - Right on Bello Street to the Highway 101 northbound on-ramp at Bay Street
    - Straight on Wadsworth Street toward the beach

[13] Federal Highway Administration website: http://www.ops.fhwa.dot.gov/weather/q1_roadimpact.htm.

Using existing intersection analysis for Bello Street at Price Canyon Road as a surrogate for constrained delay at a main through road intersection led to the following findings:

- Vehicles on the eastbound approach are estimated to experience about 15 seconds of delay during AM and PM peak periods. Each vehicle ahead of the last vehicle to exit the development would experience that level of delay.
- If all 1,149 vehicles to exit the development were equally divided among the four available route choices, 287 vehicles would have to navigate the Bello Street intersection. The time required would be 4,310 seconds, or 72 minutes.
- Total clearance time would increase by more than an hour, from 55 minutes to 127 minutes, due to delay at the main arterial intersection. Anecdotal information confirms that it takes this long to exit the development on such holidays as the Fourth of July, when many people are leaving the subdivision after watching the fireworks on the pier.

Table 2-4 shows comparative results that led to the following conclusion:

Potential effects of perennial delays at a primary through road intersection can add significantly to clearance times.

Table 2-4: Potential Effects of Delay at Main Through Road Intersection

	Normal Travel Time of Farthest Vehicle (seconds)	**Delay to Farthest Vehicle (seconds)**	**Total Travel Time for Farthest Vehicle Time (seconds)**	**Number of Vehicles to Clear**	**Average Network/Facility Operating Speed (mph)**	**Total Clearance Time (minutes)**
Excluding delay at through road intersection	217	200	417	1,149	**6**	**55**
Including delay at through road intersection						**127**

Reassessment of Existing Standards

Findings from the case studies confirm initial assessments of the existing standards from earlier testing of hypothetical situations, which were crafted to conform to the parcel-size and distance specifications of the law. Table 2-5 shows similar patterns of results with application of the tool to hypothetical cases, as compared to the initial, quick analyses of hypothetical situations.

Table 2-5: Potential Effects of Delay at Main Through Road Intersection on Hypothetical Cases

	Normal Travel Time of Farthest Vehicle (seconds)	Delay to Farthest Vehicle (seconds)	Total Travel Time for Farthest Vehicle (seconds)	Number of Vehicles to Clear	Average Network/Facility Operating Speed (mph)	Total Clearance Time -- No Delay at Through Road Intersection (minutes)	Total Clearance Time -- With Delay at Through Road Intersection (minutes)[1]
Various parcel sizes – without mitigation options							
< 1acre; 120 DU	22	47	68	293	7	13	87
1 to 4.99 acres; 44 DU	36	10	46	112	14	6	34
5 to 19.99 acres; 34 DU	72	23	95	83	20	5	26
20 acres +; 36 DU	144	47	191	88	22	7	29
Parcels zoned for less than 1 acre – with potential mitigation options							
240 dwelling units (DU)	22	93	115	587	4	26	173
120 DU; 1 exit lane	22	47	68	293	7	13	87
120 DU; 2 exit lanes	22	23	45	293	9	13	86
120 DU; 1 lane; 2 exits	22	47	68	147	8	7	44
120 DU + school; 1 lane	22	127	148	538	5	25	159
120 DU + school; 2 lanes	22	63	85	538	7	24	158
120 DU + school; 2 exits	22	130	152	269	5	14	81

[1] *Assumes an average of 15 seconds of delay per vehicle accumulated from first exiting to last exiting vehicle.*

Summary of Preliminary Conclusions from Case Studies

In summary, the case studies led to the following preliminary conclusions:

1. The type and intensity of land use in single-access subdivisions should not be ignored.
2. Simply providing two entrances for a development of uncontrolled size may not be sufficient to ensure safe evacuation of occupants in the event of an emergency.
3. Potential effects of fire on visibility can add significantly to clearance times.
4. Potential effects of perennial delays at a primary through road intersection can add significantly to clearance times
5. Simply adding an additional lane to the primary single access road for evacuation does not appear to improve evacuation times. Adding a true second access that is independent of the first (meaning the two exits are neither close together nor access the same through road) offers a significant reduction in clearance time. In developments with high intensities of land use, however, clearance time can remain high. Under these conditions, multiple entrances (not just one or two) could offer the highest potential for timely evacuation.

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3.0 Fire Behavior Modeling

Overview

The inputs used by CAL FIRE in the calculations that lead to designation of Fire Hazard Severity Zones (FHSZs) have been codified into California law and are accepted as being based on sound science. For these reasons, we initially hoped to model potential fire behavior (i.e., flame length and rate of spread) using these same inputs. FHSZs are categorized as Moderate, High, or Very High and are designated based upon multiple characteristics for a given area, including:

1. Potential vegetation type, structure, and moisture
2. Topographic slope
3. Likelihood of a fire transitioning from a surface fire to a crown fire
4. Firebrand generation
5. Probability of burning (based on historical fire frequency of an area)

Unfortunately, we could not simply use the specific inputs used to categorize FHSZs for a given site, because the inputs are not publicly available. Further, we could not simply use the FHSZ designation for a given area as a surrogate for fire behavior, because these designations incorporate an element of probability of the area burning, which varies from place to place even if all else is equal; thus, two areas could be identical in vegetation and slope but could differ in FHSZ designation due to differing probabilities of burning, which are based on the historical fire frequency of the area. For the purpose of our study, probability was not relevant, since our concern was safe ingress and egress ***given the occurrence of a fire***, irrespective of the likelihood that it would occur.

While we were precluded from using the specific fire behavior calculations used in designating FHSZs, we still attempted to use those same general principles and methodologies to estimate relative fire rates of spread and intensity. For example, we used NEXUS software (Scott & Burgan 2001) to calculate fire intensity and spread. Further, we also used fuel moisture inputs based upon a “normally severe fire weather day,” a common precept in FHSZ calculations. Other inputs used here were based on personal experience in fire behavior modeling, the scientific literature, and consultation with CAL FIRE fire scientists at the Fire and Resource Assessment Program.

Modeling Inputs

We modeled flame length and spread rate for the following four general vegetation classes:

- Grass (see examples in Figure 3-1)
- Shrubs (see examples in Figure 3-2)
- Coniferous forest (see examples in Figure 3-3)
- Broadleaf forest (see examples in Figure 3-4)

While these vegetation classes do not come close to simulating the vast array of fine-scale variability found from site to site in California, they provide general types that would be easily understood by non-practitioners.

Figure 3-1: Examples of Grass Vegetation Class

Grass vegetation class: *Potential examples include grasslands, oak savannahs, meadows, and others. Photos obtained from the Natural Fuels Photo Series published by the Pacific Northwest Forest Fire Laboratory ([http://www.fs.fed.us/pnw/fera/publications/photo_series_pubs.shtml)](http://www.fs.fed.us/pnw/fera/publications/photo_series_pubs.shtml).*

Figure 3-2: Examples of Shrub Vegetation Class

***Shrub vegetation class**: Potential examples include chaparral, coastal sage scrub, Great Basin sagebrush, and others.*

Figure 3-3: Examples of Coniferous Vegetation Class

***Coniferous vegetation class**: Potential examples include mixed conifers, ponderosa pine, redwood, Douglas fir, and others.*

Figure 3-4: Examples of Broadleaf Vegetation Class

***Broadleaf vegetation class**: Potential examples include closed canopy oak, madrone, tanoak, and bay laurel.*

As previously noted, fire behavior simulations were intended to approximate a "normally severe fire weather day," a precept in FHSZ calculations. To that end, all vegetation/slope combinations were calculated over a range of wind speeds from 0 to 60 mph, enabling users to determine which wind speed is of most realistic concern for their local area. Further, as in FHSZ calculations, fuel moistures were calculated under a "very low dead, fully cured herb" moisture scenario, which is a common term used in fire behavior modeling.

Also as in FHSZ calculations, topography (slope) was categorized into six basic classes, which are based on National Fire Danger Rating System categories. Median values for the following classes were used in fire behavior calculations:

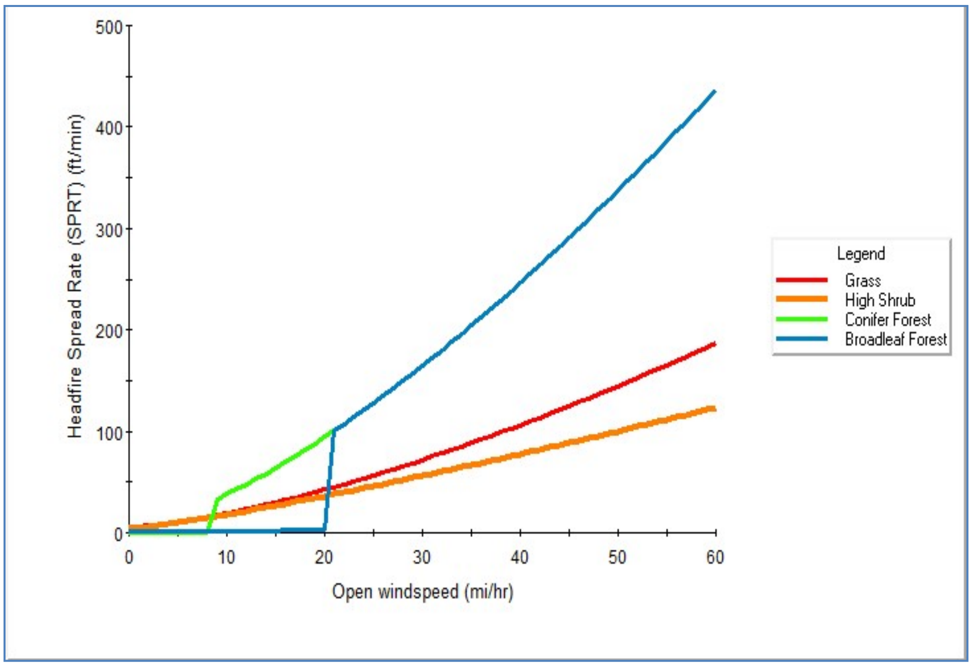
- 0%
- 1-25%
- 26-40%
- 41-55%
- 56-75%
- >85%

Details regarding the specific fuel, weather, and topography inputs used for fire behavior simulations are provided in Appendix 2. Note that, due to differences in vegetative structure, vegetation classes do not all require the same types of inputs. (For example, grass has no tree canopy properties, and thus these inputs are precluded in the fire behavior calculations for that vegetation class.)

Outputs

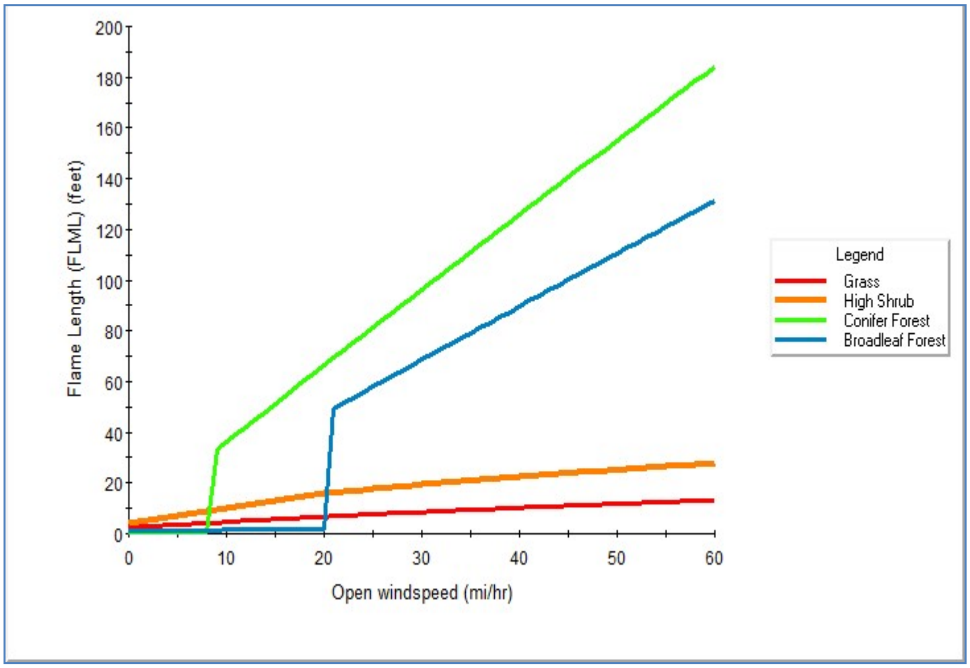
Figures 3-5 and 3-6 illustrate simulated rates of fire spread and flame length, respectively, over a range of wind speeds. In general, spread rate and flame length were greatest for shrubs, then grass, and then forests until wind exceeded a threshold speed and fires in the forest types transitioned from a low-intensity surface fire into a high-intensity crown fire. We hold that these trends, while generalized for a given vegetation class, are realistic.

Figure 3-5: Fire Spread Rate for Vegetation Classes –
"Normally Severe Fire Weather Day" Scenario



*Fire **spread rate** (in feet per minute) for four vegetation classes under a "normally severe fire weather day" scenario.*

Figure 3-6: Fire Flame Length for Vegetation Classes –
"Normally Severe Fire Weather Day" Scenario



*Fire **flame length** (in feet) for four vegetation classes under a "normally severe fire weather day" scenario.*

Based on these simulation outputs, look-up tables of fire behavior (i.e., spread rate and flame length) were created for each of the vegetation classes under multiple defined combinations of wind speed and slope. An example (for grass) is provided in Table 3-1; others can be found in Appendix 2.

Table 3-1: Look-Up Table of Fire Behavior for Grass Vegetation Class under Varying Combinations of Slope and Wind Speed

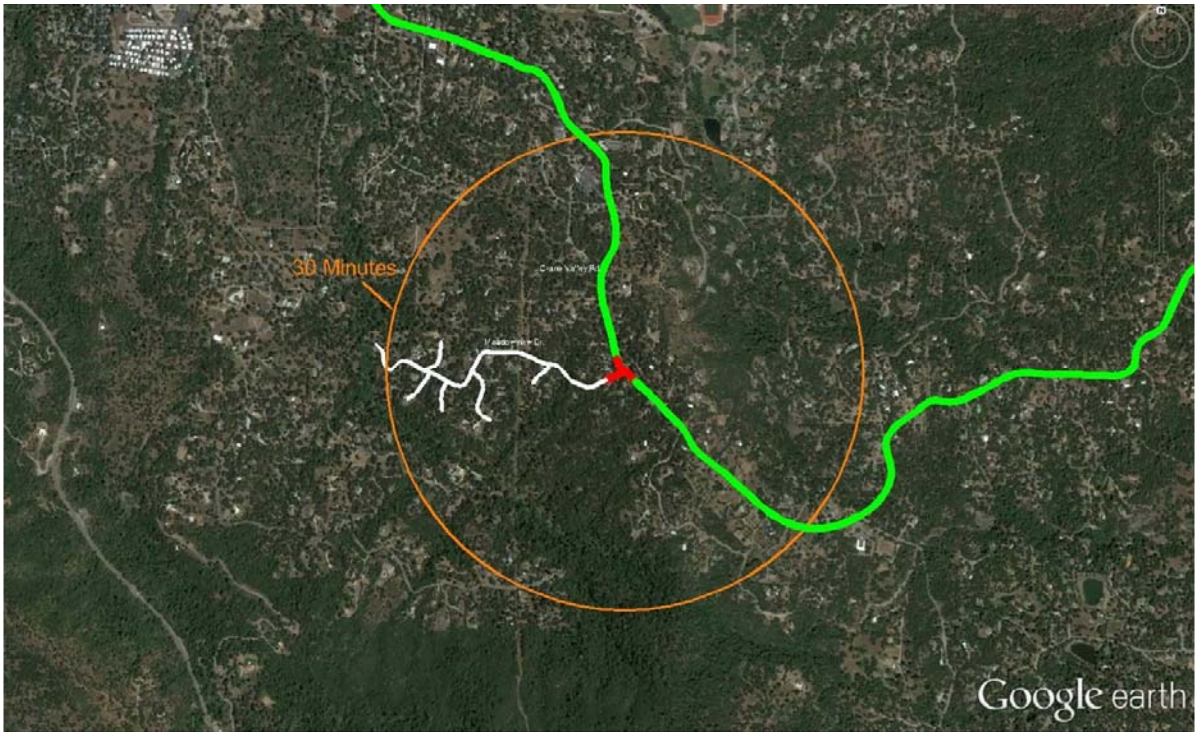
Vegetation: Grass						
	Open Wind Speed (mph)					
Slope (%)	0	10	20	30	40	50
0	ROS: 6'/min FL: 3'	ROS: 19'/min FL: 5'	ROS: 42'/min FL: 7'	ROS: 71'/min FL: 9'	ROS: 106'/min FL: 10'	ROS: 144'/min FL: 12'
1-25	ROS: 9'/min FL: 3'	ROS: 23'/min FL: 5'	ROS: 46'/min FL: 7'	ROS: 75'/min FL: 9'	ROS: 110'/min FL: 10'	ROS: 148'/min FL: 12'
26-40	ROS: 29'/min FL: 6'	ROS: 42'/min FL: 7'	ROS: 65'/min FL: 8'	ROS: 95'/min FL: 10'	ROS: 129'/min FL: 11'	ROS: 168'/min FL: 13'
41-55	ROS: 55'/min FL: 8'	ROS: 69'/min FL: 8'	ROS: 91'/min FL: 10'	ROS: 121'/min FL: 11'	ROS: 155'/min FL: 12'	ROS: 194'/min FL: 14'
56-75	ROS: 96'/min FL: 10'	ROS: 109'/min FL: 10'	ROS: 132'/min FL: 11'	ROS: 162'/min FL: 12'	ROS: 196'/min FL: 14'	ROS: 234'/min FL: 15'
>75	ROS: 159'/min FL: 12'	ROS: 173'/min FL: 13'	ROS: 196'/min FL: 14'	ROS: 225'/min FL: 14'	ROS: 260'/min FL: 15'	ROS: 298'/min FL: 16'

ROS = rate of spread; FL = flame length.

Conclusions Regarding Fire Behavior Modeling

Unfortunately, direct linkage with the access model is presently precluded. Fire behavior calculations here are instead intended to provide planners with a valuable source of information to inform their decision making. That said, one could potentially reverse-engineer a fire's area of influence from a given point (e.g., the exit point of a single-access subdivision) based upon potential fire rate of spread and a specific time of interest. For example, the transportation model might predict that 30 minutes are required to fully evacuate a given subdivision. Given the predicted fire rate of spread (See tables in Appendix 2), a planner could then determine the relative boundaries of a fire's influence from that given point (see Figure 3-7). In this hypothetical scenario, a fire could reach the access point from any point within the 30-minute boundary, dependent on direction of spread and other factors.

Figure 3-7: Conceptual Area of Fire Influence within 30 Minutes of Access Point



*Conceptual area of **fire influence within 30 minutes** of the access point for Oakhurst subdivision.*

Users should be cautioned that the fire behavior values here are to be used as a general guide and not as a sound predictor of site-specific fire behavior. The latter would require an expert in fire prediction systems or a future spatial tool that gives users easy access to the fire behavior predictions used in the FHSZ designation of a given area. For example, as previously noted, vegetation was divided into just four classes, an approach that provides for easy understanding but does not account for the enormous fine-scale variability found throughout California. Further, calculations here do not include any mitigation measures (e.g., fuel treatments) that might modify fire behavior; as in FHSZ calculations, the calculations presented here are intended to illustrate realistic fire behavior in mature vegetation on a “normally severe fire weather day.” Also, spread rate here does not consider spotting from embers, which can exponentially increase the spread of a fire, especially as it transitions from a surface fire into a crown fire.

Finally, we believe that future endeavors could improve predictions of both egress and fire behavior by creating a tool that would enable a user to easily obtain the same site-specific fire behavior calculations used in FHSZ designation. The function of this tool would be maximized by seamlessly linking the access model with fire behavior predictions.

4.0 Illustrations: Linking Access With Fire Behavior

Introduction

This section contains illustrations (utilizing actual case study sites) of the manner in which information from the fire behavior modeling might be used to assist planners in deciding whether occupants would be able to evacuate safely before being overtaken by fire, **subject to the caveats expressed in Section 3.0.** There are four illustrations from the Oakhurst case study and seven from the Heritage Ranch case studies. The analyses are based on prevailing as well as more extreme conditions (e.g., wind speed) at each site.

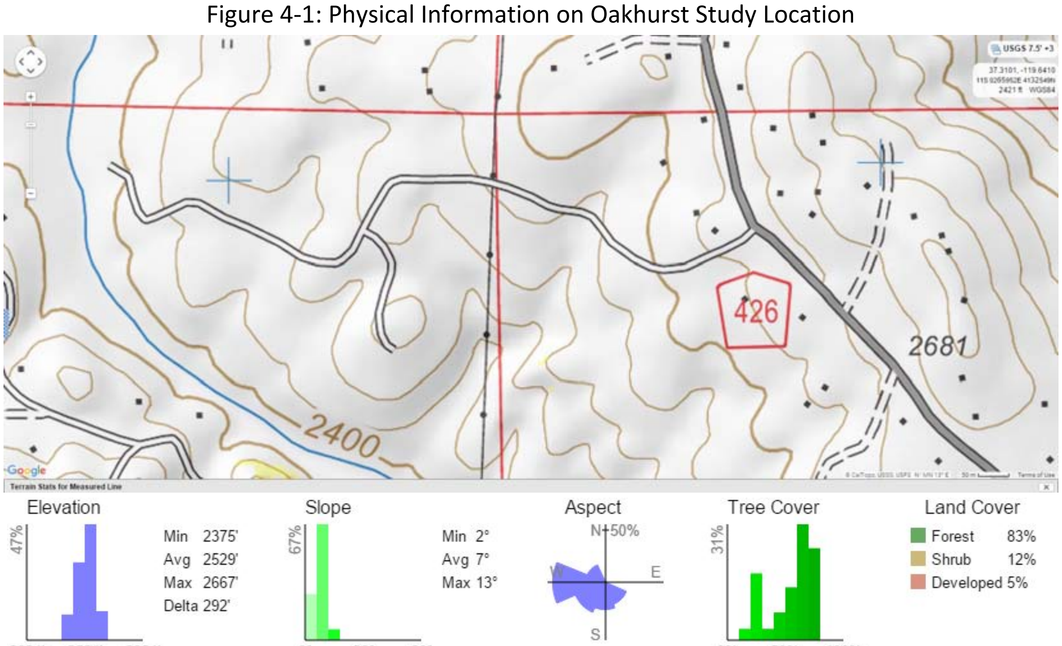
Case Study: Oakhurst – 1

Conditions

Figure 4-1 shows existing physical conditions in the vicinity of the Oakhurst case study site. In summary, conditions depict the following:

Vegetation: Broadleaf Forest (existing)
Slope: 1% to 25% (existing)
Wind speed: 30 mph (assumed for a "normally severe fire weather day")

Figure 4-1: Physical Information on Oakhurst Study Location



Source: Cal Topo using resources from Google Maps; USGS, and USFS

Associated Look-Up Table

Table 4-1 shows the appropriate look-up table for the case study site. It also shows the appropriate cell of fire behavior model parameters to use.

Table 4-1: Look-Up Table Applied to Oakhurst Study Location

Vegetation: Broadleaf Forest (Mature)						
	Open Wind Speed (mph)					
Slope (%)	0	10	20	30	40	50
0	ROS: 1'/min FL: 1'	ROS: 2'/min FL: 2'	ROS: 3'/min FL: 2'	ROS: 165'/min FL: 69'	ROS: 246'/min FL: 90'	ROS: 337'/min FL: 111'
1-25	ROS: 1'/min FL: 1'	ROS: 2'/min FL: 2'	ROS: 3'/min FL: 2'	ROS: 166'/min FL: 69'	ROS: 248'/min FL: 90'	ROS: 338'/min FL: 111'
26-40	ROS: 2'/min FL: 2'	ROS: 3'/min FL: 2'	ROS: 103'/min FL: 50'	ROS: 174'/min FL: 71'	ROS: 255'/min FL: 92'	ROS: 346'/min FL: 112'
41-55	ROS: 4'/min FL: 2'	ROS: 5'/min FL: 3'	ROS: 114'/min FL: 54'	ROS: 184'/min FL: 74'	ROS: 266'/min FL: 94'	ROS: 356'/min FL: 115'
56-75	ROS: 7'/min FL: 3'	ROS: 8'/min FL: 3'	ROS: 130'/min FL: 58'	ROS: 200'/min FL: 78'	ROS: 282'/min FL: 98'	ROS: 372'/min FL: 118'
>75	ROS: 45'/min FL: 19'	ROS: 98'/min FL: 48'	ROS: 155'/min FL: 66'	ROS: 225'/min FL: 84'	ROS: 307'/min FL: 104'	ROS: 398'/min FL: 123'

Model Parameters

For the given slope range of 1% to 25% and assumed wind speed of 30 mph, the look-up table indicates the following parameters:

Rate of spread = 166 feet per minute (1.9 mph)
Flame length = 69 feet
Start of fire = 500 feet west of development (assumed)

Potential Spread of Fire by Time Period

For an assumed location of fire at a hypothetical distance of 500 feet west of the development, Exhibit 4-2 shows how long it would take for the fire to engulf specified sections of the development in 5 minute increments assuming there were no intervention from fire professionals. Results indicate that the fire would reach points farthest west of the development In approximately 3 minutes, engulf nearly half of the development within 15 minutes, and overrun the entire development within 20 minutes.

Figure 4-2: Potential Spread of Fire at 30-mph Wind Speed from 500 Feet West of Oakhurst

Parameters

For given slope of 1% to 25%, assumed wind speed of 30 mph, and start of fire at 500 feet west of development:

Rate of spread = 166 feet per minute (1.9 mph)

Flame length =69 feet

Table 4-2 shows how these results compare with the estimated total clearance time for this development, which 6 minutes if no further delay at the exit intersection is assumed. If prevailing or projected conditions at the through road intersection (for instance from a traffic impact study) indicate that delay per vehicle is 10 seconds at the bottleneck, clearance time would more than triple to 20 minutes, threatening all residents of the subdivision, but especially those furthest west in the development. Note that this clearance time would be possible only if evacuation began immediately after the fire started. Every increase in time-lapse between start of fire and time of an evacuation order would make it less likely that all vehicles would exit the subdivision under this wind speed scenario.

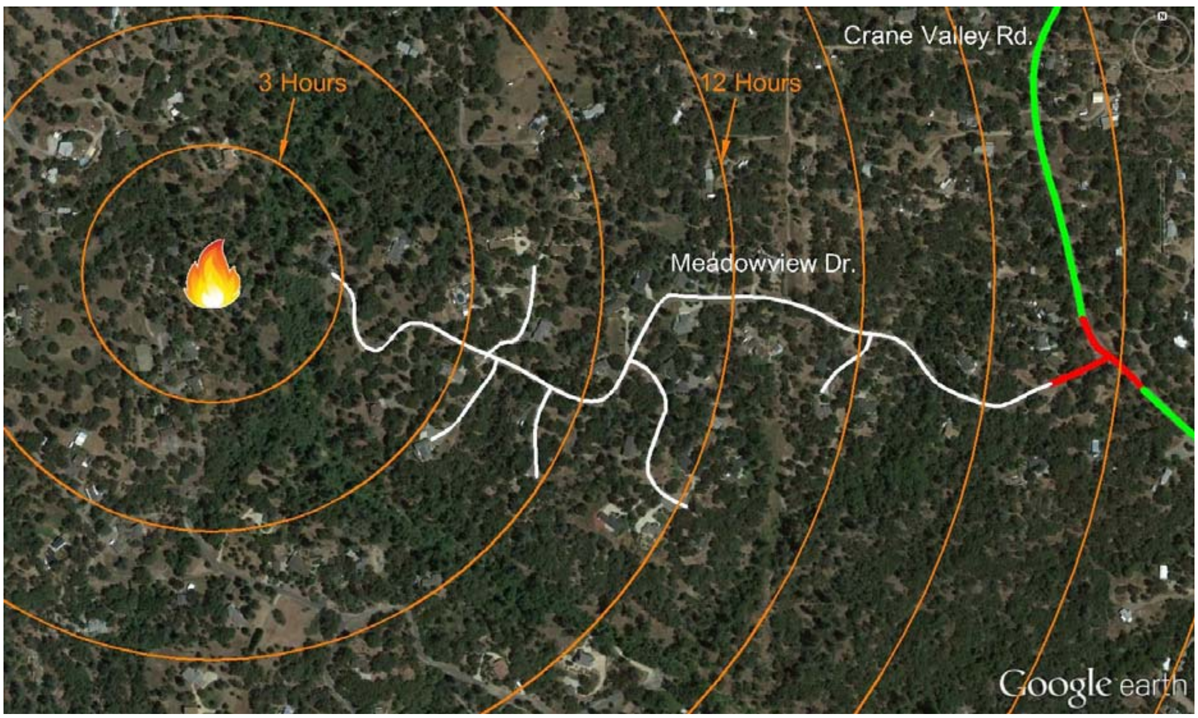
Table 4-2: Oakhurst with Potential Effects of Delay at Main Through Road Intersection

Oakhurst: *Level of Delay Assumed per Vehicle at Through Road Intersection (seconds)*	**Normal Travel Time of Farthest Vehicle (seconds)**	**Delay to Farthest Vehicle (seconds)**	**Total Travel Time for Farthest Vehicle (seconds)**	**Number of Vehicles to Clear**	**Average Network /Facility Operating Speed (mph)**	**Total Clearance Time -- No Delay at Through Road Intersection (minutes)**	**Total Clearance Time -- With Delay at Through Road Intersection (minutes)**
0	105	33	138	86	12	6	6
5							13
10							20
15							27
20							34

Case Study: Oakhurst – 2

Assuming the wind speed were 20 mph, the fire model parameters indicate a much reduced rate of spread of 3 feet per minute. Figure 4-3 indicates that the fire would reach the development in a little under 3 hours and engulf the entire subdivision in approximately 18 hours. This is close to a best case scenario. Compared to estimates from the access tool in Table 4-2, a prevailing delay of 20 seconds per vehicle at the through road intersection would result in a clearance time of 34 minutes, which is well under the time needed to clear all residents before the fire reaches the farthest west part of the subdivision assuming no intervention.

Figure 4-3: Potential Spread of Fire at 20-mph Wind Speed from 500 Feet West of Oakhurst



Parameters

For given slope of 1% to 25%, assumed wind speed of 20 mph, and start of fire at 500 feet west of development:

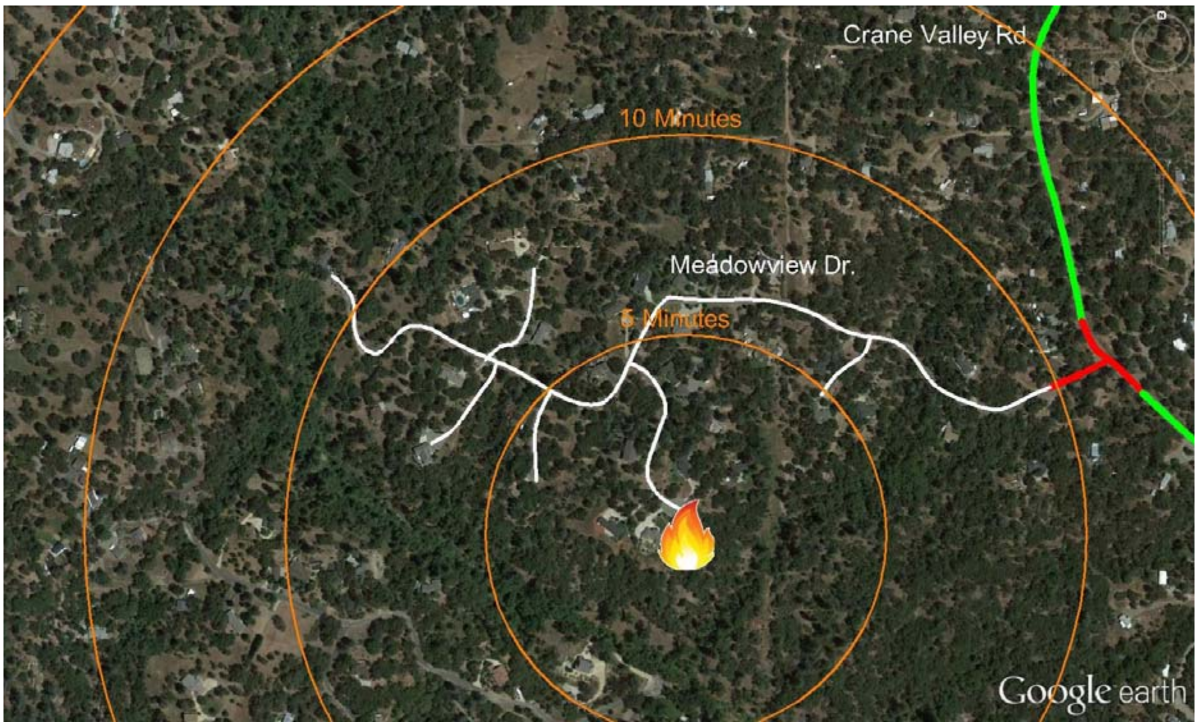
Rate of spread = 3 feet per minute (0.034 mph)

Flame length = 2 feet

Case Study: Oakhurst – 3

Figure 4-4 depicts another hypothetical situation that assumed the fire begins close to the outskirts of the development, 100 feet to the south. Given the proximity of the fire, the entire development would be threatened sooner than the first case. The fire could potentially engulf the subdivision within 10 minutes.

Figure 4-4: Potential Spread of Fire at 30-mph Wind Speed from 100 Feet South of Oakhurst



Parameters

For given slope of 1% to 25%, assumed wind speed of 30 mph, and start of fire at 100 feet south of development:

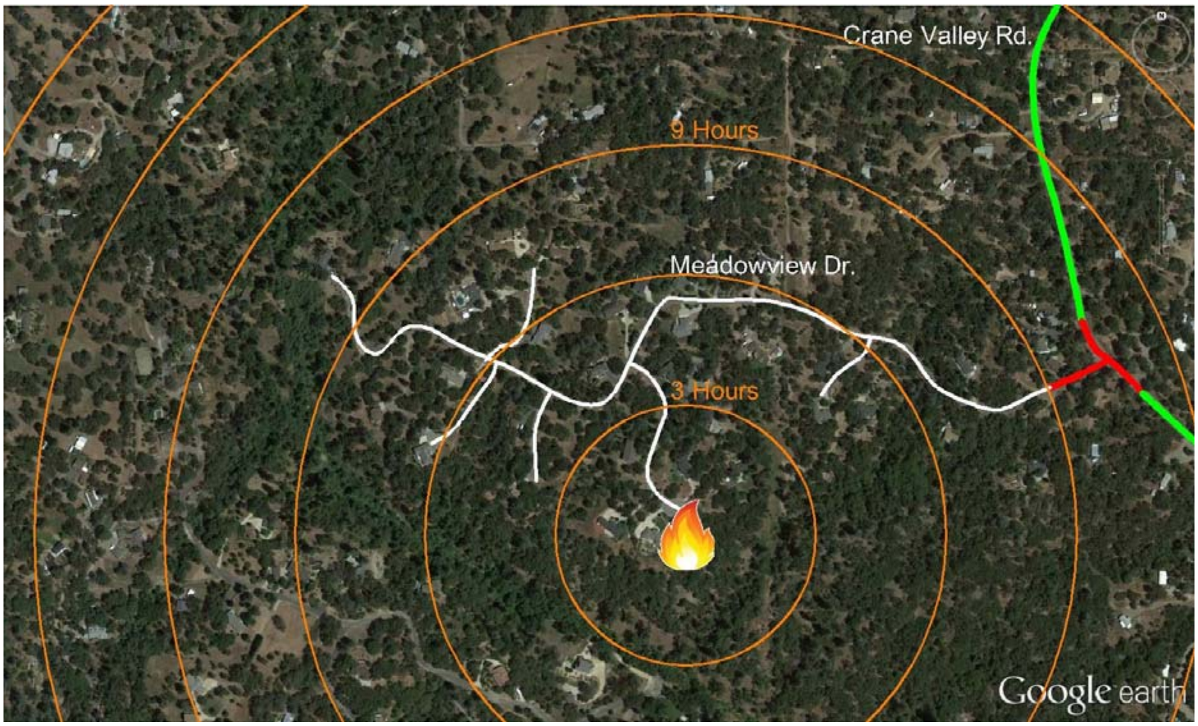
Rate of spread =166 feet per minute (1.9 mph)

Flame length = 69 feet

Case Study: Oakhurst – 4

Figure 4-5 similarly depicts a hypothetical situation where the fire begins 100 feet south of the southernmost property in the development, but under a lower wind speed of 20 mph. Given the proximity of the fire, the development would be threatened sooner than in the first case, but the fire would take a little over 30 minutes to reach the subdivision; this could provide ample time to clear all vehicles if average delay at the through road intersection were 15 seconds or lower per vehicle.

Figure 4-5: Potential Spread of Fire at 20-mph Wind Speed from 100 Feet South of Oakhurst



Parameters

For given slope of 1% to 25%, assumed wind speed of 20 mph, and start of fire at 100 feet south of development:

Rate of spread = 3 feet per minute (0.034 mph)

Flame length = 2 feet

Oakhurst Summary

Table 4-3 summarizes various hypothetical fire scenarios for the Oakhurst subdivision. It also shows comparative times to clear all vehicles out of the subdivision under various conditions of delay at the through road intersection. This juxtaposition of fire spread potential against clearance time helps to inform decision makers reviewing development proposals as to whether occupants could be evacuated safely in the event of a fire, under specified conditions.

Table 4-3: Summary of Potential Spread of Fire vs. Clearance Times at Oakhurst

Hypothetical Fire Scenario	Rate of Spread (feet per second)	Time to Reach Development (minutes)	Time to Engulf 50% of Development (Minutes)	Time to Engulf 100% of Development (minutes)
Slope of 1% to 25%, assumed wind speed of 3**0** mph, and start of fire at 5**00** feet south of development	166	3	12	20
Slope of 1% to 25%, assumed wind speed of **20** mph, and start of fire at 5**00** feet west of development	3	150	600	1080
Slope of 1% to 25%, assumed wind speed of 3**0** mph, and start of fire at **100** feet south of development	166	0.5	5	10
Slope of 1% to 25%, assumed wind speed of **20** mph, and start of fire at **100** feet west of development	3	30	300	540

Clearance Times

Delay per Vehicle at Through Road Intersection	Clearance (minutes)
0 seconds	6
5 seconds	13
10 seconds	20
20 seconds	34

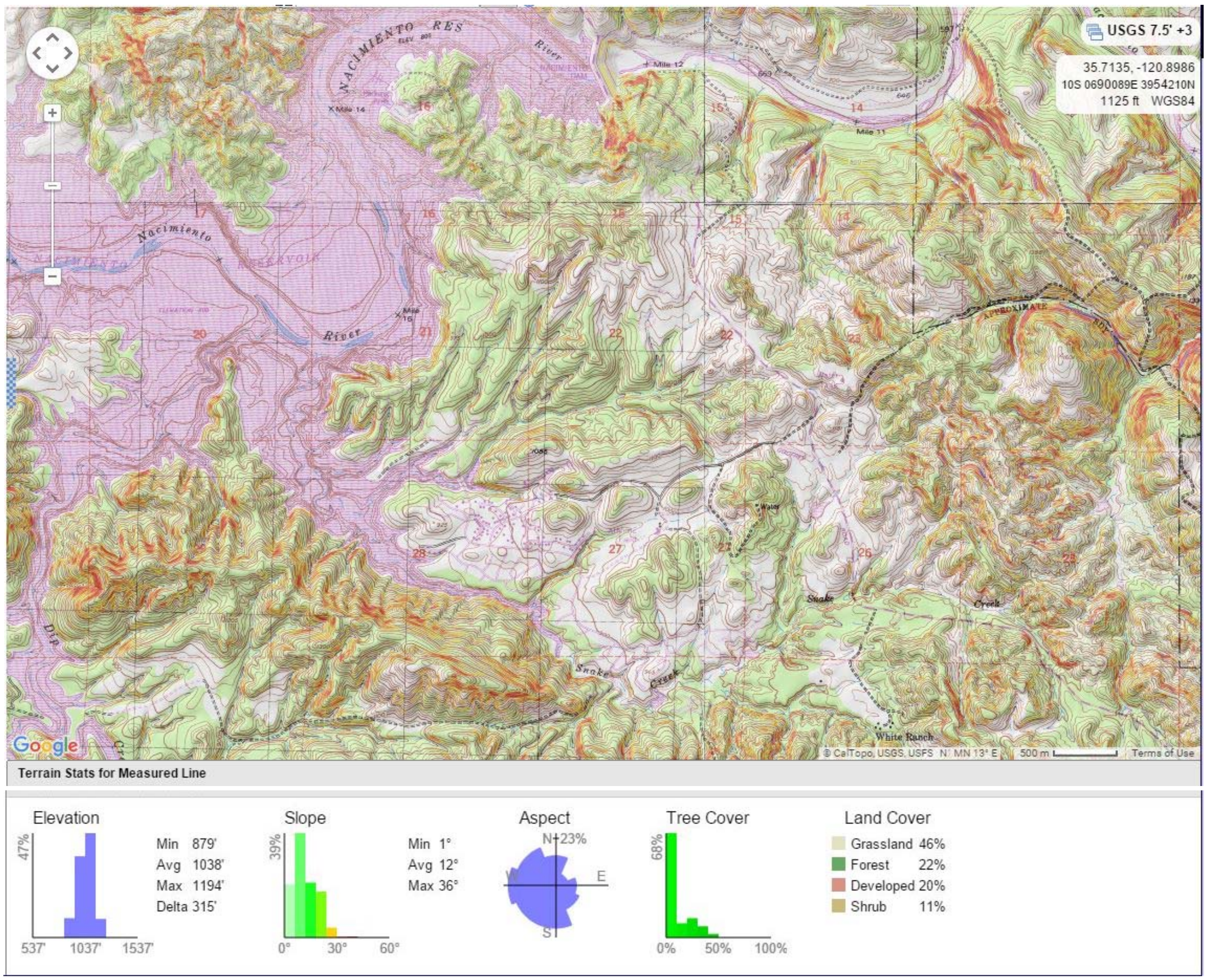
Case Study: Heritage Ranch – 1

Conditions

Figure 4-6 shows existing physical conditions in the vicinity of the Heritage Ranch case study site. In summary, conditions depict the following:

Vegetation: Grass (existing)
Slope: 1% to 25% (existing)
Wind speed: 30 mph (assumed for a "normally severe fire weather day")

Figure 4-6: Physical Information on Heritage Ranch Study Location



Source: Cal Topo using resources from Google Maps; USGS, and USFS

Associated Look-Up Table

Table 4-4 identifies the appropriate look-up table for the case study site. It also shows the appropriate cell of fire behavior model parameters to use.

Table 4-4: Look-Up Table Applied to Heritage Ranch Study Location

Vegetation: Grass (Mature)						
	Open Wind Speed (mph)					
Slope (%)	0	10	20	30	40	50
0	ROS: 6'/min FL: 3'	ROS: 19'/min FL: 5'	ROS: 42'/min FL: 7'	ROS: 71'/min FL: 9'	ROS: 106'/min FL: 10'	ROS: 144'/min FL: 12'
1-25	ROS: 9'/min FL: 3'	ROS: 23'/min FL: 5'	ROS: 46'/min FL: 7'	ROS: 75'/min FL: 9'	ROS: 110'/min FL: 10'	ROS: 148'/min FL: 12'
26-40	ROS: 29'/min FL: 6'	ROS: 42'/min FL: 7'	ROS: 65'/min FL: 8'	ROS: 95'/min FL: 10'	ROS: 129'/min FL: 11'	ROS: 168'/min FL: 13'
41-55	ROS: 55'/min FL: 8'	ROS: 69'/min FL: 8'	ROS: 91'/min FL: 10'	ROS: 121'/min FL: 11'	ROS: 155'/min FL: 12'	ROS: 194'/min FL: 14'
56-75	ROS: 96'/min FL: 10'	ROS: 109'/min FL: 10'	ROS: 132'/min FL: 11'	ROS: 162'/min FL: 12'	ROS: 196'/min FL: 14'	ROS: 234'/min FL: 15'
>75	ROS: 159'/min FL: 12'	ROS: 173'/min FL: 13'	ROS: 196'/min FL: 14'	ROS: 225'/min FL: 14'	ROS: 260'/min FL: 15'	ROS: 298'/min FL: 16'

Model Parameters

For the given slope range of 1% to 25% and assumed wind speed of 10 mph, the look-up table indicates the following parameters:

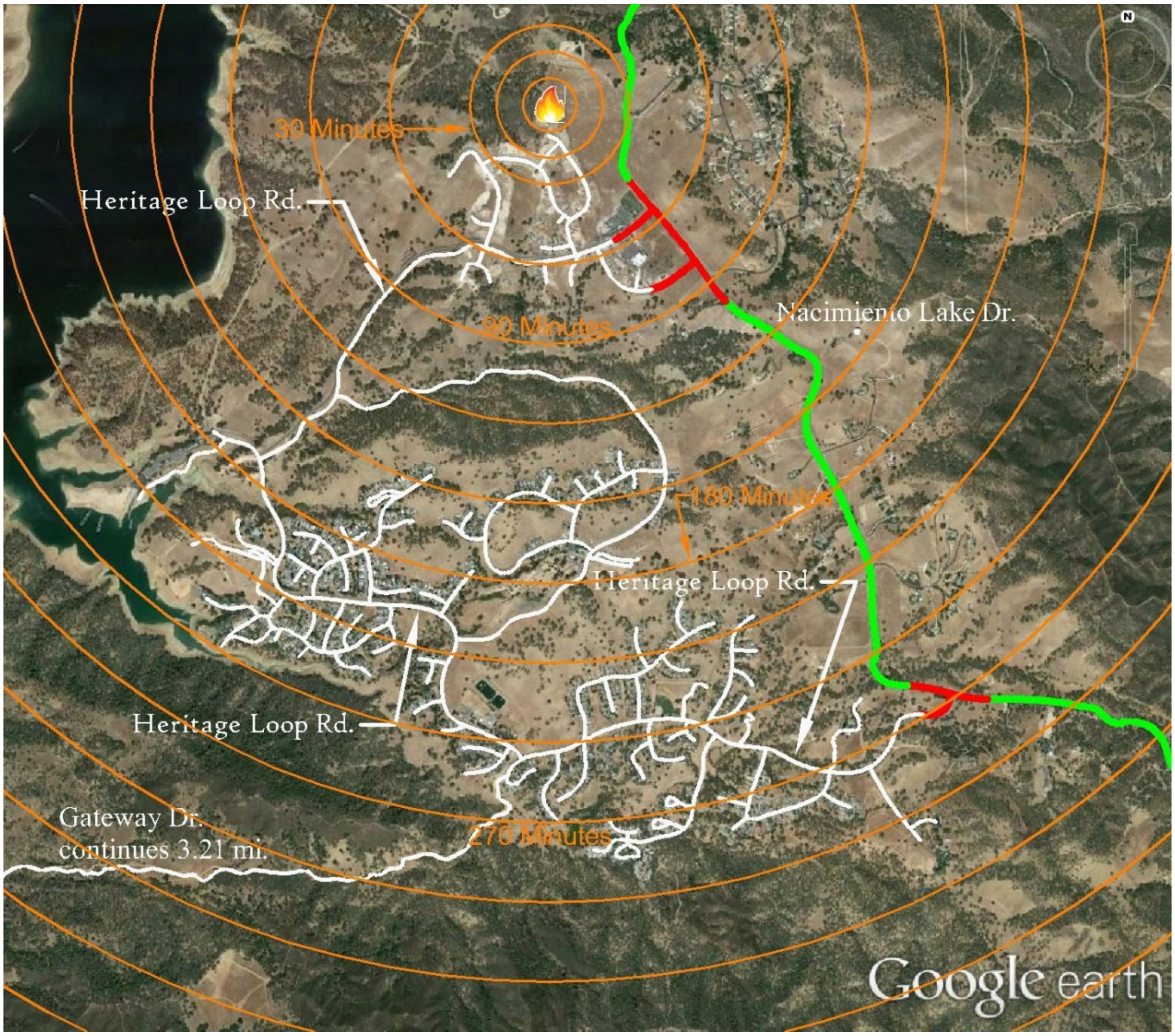
Rate of spread = 75 feet per minute (0.85 mph)
Flame length = 9 feet
Start of fire = 100 to 500 feet from development

Potential Spread of Fire by Time Period

The Heritage Ranch illustration covered three different wind speed scenarios. The scenarios assumed the location of a fire at hypothetical distances of 100 feet and 500 feet from the development. One scenario assumed a best-case wind speed of 10 mph. Figure 4-7 shows how long it would take for the fire to engulf specified sections of the development in 30-minute increments assuming there were no intervention from fire professionals. Results indicate that the fire would reach points farthest north of the development in approximately 10 minutes, overrun the northern (also called western) entrance within 60 minutes, and threaten most of the development within 4 hours.

As shown in Table 4-5, these results compare favorably with the estimated total clearance time of 117 minutes for this development only assuming no further delay at the exit intersection. If prevailing or projected conditions at the through road intersection (for instance from a traffic impact study) indicate that delay per vehicle is 5 seconds at the bottleneck, clearance time would nearly triple to 323 minutes (or 5.4 hours), threatening a large number of residents of the subdivision.

Figure 4-7: Potential Spread of Fire at 10-mph Wind Speed from 500 Feet North of Heritage Ranch



Parameters

For given slope of 1% to 25%, assumed wind speed of 10 mph, and start of fire at 500 feet north of development:

Rate of spread = 23 feet per minute (0.26 mph)

Flame length = 5 feet

Table 4-5: Heritage Ranch with Potential Effects of Delay at Main Through Road Intersection

Heritage Ranch: *Level of Delay Assumed per Vehicle at Through Road Intersection (seconds)*	**Normal Travel Time of Farthest Vehicle (seconds)**	**Delay to Farthest Vehicle (seconds)**	**Total Travel Time for Farthest Vehicle (seconds)**	**Number of Vehicles to Clear**	**Average Network/Facility Operating Speed (mph)**	**Total Clearance Time -- No Delay at Through Road Intersection (minutes)**	**Total Clearance Time -- With Delay at Through Road Intersection (minutes)**
0	765	33	799	2,476	6	117	117
5							323
10							529
15							736
20							942

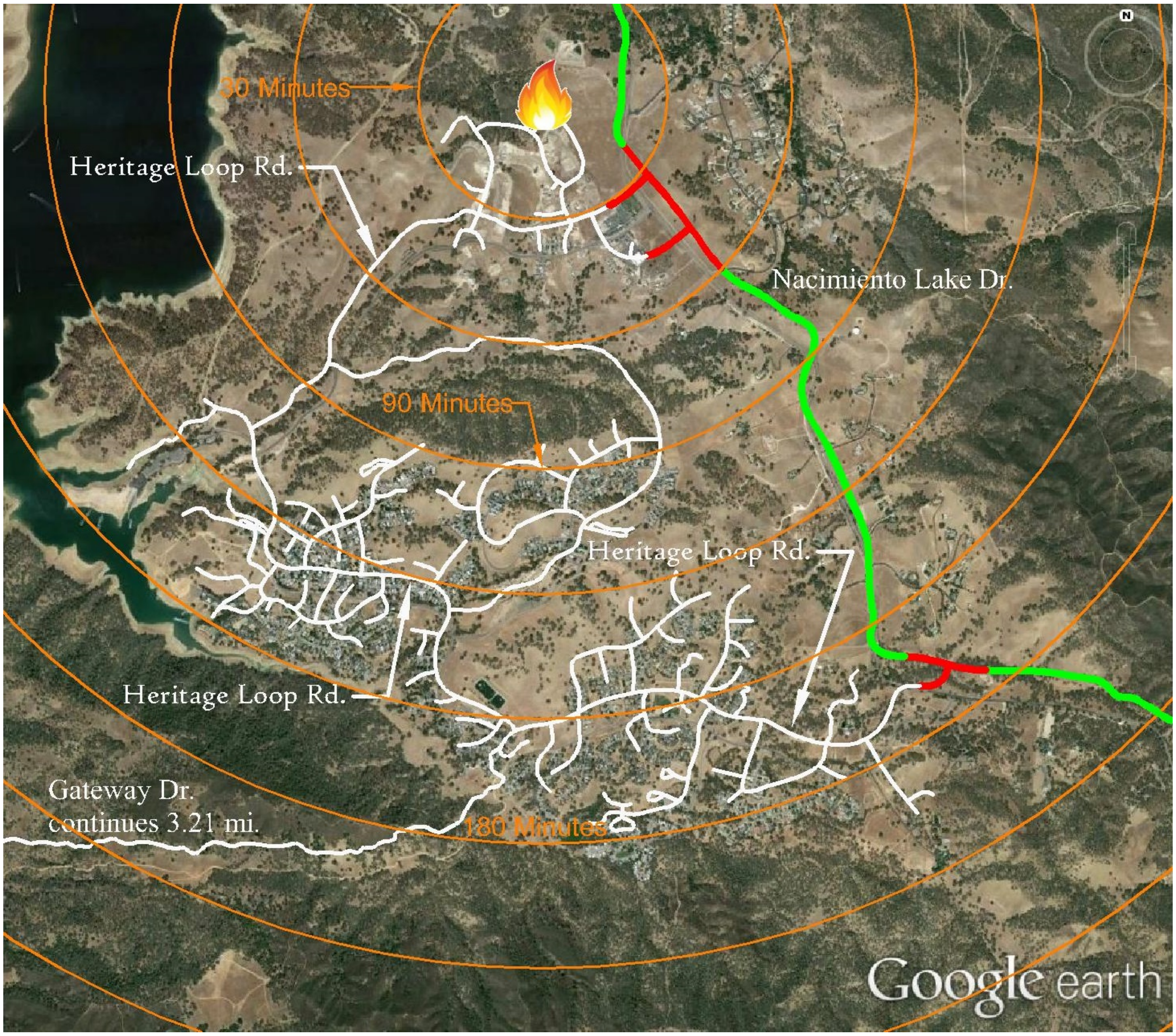
Case Study: Heritage Ranch – 2

Figures 4-8 and 4-9 depict two other hypothetical situations where the fire begins close to the development just 100 feet to the north under higher prevailing wind speeds of 20 mph and 30 mph respectively. The proximity of the fire and the higher wind speeds depict much worse potential outcomes than for the first scenario.

Under the 20 mph scenario, results indicate that the fire would reach points farthest north of the development in approximately 2 minutes and overrun the northern (also called western) entrance within 30 minutes. The fire could engulf the development within 3 hours.

Under the 30 mph scenario, results indicate that the fire would reach points farthest north of the development in approximately 1 minute and overrun the northern (also called western) entrance within 20 minutes. The fire could engulf the development within 2 hours.

Figure 4-8: Potential Spread of Fire at 20-mph Wind Speed from 100 Feet North of Heritage Ranch



Parameters

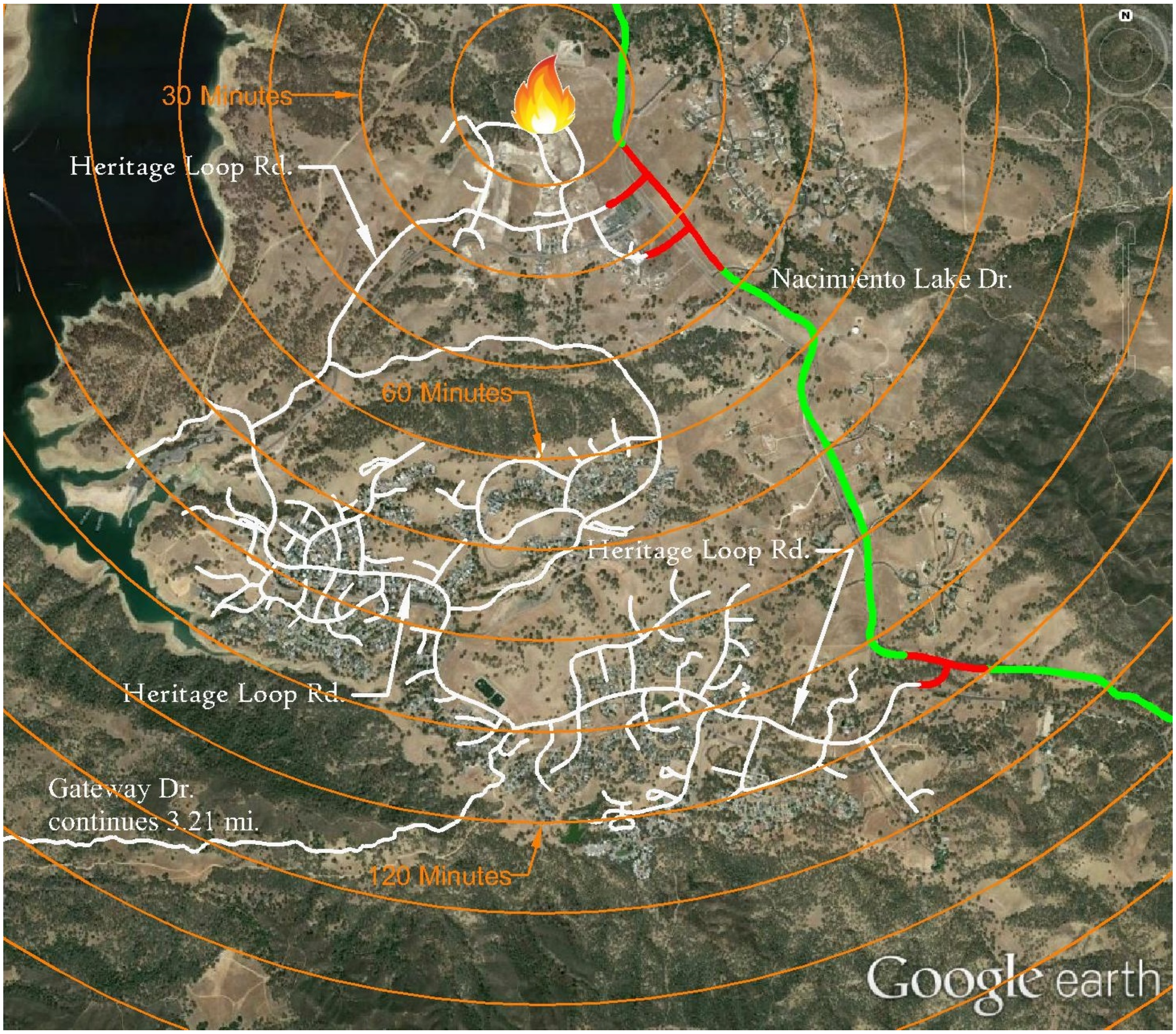
For given slope of 1% to 25%, assumed wind speed of 20 mph, and start of fire at 100 feet north of development:

Rate of spread = 46 feet per minute (0.52 mph)

Flame length = 7 feet

Case Study: Heritage Ranch – 3

Figure 4-9: Potential Spread of Fire at 30-mph Wind Speed from 100 Feet North of Heritage Ranch



Parameters

For given slope of 1% to 25%, assumed wind speed of 30 mph, and start of fire at 100 feet north of development:

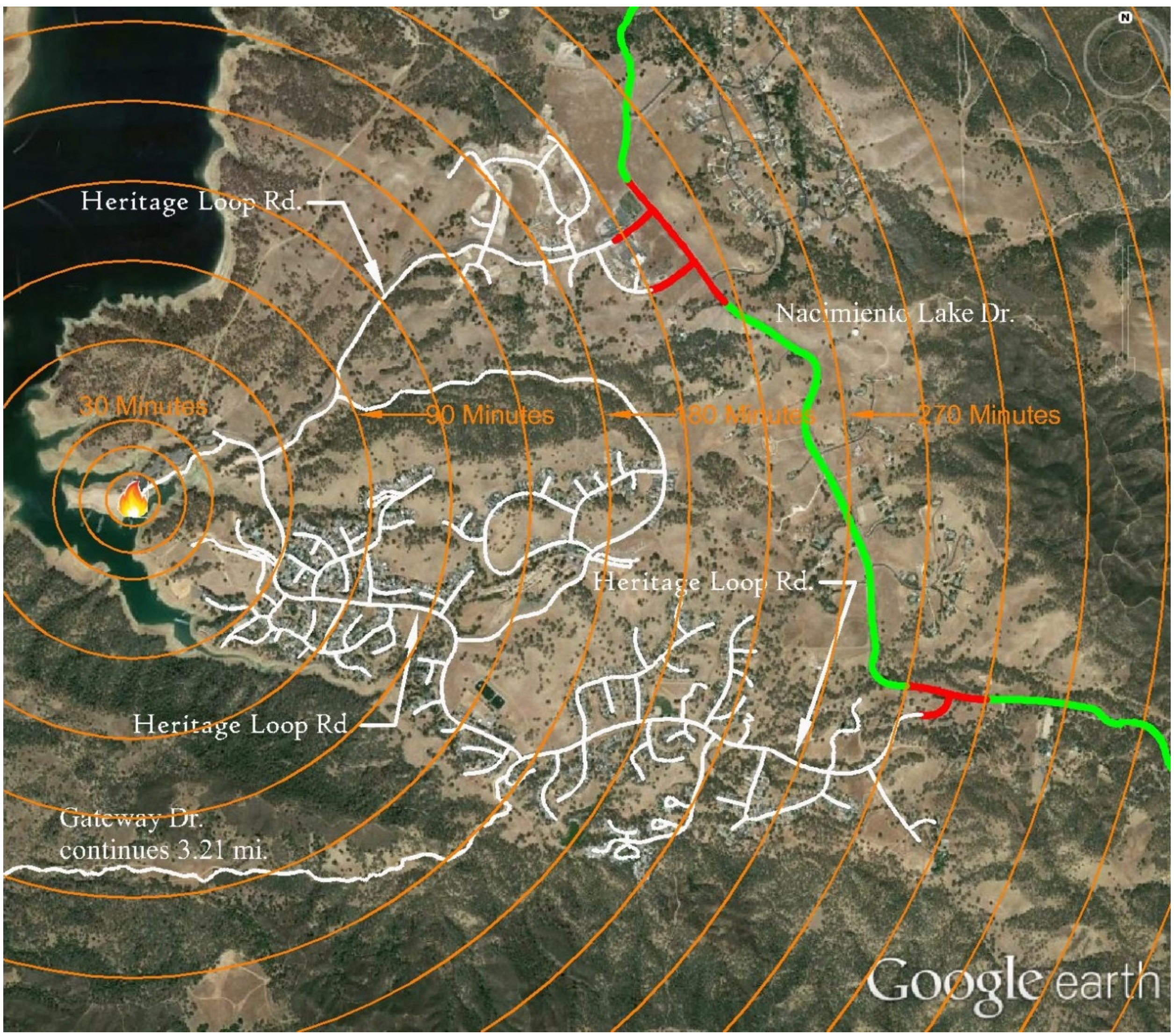
Rate of spread = 75 feet per minute (0.85 mph)

Flame length = 9 feet

Case Study: Heritage Ranch – 4

Figure 4-10 depicts another hypothetical situation where the fire begins 100 feet west of the development under 10 mph wind condition. Given the proximity of the fire, half of the development would be overrun within 1.5 hours and the entire development would be threatened within 5 hours. Figures 4-11 and 4-12 depict two other hypothetical situations where the fire begins further from the development, 500 feet to the west, under higher prevailing wind speeds of 20 mph and 30 mph respectively. The proximity of the fire and the higher wind speeds depict worse potential outcomes than for the previous scenarios.

Figure 4-10: Potential Spread of Fire at 10-mph Wind Speed from 100 Feet West of Heritage Ranch



Parameters

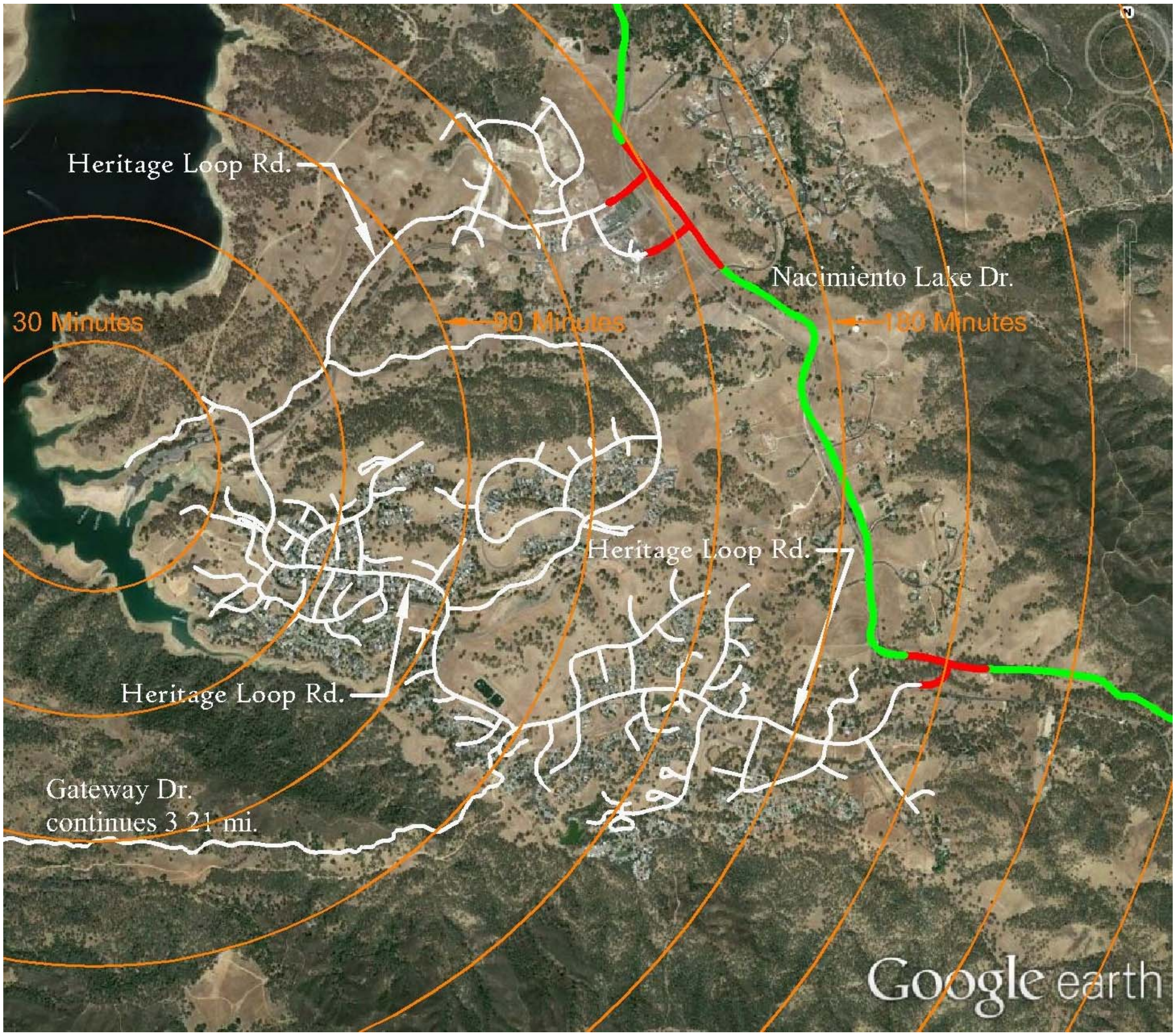
For given slope of 1% to 25%, assumed wind speed of 10 mph, and start of fire at 100 feet west of development:

Rate of spread = 23 feet per minute (0.26 mph)

Flame length = 5 feet

Case Study: Heritage Ranch – 5

Figure 4-11: Potential Spread of Fire at 20-mph Wind Speed from 500 Feet West of Heritage Ranch



Parameters

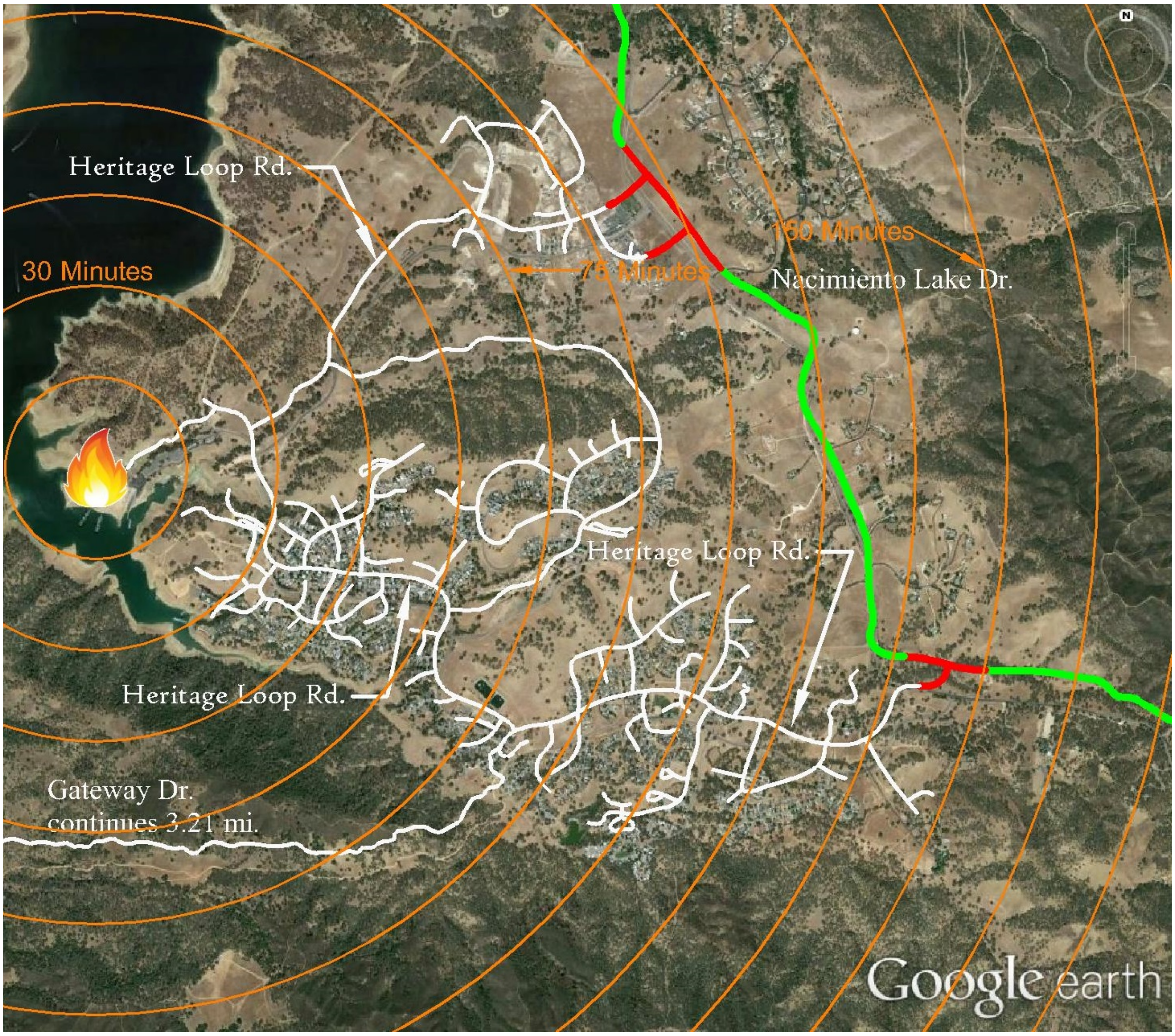
For given slope of 1% to 25%, assumed wind speed of 20 mph, and start of fire at 500 feet west of development:

Rate of spread = 46 feet per minute (0.52 mph)

Flame length = 7 feet

Case Study: Heritage Ranch – 6

Figure 4-12: Potential Spread of Fire at 30-mph Wind Speed from 500 Feet West of Heritage Ranch



Parameters

For given slope of 1% to 25%, assumed wind speed of 30 mph, and start of fire at 500 feet west of development:

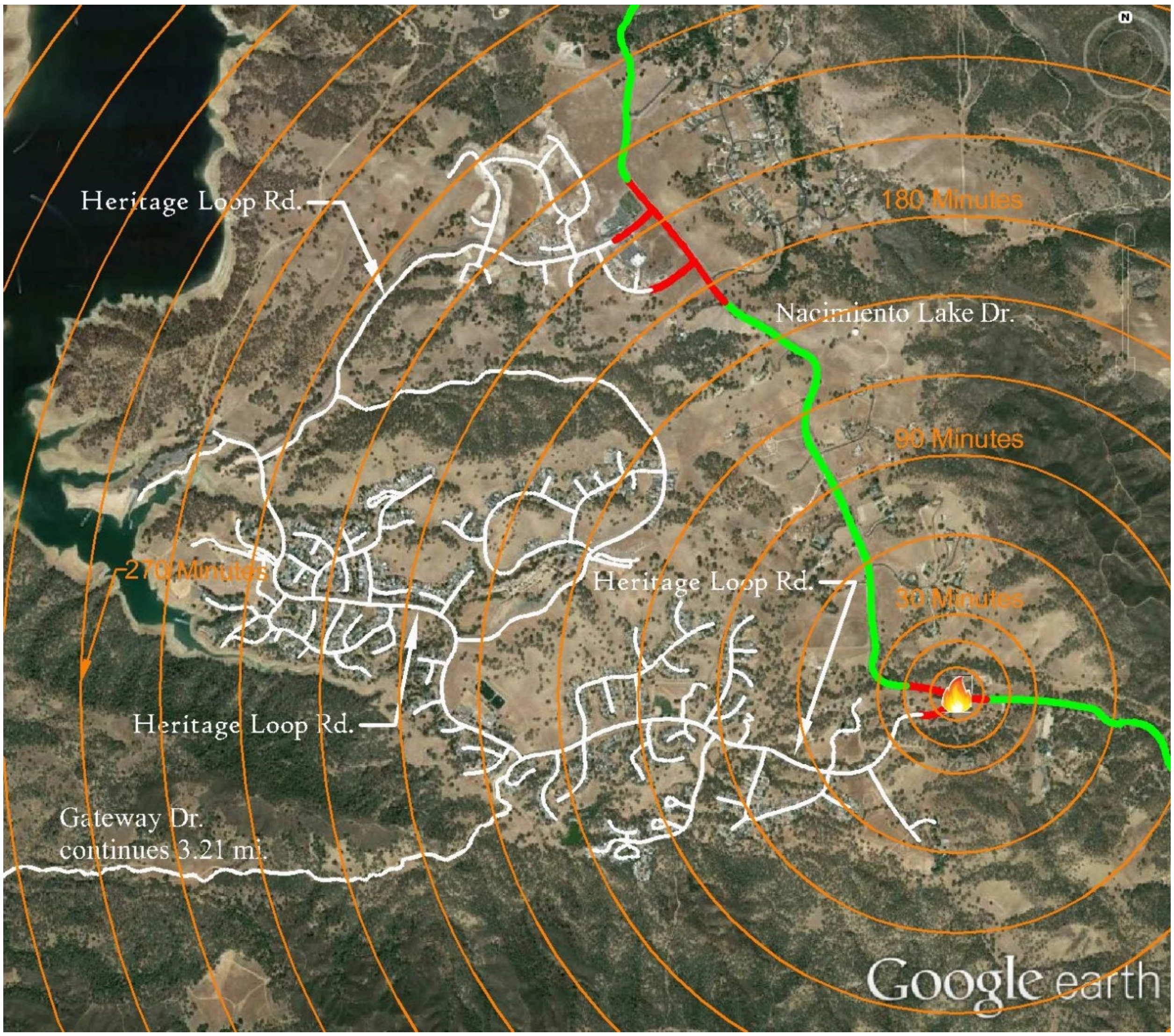
Rate of spread = 75 feet per minute (0.85 mph)

Flame length = 5 feet

Case Study: Heritage Ranch – 7

Figure 4-13 similarly depicts a hypothetical situation where the fire begins 100 feet east of the development. Given the proximity of the fire, half of the development would be overrun within 1.5 hours and the entire development would be threatened within 4 hours.

Figure 4-13: Potential Spread of Fire at 10-mph Wind Speed from 100 Feet East of Heritage Ranch



Parameters

For given slope of 1% to 25%, assumed wind speed of 10 mph, and start of fire at 100 feet east of development:

Rate of spread = 23 feet per minute (0.26 mph)

Flame length = 5 feet

Summary

Table 4-6 summarizes the various hypothetical fire scenarios at the Heritage Ranch subdivision. It also shows comparative times to clear all vehicles out of the subdivision under various conditions of delay at the through road intersection. It is noteworthy that it would only take 5 seconds of delay at the through road intersection for any of the scenarios to depict the potential for catastrophic consequences.

Table 4-6: Summary of Potential Spread of Fire vs. Clearance Times at Heritage Ranch

Hypothetical Fire Scenario (Slope of 1% to 25%)	**Rate of Spread (feet per minutes)**			**Time to Engulf 100% of Development (minutes)**
Wind speed of **10** mph, and start of fire at **500** feet north of development	23			270
Wind speed of **20** mph, and start of fire at **100** feet north of development	46			180
Wind speed of **30** mph, and start of fire at **100** feet north of development	75			120
Wind speed of **10** mph, and start of fire at **100** feet west of development	23			300
Wind speed of **20** mph, and start of fire at **500** feet west of development	46			210
Wind speed of **30** mph, and start of fire at **500** feet west of development	75			120
Wind speed of **10** mph, and start of fire at **100** feet east of development	23			240
Clearance Times				
Delay per Vehicle at Through Road Intersection				**Clearance (minutes)**
0 seconds				117
5 seconds				323
10 seconds				529
15 seconds				736
20 seconds				942

5.0 STUDY RECOMMENDATIONS

The following are the Cal Poly team's recommendations, based on the findings of our study to date.

1. Amend the existing dead-end road standards

We recommend that the existing standards be amended for the following reasons:

a) Maximum dead-end road lengths are based solely on parcel size.
b) The standards assume that subdivisions are only for single-family residential uses.
c) The standards place no limit on the number of lots in subdivisions.
d) The standards allow for stacking of multiple roadways within maximum length limits.
e) The standards do not provide for reasonable evacuation times for all road length categories.
f) The standards do not consider other land uses such as commercial uses, apartments, or schools.
g) The standards do not take into account potential long-term land use intensification.
h) There is no clearly stated enforcement mechanism or penalty for non-compliance.

To eliminate existing flaws and loopholes, and to provide informed guidance to jurisdictions, developers, and other stakeholders, we recommend that the standards be amended with the following considerations in mind:

a) The existing table of maximum road lengths for dead-end roads should be eliminated.
b) Other factors in addition to lot size should be addressed, including potential land uses, with attention paid to likely occupancy, now and in the future.
c) Open-ended loophole wording, such as "regardless of number of lots," should be eliminated.
d) The stacking of multiple roadways within maximum road length limits should be limited.
e) The maximum evacuation traffic generation potential of all land uses, including commercial uses, apartments, and schools, should be taken into account.
f) Potential long-term land use intensification should be addressed.

2. Require application of the tool and appropriate mitigation measures

We recommend that any proposal for a single-access subdivision in an SRA (or in a Local Responsibility Area [LRA] if the local jurisdiction has adopted the state's recommendation of a Very High Fire Hazard Severity Zone [FHSZ]) should trigger analysis by means of the tool developed in this study. Even when secondary access is available, we recommend requiring analysis by means of the tool in any SRA that is categorized as a High or Very High FHSZ. We recommend this because, depending on the size of the subdivision, secondary access does not necessarily guarantee adequate exiting capacity. Exiting capacity is relevant for all wildland-urban interface subdivisions, not just single-access subdivisions.

Use of the tool would permit agencies having jurisdiction to estimate the time required to evacuate the occupants of a proposed subdivision in the event of a fire or other emergency. It would then be up to the agency to decide whether the time is likely to exceed that needed for occupants to be evacuated safely. As mentioned in Section 1.0 of this report, if the intent of the regulation is to be met, the agency cannot avoid deciding on an evacuation time considered to be safe, if not explicitly then implicitly.

Results from application of the fire behavior model might help the agency decide on a safe evacuation time, as suggested in Section 3.0 of this report. However, the model cannot tell us with precision how quickly occupants would be overtaken by a fire, both because of our inability to predict where a fire might start and because the model was intentionally designed to be overly simplified in order to allow its application by those who are not experts in fire behavior. Potentially, as part of the regulation, the state could specify an upper limit to this time, to ensure that an agency stays within reasonable boundaries.

If the agency decides that the egress time from a proposed subdivision is likely to be too long for occupants to be evacuated safely in the event of a fire, an option would be for the analysis to be repeated with additional mitigation measures incorporated into the proposal.[14] These measures may include, for example, changes in the capacity of access roads in order to speed up evacuation and/or fuel modification techniques to slow the spread of fire. The analysis might show that, with these mitigation measures required as a condition of approval by the agency and put in place, the intent of the regulation would now likely be met.

3. Tie in the preceding recommendations with Senate Bill 1241 (2012)

General plans govern land use intensification and are especially relevant to single-access subdivision land use capacity and occupancy considerations. As mentioned at the beginning of this report, tentative map approval for a new subdivision is contingent on the proposal being consistent with the general plan.

Legislation enacted in 2012 (Senate Bill 1241) requires that additional mandatory findings be made before tentative map approval can be granted to a proposed subdivision in an area located within an SRA or a locally adopted Very High FHSZ, specifically (1) that the design and location of the subdivision are consistent with applicable regulations adopted by the State Board of Forestry and Fire Protection pursuant to PRC Sections 4290 and 4291, (2) that structural fire protection and suppression services will be available for the subdivision, and (3) that, to the extent practicable, ingress and egress for the subdivision meet the regulations regarding road standards for fire equipment access adopted pursuant to PRC Section 4290 and any applicable local ordinance. We recommend that special attention be given to implementing these requirements for additional mandatory findings under Senate Bill 1241.

[14] "Additional" reflects the assumption that some mitigation measures would have been included in the proposal as originally submitted and analyzed.

4. Explore potential opportunities and challenges related to strengthening enforcement of the modified dead-end road standards

We recommend giving attention to possible mechanisms to bring about more uniform compliance, addressing non-compliance situations and seeking options (such as fines and other penalties) at the local level that go beyond case law. We further recommend the establishment of a mandatory appeal process to a higher authority such as the State Board of Forestry and Fire Protection.