NIST NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
U.S. DEPARTMENT OF COMMERCE

WUI Fire Evacuation and Sheltering Considerations

Assessment, Planning and Execution

ESCAPE

NIST WUI DAYS 2023 – Session 2.8

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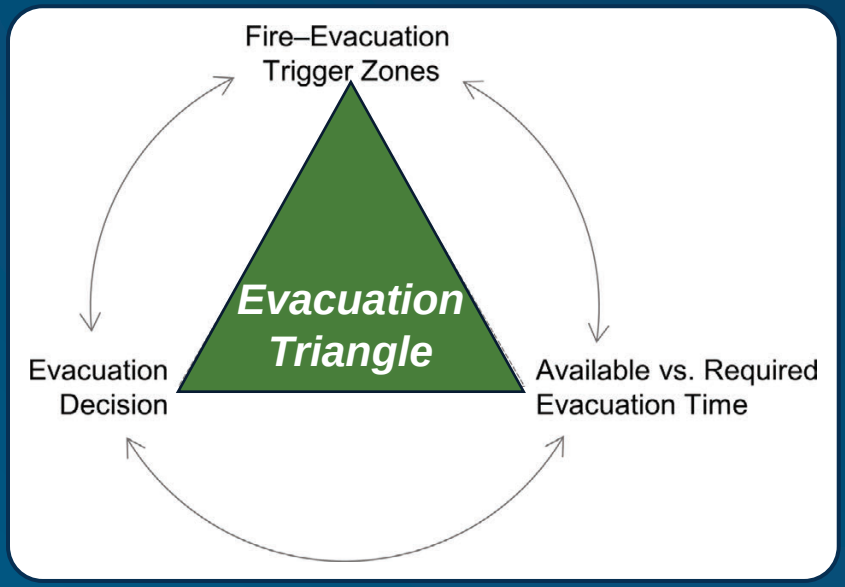
Photo courtesy of Paradise Rolice Department


Photo courtesy of CAL FIRE

Outline

- Why was ESCAPE developed?
- What is the problem?
- Why WUI fires and evacuations are different from other disasters?
- Existing practices
- Evacuation failures
- Addressing evacuation failures
- Spatiotemporal relationships between fire and evacuations
- Proposed approach
- Implementation: Assessment, Planning, and Execution



Why was ESCAPE developed?

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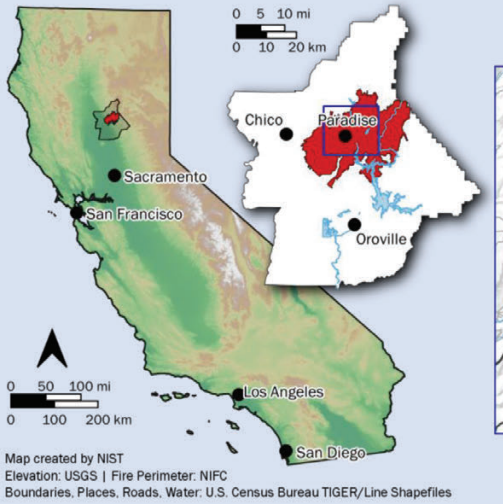
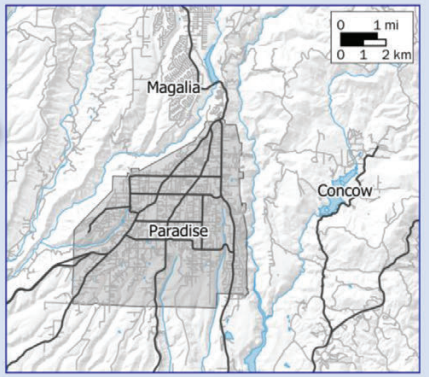
- To facilitate the use of lessons learned from the Camp Fire Case Study.
- ESCAPE is a methodology for small to intermediate size intermix communities to assist with the development and implementation of Notification and Evacuation Plans
- 24 examples from the Camp Fire case study

Camp Fire Example 1. Introduction to the 2018 Camp Fire.





The 2018 Camp Fire in Butte County, California rapidly impacted the communities of Concow, Paradise, and Magalia, triggering widespread evacuation of 40 000 people. The maps above show the location of Butte County in California, the final fire perimeter, and the local area around Paradise.

The fire was the most deadly and destructive fire in California history, resulting in 85 fatalities and more than 18 000 destroyed structures. The Camp Fire ignited at approximately 06:20 off Camp Creek Road near the small community of Pulga in the Feather River Canyon, northeast of Concow. After immediately impacting Pulga, the fire spread southwest over a ridge, spotting and burning into Concow by 07:30, 6.4 km (4 mi) away. By 08:00 spot fires were igniting in Paradise, an additional 6 km (3.75 mi) west of Concow. The fire front impacted eastern Paradise forty minutes later.

A post-fire case study was conducted, resulting in two primary reports to date: the first on the fire progression timeline, fire behavior, and identified civilian burnover events [7], and the second on life safety aspects including notification, evacuation, traffic, temporary refuge areas, rescues, and fatalities (collectively, NETTRA) [6]. Various examples from the Camp Fire are introduced in this report to provide recent real-world examples that illustrate some of the considerations and challenges that are presented here.

What is the Problem?

- Addressing the life safety risk when there is insufficient time to evacuate out of the community
- Burnovers and need for Temporary Refuge Areas (TRAs)
- Existing built environment is not designed to act as fire shelters

Camp Fire Example 3. Inadequacy of existing infrastructure buildings as fire shelters.

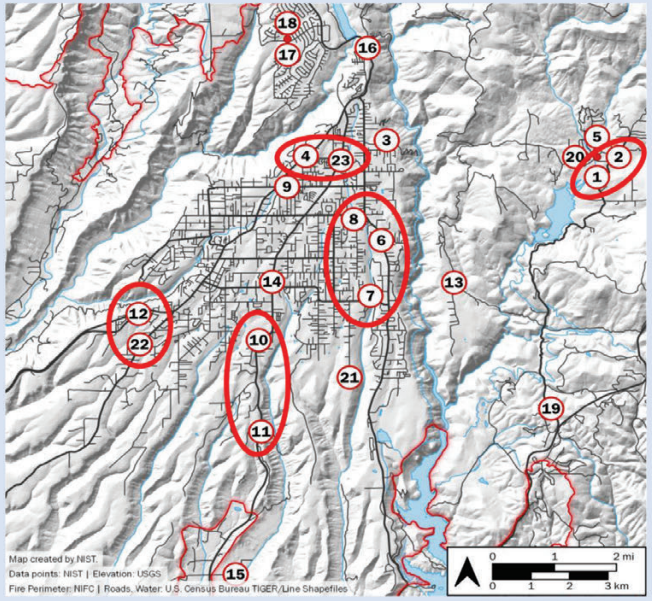
a) Ponderosa Elementary School

b) Feather River Hospital

c) Feather River Hospital

The damage to Ponderosa Elementary School (a) and Feather River Hospital (b and c) illustrate just two examples of existing infrastructure that were not adequate for use as WUI fire shelters during the Camp Fire. Despite having more robust construction than typical residential structures, they are not currently designed to withstand WUI fire exposures. Both the school and hospital buildings ignited and were actively defended by firefighters, largely saving the structures. The damage to the buildings was extensive, even with significant efforts by firefighters, and one defended hospital building was destroyed. School children, hospital patients, and other susceptible populations cannot shelter in place in existing infrastructure that is not designed specifically to withstand WUI fire and ember exposures.

Camp Fire Example 9. Burnover events that impacted evacuating civilians and responding emergency personnel.



Entrapment/burnover events are defined as life-threatening situations where planned escape routes or safety zones are inadequate or compromised and individuals are overtaken or trapped by fire, often resulting in equipment damage and personal injury or death. The post-fire case study identified 23 such events that occurred in the first 26 hours of the Camp Fire [6, 7, 78], 17 of which involved an estimated combined total of up to 500 civilians. A total of seven civilians were killed in three of the 23 events. The locations of the 23 burnover incidents are shown in the map above, occurring throughout the fire area.

Out of the 23 identified burnovers, 11 impacted primary egress arteries during the peak of the evacuation, roughly between 08:00 and 12:00. These events are indicated by the circled burnover ID points in the map above. Fire overtook evacuees who were stuck in gridlocked traffic in five instances, and intense fire impeded or trapped moving traffic in six instances. The closure of Concow Road, the sole egress route in Concow, significantly affected the evacuation of that community. In Paradise, some egress arteries were closed for several hours, impacting both civilian egress and first responder access and operations. At 09:45, two hours after the first spot fire ignited in Paradise and a little over three hours after the fire was reported, two of the four southbound egress arteries were closed due to fire. By 11:45, during the peak of the Paradise evacuation, three of the four were closed due to fire, significantly impacting evacuation.

The concurrence of evacuation and fire impact on the community significantly affected the life safety of evacuating civilians. The formation and use of TRAs significantly enhanced the life safety of entrapped individuals.

What is the Problem?

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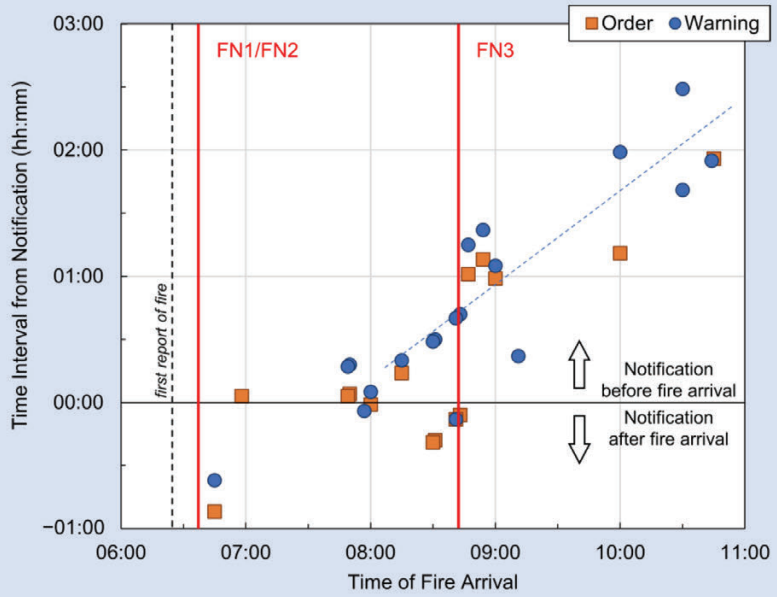
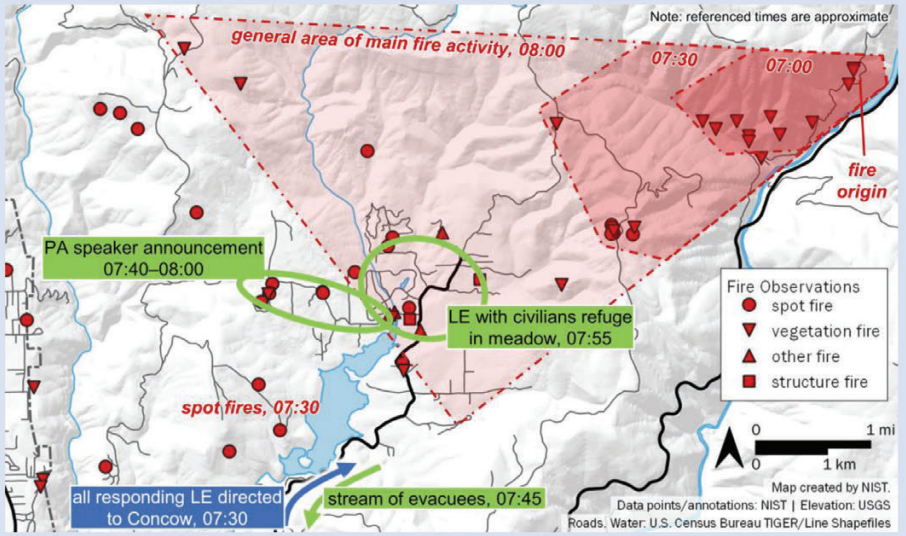
Time and distance to safety

Camp Fire Example 11. Time of fire arrival and first official evacuation notification, by evacuation zone.



The plot above, adapted from Ref. [6], illustrates the time gap between time of fire arrival and the time of official notification for each evacuation zone for the Camp Fire as it spread through Concow and Paradise. Early in the incident, before 08:45, evacuation notifications were sent after or concurrent with the arrival of the fire in each evacuation zone (FN1 and FN2). This is represented in the plot by data points below the *x*-axis. At 07:45, 80 minutes after the first report of the fire, evacuation notifications were being sent at the same time as fire arrived within the notified evacuation zones. The positive gap illustrated on the right side of the graph, after 08:45, shows how notifications were issued ahead of the fire as the incident continued to evolve, giving the civilians in these zones more time to evacuate before the arrival of fire (FN3).

Camp Fire Example 12. Simultaneous arrival of fire and evacuation notification, leading to entrapment during evacuation in Concow.



The map above shows the area of Concow, a rural community located between the origin of the fire in Pulga and the town of Paradise. Red data points indicate individual fire observations before 08:00. The red shaded areas roughly indicate the area of main fire activity in 30-minute intervals after ignition. Note the significant number of spot fires ahead of the main fire activity.

The IC requested evacuation of Concow at 07:37, seven minutes after the first 911 calls were received reporting spot fires in the area. All responding law enforcement officers (LE) were directed to Concow to begin evacuations. Due to the location and the scattered spot fires ahead of the main fire front, the 911 calls were the first indication to the IC that the fire was within Concow. Firefighters on the ridge between Concow and Pulga observed the fire front spreading west at 07:30, indicated by the intermediate shaded polygon.

One of the first firefighters to access the Concow area conducted drive-by notifications of residents using the vehicle siren and public address speaker between 07:40 and 08:00. At the same time, law enforcement was directing civilians to seek shelter in the designated Wild Fire Safety Zone at the Camelot Meadow. Multiple spot fires grew rapidly and within minutes created impassable conditions, entrapping evacuating civilians and first responders at several locations and resulting in multiple burnover events and the formation of multiple TRAs (see Camp Fire Examples 15 and 19).

TRAs and Wildfire Safety Zones

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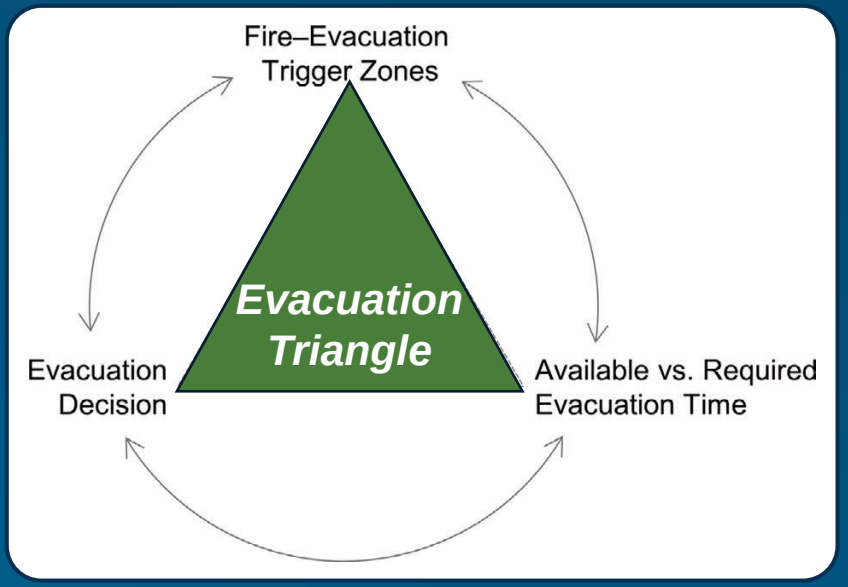
- TRAs – two uses
  - address immediate threat to life safety (from burnovers)
  - manage evacuating civilian flow

a) Pearson Road TRA

b) Optimo TRA

Presentation Outline

- Where are we now?
- How to go forward – using the lessons from the Camp Fire.
  - For *existing* communities now
  - For future (new) communities
  - Guide research and engineering



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WUI Fire Evacuation Challenges

Why WUI Evacuations are Different from other Disasters

- WUI events are self propagating – the community is the fuel
- Event starts other similar events

Characteristic	Hurricane	Flood	Tornado	Earthquake	WUI Fire
Built environment adds energy to fuel event	No	Yes [a]	No	No	Yes
Defensive actions during event change outcome [b]	No	No	No	No	Yes
Event energy can be managed beforehand	No	No [c]	No	No	Yes
Event starts other similar events	No	No	No	Yes	Yes
Notification period	Days	Variable [d]	Minutes	None	Variable [d]
Extent of evacuation	Region	Community/ Region	Shelter-in-place	Shelter-in-place	Community/ City/Region
Building construction or sheltering standards	Yes	Yes	Yes	Yes	Limited

[a] infrastructure failure; dams, levee systems (not individual buildings)
[b] including residential and commercial structures or other infrastructure
[c] amount of precipitation cannot be controlled; flood water can potentially be managed
[d] minutes to hours to days

Table 2

Why WUI Evacuations are Different that other Large-Scale Evacuations

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While Fire Weather Watches and ***Red Flag Warnings*** are issued ahead of qualifying weather days, these general warnings ***do not indicate there is a fire***; the actual ignition location, direction of fire spread, and fire intensity are not determined until after an ignition.

For hurricanes:

- Hurricane watches and warnings are issued based on a ***standardized system*** for predicting the track of the hurricane, including confidence and uncertainty analyses.
- ***The lead time of hurricanes is typically measured in days***, not hours or minutes.
- There is a ***national decision support tool*** with clear temporal thresholds in place for triggering evacuations for hurricanes (HURREVAC).

Frequency of Wildland and WUI Fires

- The upper bound for the number of Atlantic hurricanes in a season is 30 named storms (2020), with a 30-year average of 15.
- Not all of them will impact land and require evacuation.

- The National Interagency Fire Center reported a total of 58,733 wildland fires in 2021.
  - Not all of them will impact communities and require evacuation.
  - There are no standardized metrics to determine which ones will be problematic
  - There is no readily available national data on how many impact communities

Evacuations – Different Scales

Aspect	Commercial building [a]	Campus	Community or part of community
Codes used in design and construction addressing fire	Yes	Yes	No
Regional coordination needed	No	No	Yes
Safety zone location	Outside assembly area, typically in parking lot	Variable/undetermined	Can be miles away and will likely require travel in vehicle(s)
Evacuation impact on overall community	Low	Low to Moderate	High
Community road capacity impact on evacuation	Low	Variable	High
Potential impact of evacuees	Parcel only or Local	Local/Community	Community to regional

[a] selected for comparison due to specific code requirements for evacuation and construction compare[illegible]ingle-family residential type buildings

Limited availability of standards for road capacity and fire shelters design and maintenance

Table 3

Civilian Evacuations

Location	have means to evacuate	do not have means to evacuate	require assistance to evacuate
Residence	✓	✓	✓
Work	✓	✓	✓
Schools	variable	✓	✓
Care Facilities	employees	✓	✓

Table 4

See Camp #4 NETTRA for Rescues

Primary Technical Challenges of WUI Evacuations

Before the Fire

1. Large number of possible fire scenarios (ignition location, fuel presence, fuel moisture content, weather).
2. Chaotic behavior, in which small perturbations of variables can result in large changes in predicted event outcomes.
3. Difficulty in characterizing, quantifying, and analyzing the large number of different fire scenarios.
4. Complexities of modeling and predicting human behavior in evacuations and response to emergency situations.
5. Difficulties in how to account for the uncertainties in the methods used to generate the different scenarios/predictions.
6. Difficulties in how to use/implement the findings from the above-mentioned scenarios/predictions.
7. Need to characterize and quantify the possibility of non-containment of the fire (to address the large number of ignitions that do not result in catastrophic events).

Primary Technical Challenges of WUI Evacuations

Before the Fire

8. Need to develop contingencies for events like loss of communication and power.
9. Need to develop contingencies for potential closures or obstructions of egress arteries.
10. Need to evaluate evacuation through high-hazard wildland areas (which may result in burnovers), an issue that is particularly important for remote intermix communities.
11. Need to evaluate evacuation pathways that lead through urban areas for intermix communities adjacent to or near a large urban area.
12. Need to develop evacuation plans that address the above issues.
13. Need to disseminate the evacuation plans to first responders and the public.

Primary Technical Challenges of WUI Evacuations

During the Fire

1. Limits in situational awareness, including dynamic outages in data sources and communications.
2. Integration of rapidly changing conditions into ongoing evacuation activities.
3. Large uncertainty in fire spread during incidents.
4. Communication to first responders and civilians of any changes to the evacuation plan.

Existing Practices and Current Research

Leaving

- Emphasis on early out – Ready Set Go

Staying

- Some jurisdictions recommend Stay and Defend

There is no standardized way to determine what is defensible – including by whom and with what equipment and under what conditions

- Some jurisdictions recommend Shelter in Place or offer Shelter in Community (wildfire safety zones)

There are no standards for fire shelters or wildfire safety zones

Civilian Stay and Defend

Critical difference in fuel density from large rural parcels to suburban settings

Table 1. Differences between private civilians and firefighters.

Preparedness/Response Attribute	Typical Civilian	Firefighter
Training and maintenance of proficiency of WUI/wildland firefighting strategies and tactics	Limited	Mandatory training; experience gained through practice and annual recertification
Physical fitness	Variable	Required, tested
Equipment	Limited	Available, maintained, tested, and specialized
Standalone water supply (independent of community infrastructure)	Variable	Available on apparatus and locally accessible sources
PPE and safety training, including wildland fire shelter use	Likely inadequate	Standard and required
Situational awareness	Limited to media, internet, and radio scanners, and may be dependent on electrical power supply	Fully integrated in ICS with an incident action plan (IAP)
Lookouts, Communication, Escape Routes, and Safety Zones (LCES)	Unlikely	Yes
Operational support	No	Yes

Camp Fire Example 2. Defensible space and exposures from neighboring parcels.

Exposures from neighboring parcels must be accounted for when assessing the defensibility of a property. The fully involved parcel (including structure, vehicle, and vegetation) seen above illustrates the very high fire exposures that can be generated during WUI fires. Fully involved fuels with flame lengths greater than 6 m (20 ft), as in the image above, would be difficult to contain even with several firefighting apparatus and cannot be contained by defensive actions by residents.

In this scenario, the structure separation distance (SSD) was 13 m (43 ft) from the burning home shown in the image to the neighboring structure. The structure to property line distance (SPLD) was 8 m (26 ft). Defensible space may be difficult to implement in moderate and high-density communities where significant fire exposures can originate from neighboring parcels and structures are spaced even closer than in this example.

Exposure sources from adjacent parcels are beyond the control of residents and typically beyond their ability to suppress them

Table 1 and Camp Fire Example 2

Consequences and the Missing Link

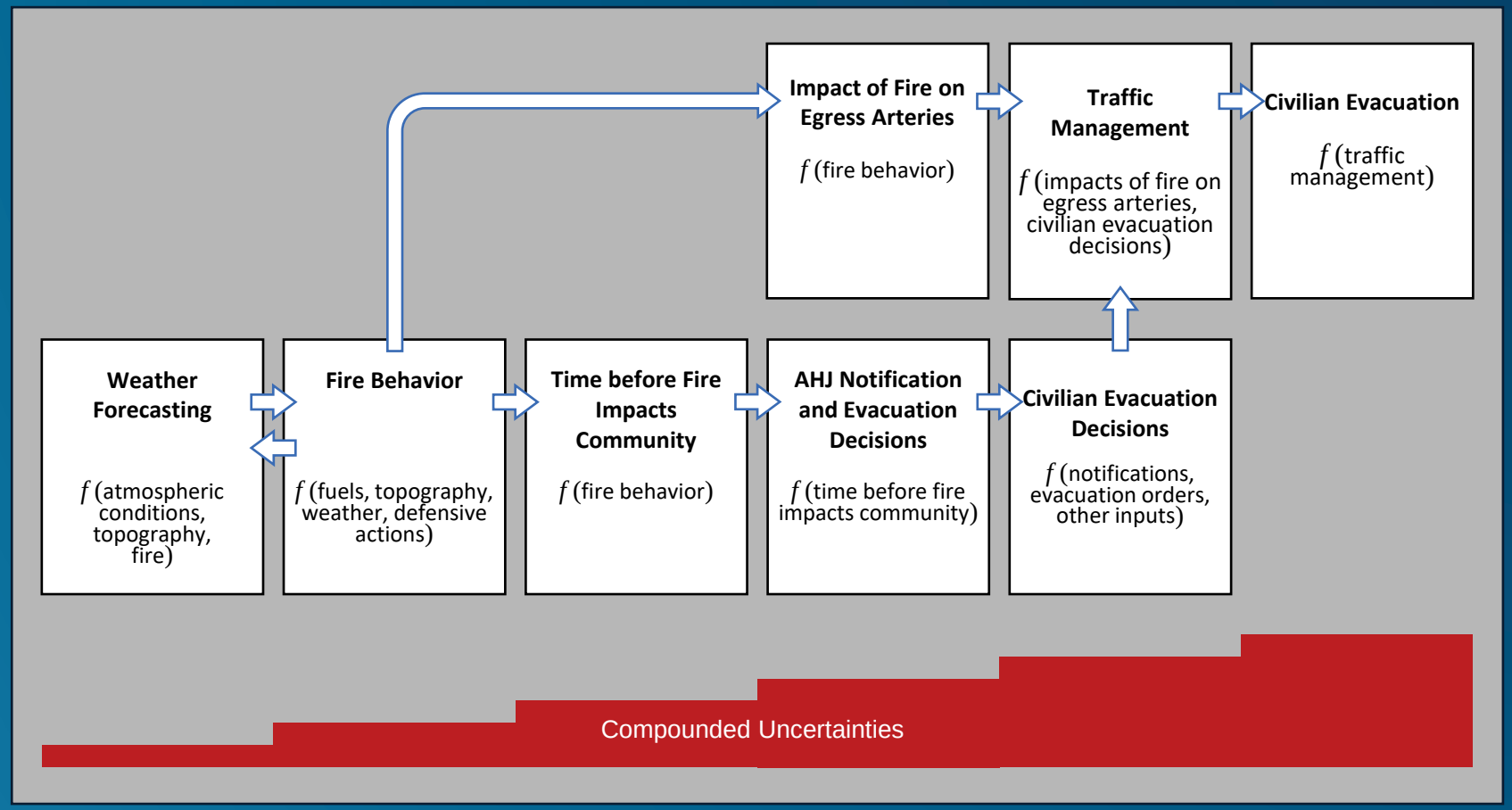
- Civilians perish in their homes
  (US, Portugal, Australia)

- Civilians perish in their vehicles as they try to evacuate
  (US, Portugal)

The missing link: addressing evacuation scenarios where there is insufficient time to evacuate from the community by *managing life safety risks*

Why is it so hard to reliably predict evacuations

Modules associated with evacuation predictions are linked or coupled.



Uncertainties are compounded and propagate from left to right and illustrated in red (not to scale).

Figure 3

Pathway from Ignition to Evacuation

Effects of Containment and Fire Impact on Community

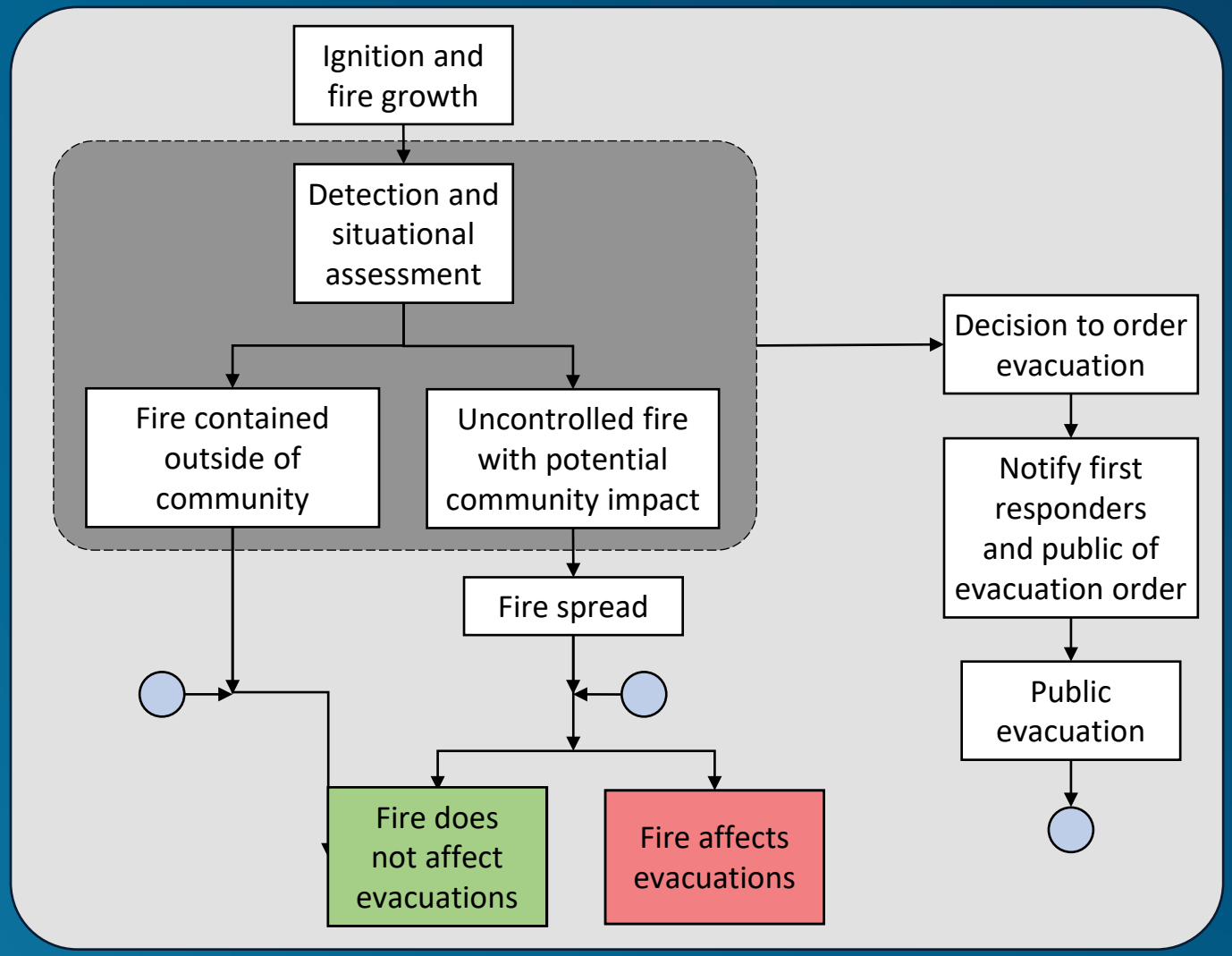


Figure 2

Evacuation "Failures"

Characterizing Evacuation "Failures"

- Type 1: Undesirable Evacuation Consequences – *no impacts to life safety*
- Type 2: Evacuation Failures – *impacts to life safety*

Type 1 Failures

Non-life safety impacts

1. Prolonged evacuation, extending beyond the expected duration (with the exception of critical evacuation of hospital patients and special needs individuals)

2. Evacuation without fire impacting the community and associated:
   a) Economic impact of evacuation
   b) Evacuation fatigue resulting in resistance to evacuate in future events.

Photo courtesy of Paradise Police Department

Addressing Type 1 Evacuation Events

- Improved fire spread predictions from local knowledge (and modeling).
- Improved evacuation time estimates from drills (and modeling),
- Economic modeling can provide guidance for benefit cost of repeated evacuations compared to probabilistic likelihood of a community getting impacted – technical challenge (large uncertainties).
- Social component and public education opportunities.

Type 2 Failures

Life safety impacts

Camp Fire Example 16. Entrapment during evacuation from the fire area.

a) Bille Road

b) Pearson Road

The Camp Fire presents multiple examples of civilians becoming entrapped during their attempted evacuation from the fire. The two photos above show areas where vehicles were abandoned in the roadway when evacuees were overcome by fire during their escape from the initial fire impact in eastern Paradise. TRAs were formed to enhance life safety in both cases pictured, a) on Bille Road, and b) on Pearson Road.

High fire exposures at their residences or during evacuation. Causes include:

- Inability to effectively communicate evacuation orders to residents in a timely fashion, delaying the start of evacuations
- Fire ignition near community resulting in only a short time to safely evacuate
- Underestimation of the fire spread rate, resulting in fire arrival at community sooner than anticipated
- Underestimation of time required to evacuate community or part of community
- Underestimation of the impact of fire on egress arteries

What causes civilians to experience high exposures?

1. An inability to evacuate owing to reduced mobility (e.g., physical or medical factors) or no access to a vehicle or other transportation.
2. High exposures at one's residence experienced after a decision to stay (whether to shelter in place or stay and defend).
3. High exposures experienced during egress;
   a) during a late or delayed evacuation after an initial decision to stay or after accomplishing specific tasks like getting kids from school.
   b) being overrun by fire due to rapid fire spread or due to traffic or other evacuation delay.

Scenarios related to staying

Scenarios related to transit

Type 2 Evacuation Events

- Civilians may be unable to evacuate owing to mobility impairments or lack of transportation.

- Injuries or fatalities may occur during:
  a) Events that occur when **there is sufficient time** to safely evacuate the community *before the fire impacts* evacuation.
  b) Events that occur when **there is little or no time** between when the fire impacts the community and when an evacuation order is issued.

Addressing Type 2 Evacuation Events

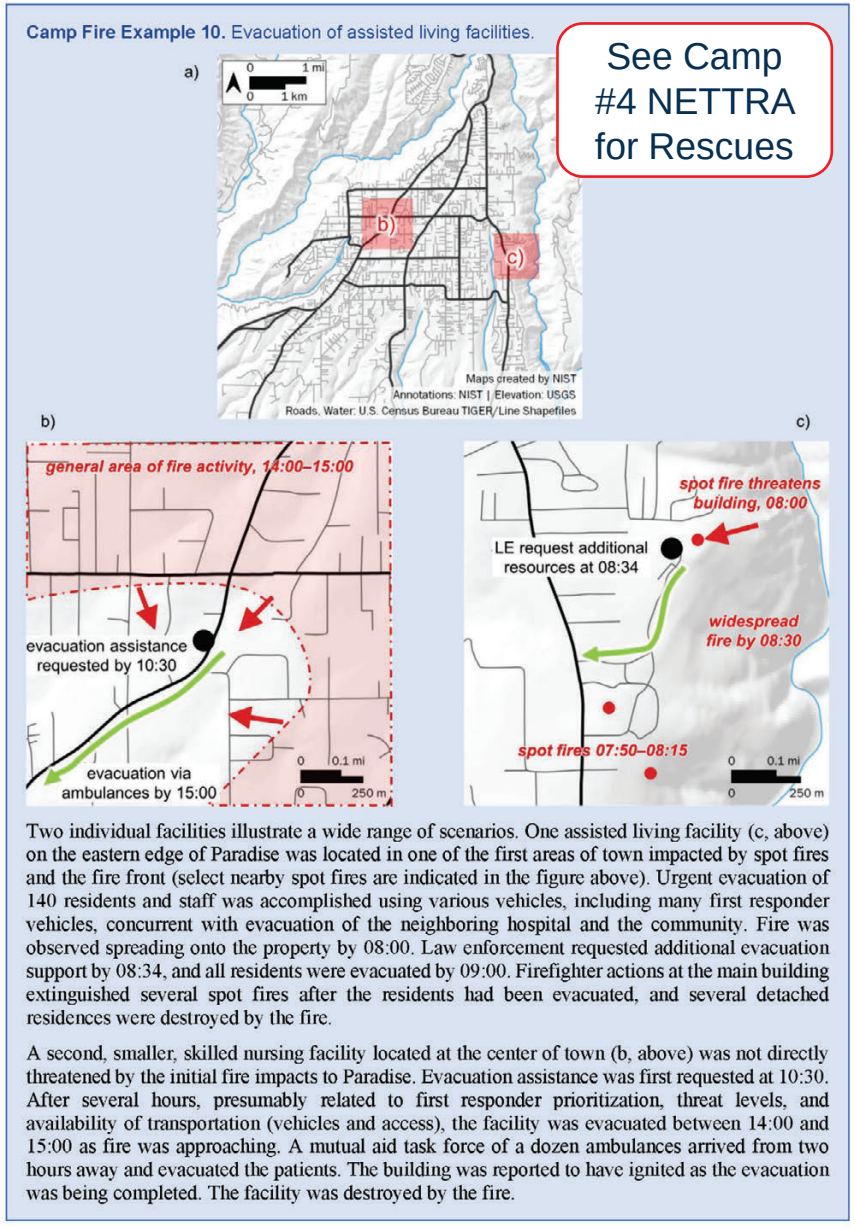
Category a) – easier (when there is time)

- Implementation of special needs evacuation programs.

Category b) – *hardest* (successes and challenges in Paradise)

- Fire may rapidly restrict access to the area for first responders
- Fire and smoke may slow down evacuations of local civilians
- Traffic may be directed out of the area using contraflow to increase capacity, making ingress of first responders difficult and dangerous

See Camp #4 NETTRA for Rescues



Addressing Type 2 Evacuation Events

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1. **Hardening Care Facilities and Buildings Requiring Evacuation Considerations including Residences**

Goal: Enhance life safety

Hardening of the structure/facility to extend the time available for evacuation . The NIST HMM is a comprehensive approach to address structure/ parcel/ community hardening for both fire and ember exposures.

Photo courtesy of TD-112, 15.10.

NIST Structure Separation Experiments

⚠ Hardening the facility against fire does not imply that the facility will necessarily be suitable as a fire shelter. Ventilation, power, and other tenability and access requirements are necessary to create a fire shelter

* Building is designed not to ignite based on expected exposures. This may not always be achievable for very high exposures. Fire shelters must "stand alone" and be able to withstand the incoming exposures

Addressing Type 2 Evacuation Events

2. High exposures (e.g., burnover conditions) at residence

Goal: Enhance life safety

- Injuries or fatality from decision to stay (shelter in place or stay and defend)

Education and "Ready Set Go"

- Education and information campaigns highlighting the dangers of wildfires, together with the challenges of reaching residents during these events, can be used to inform the public.

Addressing Type 2 Evacuation Events

3. High exposures (BO conditions) during egress that result in injuries or fatality.

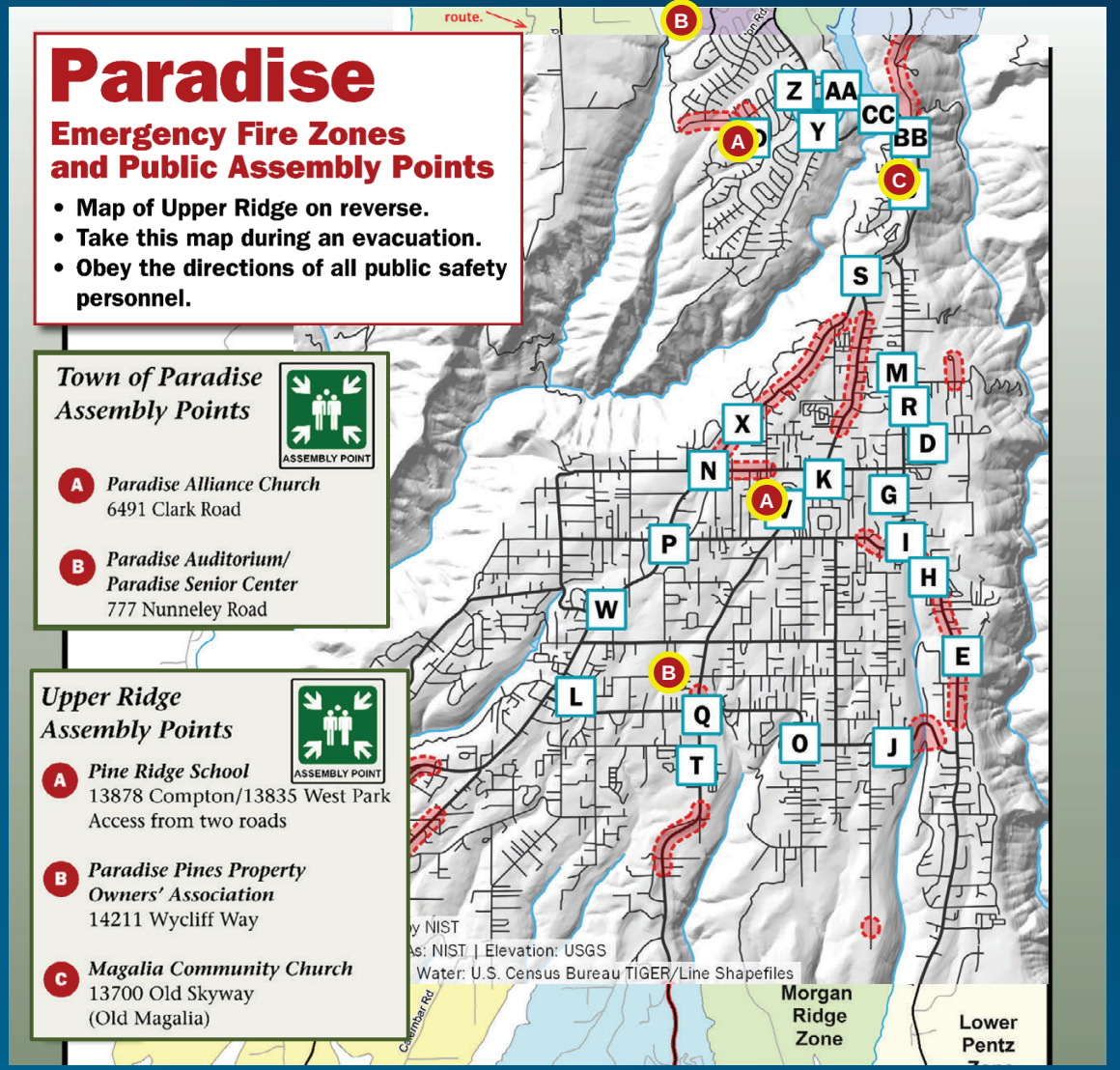
Goal: Reduce the potential for high fire exposures along the key egress routes and arteries.

- This maintains tenability of the egress routes and allows evacuees to remain in their vehicles and allows them to egress to safety.
- For this approach to be effective it will require fuel thinning and vegetation removal along these corridors and continued maintenance of these fuel treatments over time.

Addressing Type 2 Evacuation Events

- Another approach to mitigating the risk of high exposures to evacuees is to assemble residents at a wildfire safety zone.

A distributed network of wildfire safety zones can reduce travel time for residents seeking shelter when there is no safe evacuation route.



Paradise Evacuation Plan Document, combined/annotated by NIST
TRA map overlay by NIST

NIST TN 2252 Figure 25

Spatiotemporal Considerations

Community Evacuation Time

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- There is a minimum amount of time needed to execute an evacuation.
- Traditional RSET includes time for detection, alarm, pre-movement, and evacuation.

1. Ignition/first observation, t_d
2. Situational assessment
3. Decision making
4. Order to evacuate
5. Communication of evacuation order, t_{IT}
6. Activation of notification systems, t_{diss}
7. Evacuation duration (including necessary time for evacuation of critical care facilities/schools/hospitals), $(t_{prep} + t_{trans})$

(t_{FDS} = items 2–4; t_{order} = items 1–4; ITA = items 1–6; ET = item 7; ITS = items 1–7)

In the WUI, the WUI RSET (WRSET) includes time required to:

- assess the ignition/fire situation
- communicate this information to the incident commander and emergency operations center
- decide on the required evacuations
- begin the notification and evacuation processes
- conduct the evacuation.

Ignition to Safety | Ignition to Activation | Evacuation Time

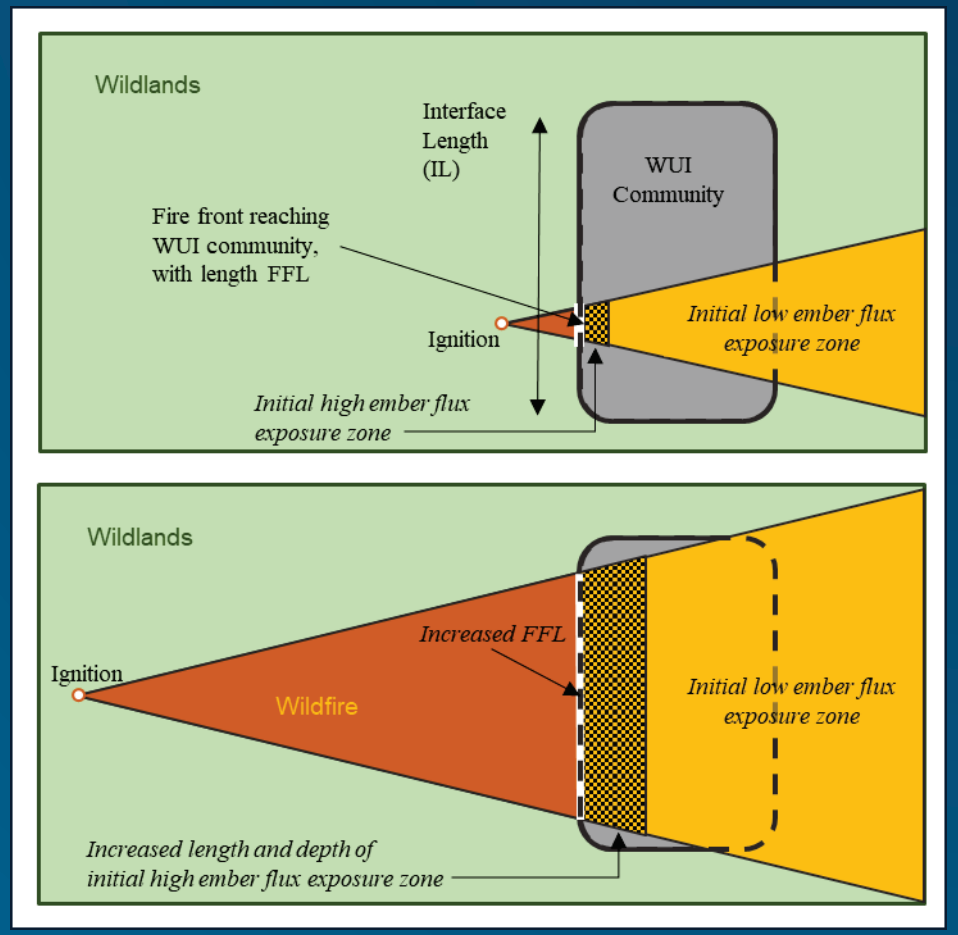
$$ITS = WRSET = ITA+ET$$

Relationship between ignition location and impact to community

Idealized relationship between ignition location:

a) near the community, limited impact on community

b) further from a WUI community – high impact on community



The wind is directed from left to right.

Figure 6

Relationship between ignition location and impact to community

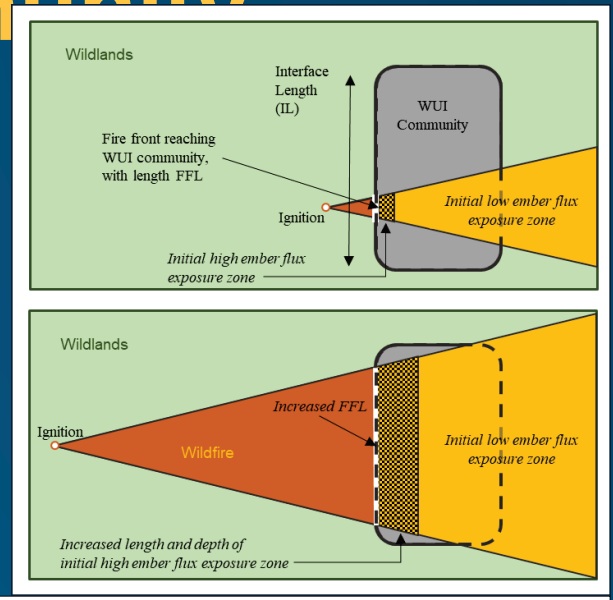
Idealized relationship between ignition location:

a) near the community, limited impact on community

b) further from a WUI community – high impact on community

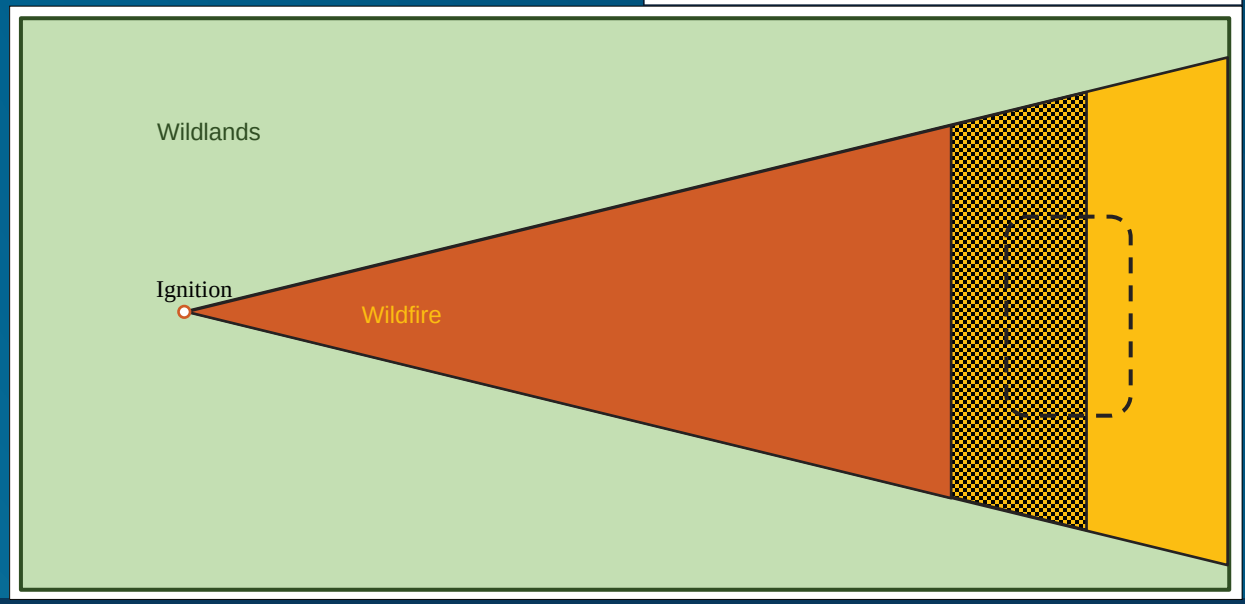
c) far from the community, same high impact on community, more time available

The wind is directed from left to right.



Limited impact
Very limited time

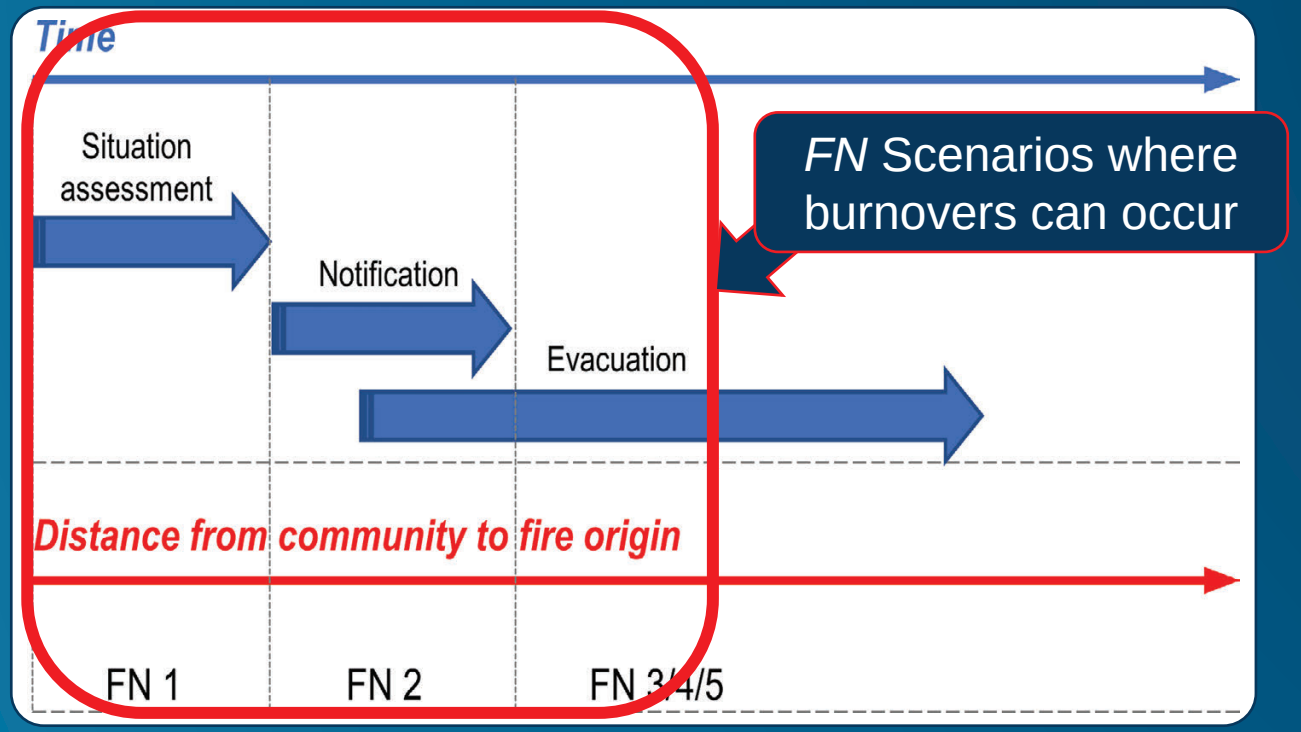
High impact
Limited time

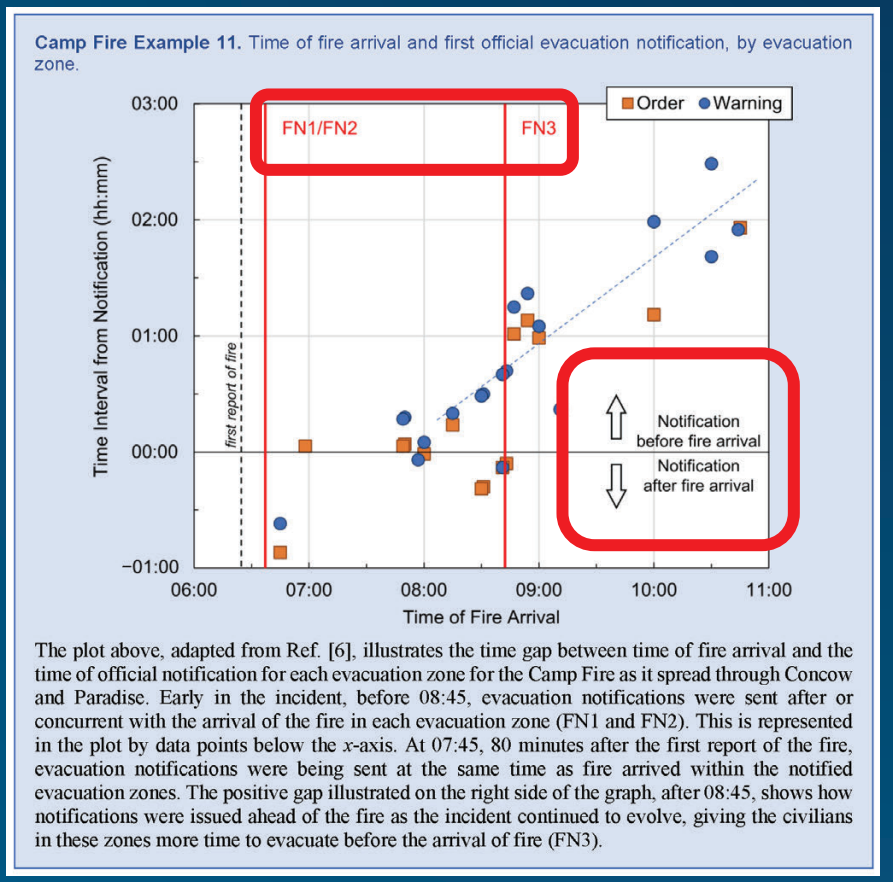


High impact
More time

Figure 6

Fire/Notification (FN) Scenarios





FN 1: Fire near or at residence, no official notification → exposure/entrapment during egress

FN2: Simultaneous arrival of fire and official notification → exposure/entrapment during egress

FN3: No fire near/at residence, official notification, egress → exposed to fire on route to safety

FN4: No fire near residence, official notification → early egress, or shelter in community wildfire safety zones without experiencing high exposures

FN5: No fire near residence, no official notification early evacuation

Figure 4 and Camp Fire Example 11

Evacuation Scenarios

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E1. Shelter in place.

E1-A: Defend the structure/property (preparations in place and life safety not impacted)

E1-B: Inadequate preparation (evacuation assistance may be needed)

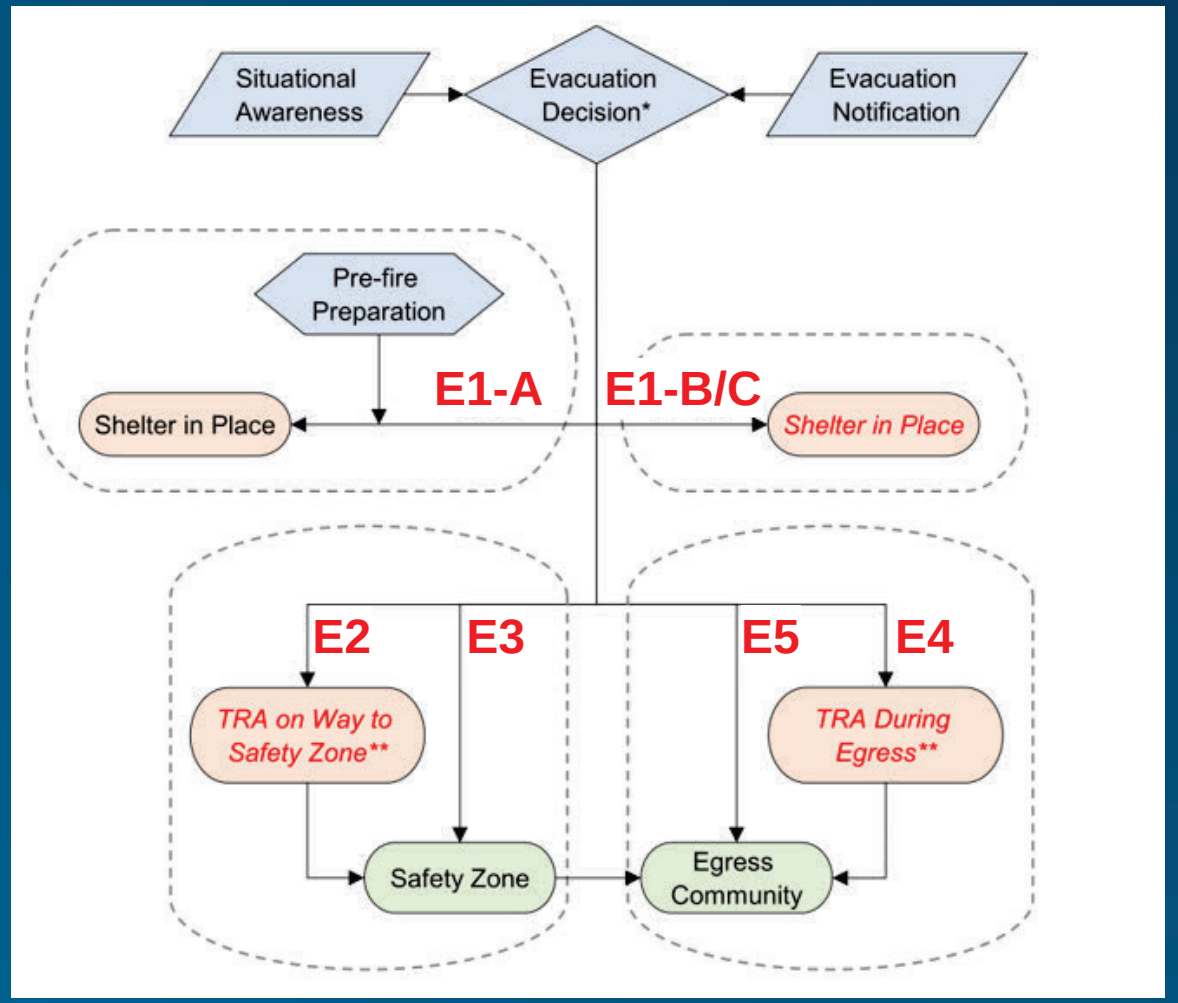
E1-C: Entrapment

E2. Become entrapped during evacuation to safety zone.

E3. Evacuate to safety zone.

E4. Become entrapped during evacuation from the fire area.

E5. Safe egress from the community or from a safety zone.



Residents can become entrapped in their building, and/or on their way to a wildfire safety zone, and/or on their way out of the community

Figure 5

Temporal Analysis of Full Community Evacuation Scenarios

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Community Evacuation – Evacuation starts when the fire arrives

Community Evacuation – Part of the community evacuates before the fire arrives

Community Evacuation – All of the community evacuates before the fire arrives

Time interval	a	b	c	d	e*	f	g	h	i
Scenario 1a – ignition near community									
Fire					F-L	F-H	F-H	F-L	F-L
Notification Warning									
Evacuation Order					O	O	O	O	O
Evacuation**					E	E	E	E-E	E-E
Scenario 1b – fire approaching, evacuation orders only when fire reaches community									
Fire					F-L	F-H	F-H	F-L	F-L
Notification Warning		W	W	W					
Evacuation Order					O	O	O	O	O
Evacuation**					E	E	E	E-E	E-E
Scenario 2 – fire approaching, earlier evacuation decisions									
Fire					F-L	F-H	F-H	F-L	F-L
Notification Warning		W							
Evacuation Order			O	O	O	O	O	O	O
Evacuation**			E	E	E	E	E-E	E-E	
Scenario 3 – fire approaching, earliest evacuation decisions									
Fire					F-L	F-H	F-H	F-L	F-L
Notification Warning	W								
Evacuation Order		O	O	O	O	O	O	O	O
Evacuation**		E	E	E	E	E-E			
Scenario 4 – fire approaching, early evacuation orders, time available for full community evacuation									
Fire					F-L	F-H	F-H	F-L	F-L
Notification Warning									
Evacuation Order	O	O	O	O	O	O	O	O	O
Evacuation**	E	E	E	E					

* Time interval of low fire intensity may be very short (approaching zero in many rapidly developing fire spread scenarios)
** Baseline evacuation without obstructions from fire, including planned contraflow and other traffic management

Fig. 7. Temporal representation of ignition, fire exposures, evacuation warning, evacuation orders, and evacuation.

CONCOW RESCUE AREA

PARADISE

HWY 32

Figure 7

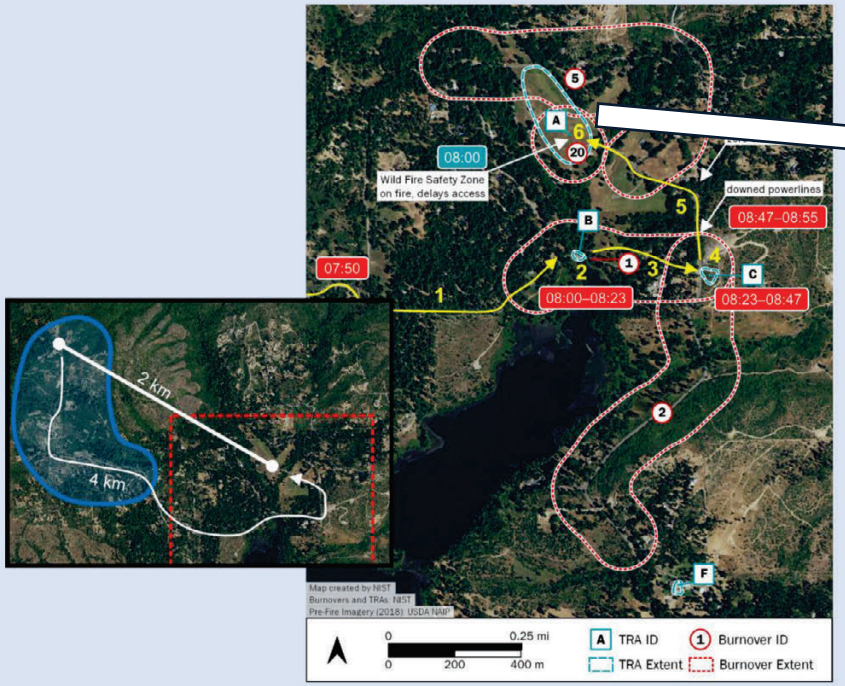
Summary of Different Evacuation and Sheltering Options

Evacuation/ sheltering option	Evacuate early	Shelter in place in residence	Shelter in community (SIC)	Evacuate in hazardous conditions/burnovers	Evacuate and shelter in TRA – not caught in burnover	Evacuate and shelter in designated safe building
Descriptions	Partial or full evacuation before fire reaches community	Residents shelter in their home	Residents shelter in a designated wildfire safety zone	Entrapped in a burnover during evacuation	Directed by first responders to take shelter in TRA	Residents shelter in designated wildfire shelter
Life safety enhancements	No exposure to fire	Limit travel in potentially hazardous conditions	Limited or no fire exposure in designated safety zone	A TRA may be formed *only* if local conditions permit	Reduced fire exposure	No fire or smoke exposure inside specially engineered building
Life safety hazards	Limited hazard associated with potential high-volume traffic; may experience smoke exposures	Can result in entrapment, injuries and/or death; may require rescue	Hazard with accessing local Safety Zone; hazard will increase with distance traveled, proximity of fire, and fuels and topography between residence and SIC location	Very hazardous; can result in injuries and/or fatalities	May experience fire and smoke exposures, although less severe than burnover conditions	Hazard while accessing local shelter; hazard will increase with distance away, proximity of fire, and fuels and topography between residence and shelter location
Travel required	By vehicle or mass transit	No travel required (if at home during incident)	By vehicle or on foot	By vehicle or mass transit	By vehicle or mass transit	By vehicle or mass transit
Notes	Road network must be able to accommodate the partial or full evacuation before hazardous conditions result in burnovers either in the community and/or in the egress corridors. Early evacuation plans must be developed in parallel with trigger points for shelter in community. This may be the desired option for mobility impaired residents and critical care and medical facilities unless a shelter in community option exists within reach and can be accessed with in-house mobility options.	Can evacuate after the fire intensity has subsided or not evacuate. If property is prepared, resident is able and equipped, and exposure levels permit, defensive actions may save residence (although likely hazardous to residents).			First responders may relocate civilians between TRAs during the event to address safety and road capacity issues.	No standards or design guidance exist for the design, construction, and maintenance of such facilities specifically for WUI applications. Such facilities will be expensive to design and maintain and may be beyond the reach of most small communities. Retrofit of existing facilities will likely also be very costly.

Table 5

Getting to the Wildfire Safety Zone

Camp Fire Example 15. Entrapment en route to the safety zone at Camelot Meadow in Concow.



Civilians evacuating from the area circled in blue, west of the egress artery, were up to 2 km (1.2 mi) straight line distance and 4 km (2.5 mi) driving distance away from the pre-designated Wild Fire Safety Zone at Camelot Meadow (*TRA-A*, indicated with a blue square and outline). These civilians were caught in two burnovers (*BO #1* and *#2*, indicated with red circles and outlines) and took shelter in two TRAs (*B* and *C*) on their way to the meadow.

Two firefighters in a pickup truck were scouting out the fire and evacuating civilians in the west portion of Concow. Returning toward the exit **(1**, in yellow text), they were blocked by fire and debris on Hoffman Road with 10 to 15 civilian vehicles following them (*BO #1*) **(2)**. The firefighters deployed fire shelters to shield civilians as they moved them to a TRA in the creek (*TRA-B*) while several vehicles were igniting. A dozer was able to access the TRA and clear the obstructed roadway **(3)**. However, the group was unable to reach the Camelot Meadow, and instead had to take refuge in a second TRA (*C*) at the intersection of Hoffman Road and Concow Road (*BO #2*) **(4)**. After 24 minutes, fire activity subsided enough that they could convoy **(5)** to the safety zone at the meadow to join the group already taking refuge there **(6)**.

The two burnovers that occurred before residents could reach the designated safety zone highlights the need for a distributed wildfire safety zone system that would reduce the travel distance between areas of relative safety.

Camp Fire Example 19. Natural areas used as wildfire safety zones.

a) Camelot Meadow

b) Crain Memorial Park

The photos above show two examples of natural area safety zones on Concow; a) Camelot Meadow and b) Crain Memorial Park. Both locations were indicated in the existing pre-fire evacuation plans for the Concow area and had signage indicating their intended use as public assembly points during fire incidents.

The Camelot Meadow was minimally maintained as a 3.2 ha (8 ac) natural grass meadow; during the Camp Fire, the safety zone was temporarily unusable while the fire burned through it. Afterwards, an estimated 70 to 85 civilians took refuge in the burned meadow in addition to several first responders. The photo above shows the condition of the meadow one year after the fire.

Crain Memorial Park was another natural safety zone in Concow, characterized by a maintained field. It's use during the Camp Fire was undetermined.

★ Mitigating Civilian Fire Exposures

Not enough time to fully evacuate before the fire impacts community

Shelter in Place/ Stay and Defend	*Evacuate to <u>nearby</u> Fire Shelter*	Evacuate residents along treated routes to safety outside of fire	Evacuate residents to nearby Distributed Safety Zone System (DSZS) within the community
Very High Hazard Potential	Science and Tech Gap ~$$$	Science and Tech Gap ~$ to $$	Science and Tech Gap ~$ to $$
Make Structure* into a Fire Shelter			
Science and Tech Gap ~$$$			

* (care facility/hospital/home)

★ Mitigating Civilian Fire Exposures During Evacuation

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Early Out
Ready Set Go

Part of comprehensive evacuation plan

Challenges:
- Public education
- Clear messaging and notification for early out vs shelter in community

Enough time to fully evacuate
before the fire impacts community

Reduce risk by mitigating the potential hazard presented by fire to the evacuating public

Fuel management within the community and along egress arteries

Challenges:
- Access
- Environmental considerations
- Maintenance

Create Distributed Safety Zone System (DSZS) within the community

Provide areas of reduced fire exposure

Challenges:
- Access
- Design Guidance: density/size
- Environmental considerations
- Maintenance
- Public education

Not enough time to fully evacuate
before the fire impacts community

Distributed Safety Zone System

- Currently no standards
- Location/placement considerations
  - *reduce exposure potential in transit*
  - leverage existing low exposure potential locations in community (e.g., parking lots, sports fields, gravel areas)
- Sizing Guidance
  - NWCG vegetative fuels guidance – good starting point for intermix communities
  - Built environment exposures – tech transfer gap

A Distributed Wildfire Safety Zone System will reduce exposure potential

ID	Name	Type	Area	
			ha	ac
A	Camelot Meadow Wild Fire Safety Zone	Natural (Maintained)	3.37	8.33
B	Hoffman Rd	Natural	0.06	0.16
C	Concow Rd "dozer zone"	Natural	0.15	0.37
D	Chris Ct	Roadway	0.30	0.74
E	Feather River Hospital	Parking Lot	1.38	3.40
F	Concow Rd "gravel area"	Parking Lot	0.08	0.20
G	Ponderosa Elementary School	Parking Lot	0.28	0.70
H	Chloe Ct	Structure	0.31	0.77
I	Bille Rd	Roadway	0.31	0.77
J	Pearson Rd	Natural	0.29	0.71
K	Paradise Plaza	Parking Lot	2.32	5.74
L	PPD/Fire Station 81	Structure	0.37	0.92
M	Paradise Ridge Southern Baptist Church	Parking Lot	0.21	0.52
N	Wagstaff Rd	Roadway	0.49	1.22
O	Fire Station 82	Structure	0.11	0.26
P	Walgreens	Structure	0.55	1.37
Q	Ace Hardware	Parking Lot	0.53	1.30
R	Beyond Fitness	Parking Lot	0.34	0.83
S	Optimo	Structure[a]	0.34	0.83
T	Best Western	Parking Lot	0.70	1.74
U	Magalia Community Church	Parking Lot	0.57	1.41
V	CMA Church	Parking Lot	2.56	6.34
W	Paradise Shopping Center	Parking Lot	0.75	1.86
X	Firland Dr	Roadway	0.11	0.28
Y	Magalia Pines Baptist Church	Parking Lot	0.93	2.31
Z	Magalia Sav-Mor	Parking Lot	0.39	0.95
AA	Rite Aid	Structure	0.55	1.37
BB	Skyway and Coutolenc Rd	Roadway	0.32	0.78
CC	Magalia Dam	Roadway	0.17	0.43
DD	Pine Ridge School	Parking Lot	1.25	3.09
EE	Concow Rd and Pinkston Canyon Rd	Roadway	0.06	0.16

[a] The parking lot was used initially, but civilians were moved into structures for increased protection.

NIST TN 2252 Table 40

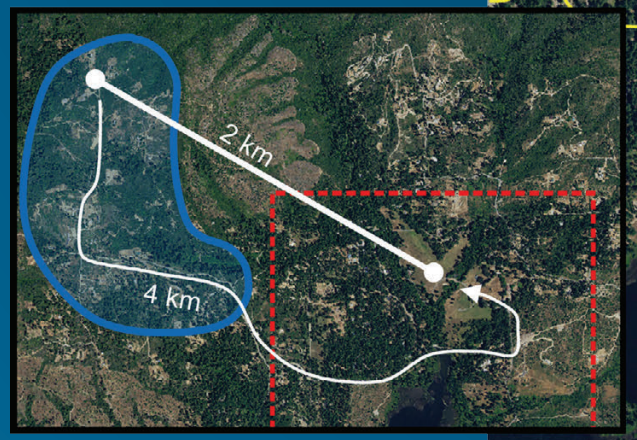
Distributed Safety Zone System

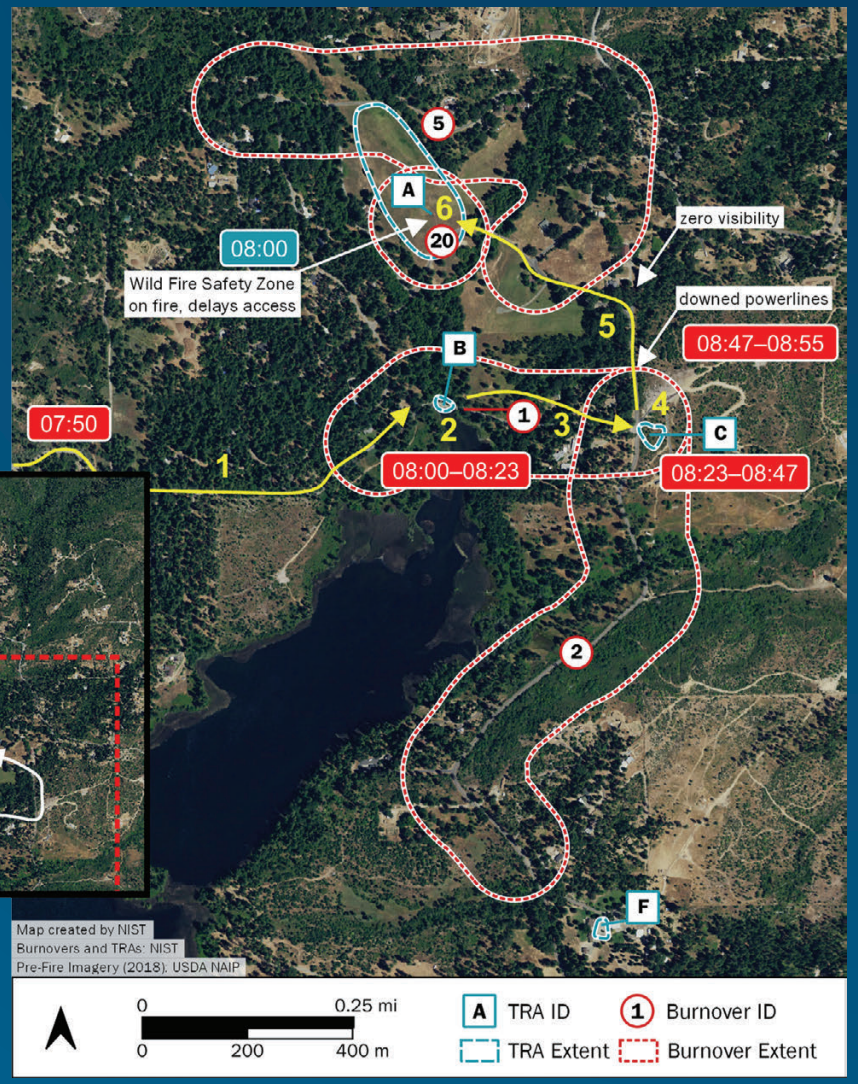
Wildfire Safety Zone "next to" residence

Least travel

Wildfire Safety Zone on "other side" of the community

Most travel



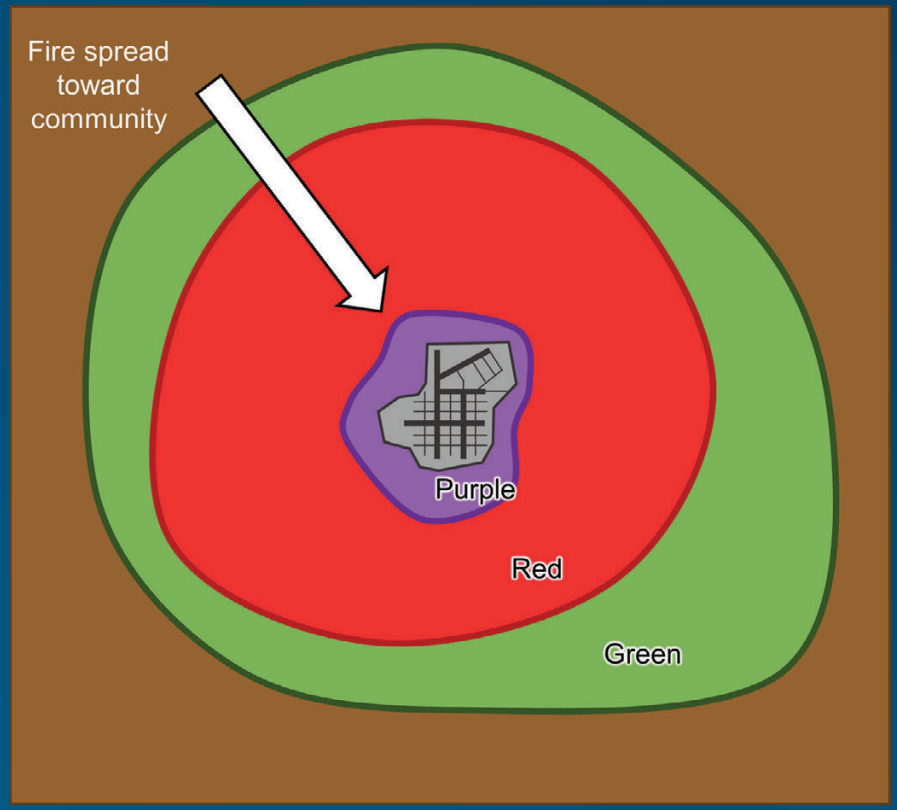


Exposure Potential, Travel Distance, Traffic and Evacuation Timing will all impact safely reaching safety zone

Proposed Implementation

Trigger Zone Definitions

Trigger Zone	Time	Action
Brown	More than sufficient to safely evacuate	Monitor, Ready Set Go
Green	Sufficient to safely evacuate	**Community Evacuation**
Red	Insufficient to safely evacuate	Shelter in Community
Purple	Partial community impact	Zoned shelter in community/partial evacuation



Trigger Zone: ignition location, rate of spread, direction and community intersect

Figure 8

Determining Ignition Zone Widths

$T_{min, C}$ or $T_{min, P}$ (hours)	FS_{max} (mi/h)			
	1	2	4	6
0.5	0.5	1	2	3
1	1	2	4	6
2	2	4	8	12
4	4	8	16	24

Table 5

★ Evacuation Triangle

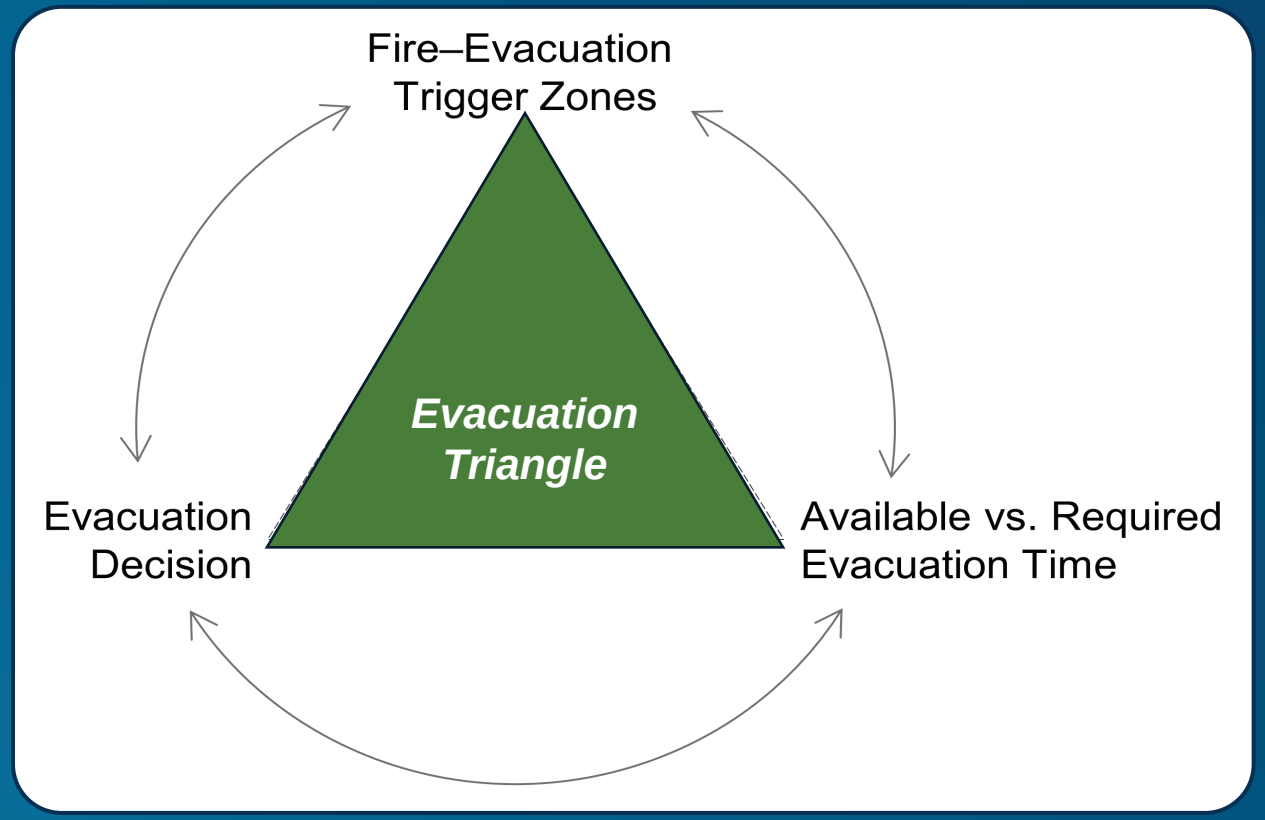
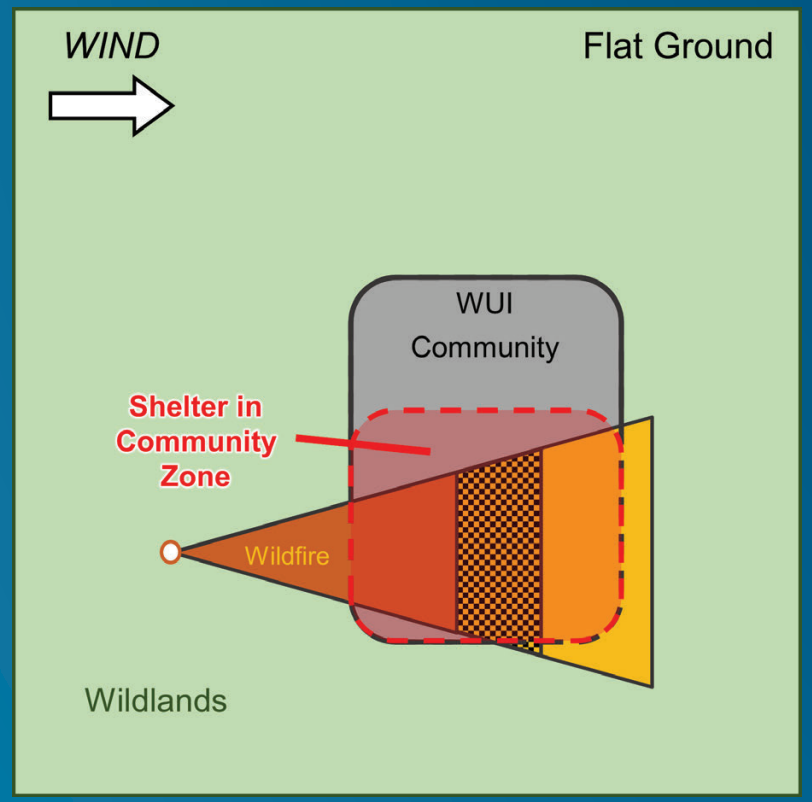


Figure 1

Partial vs Complete Community Evacuation



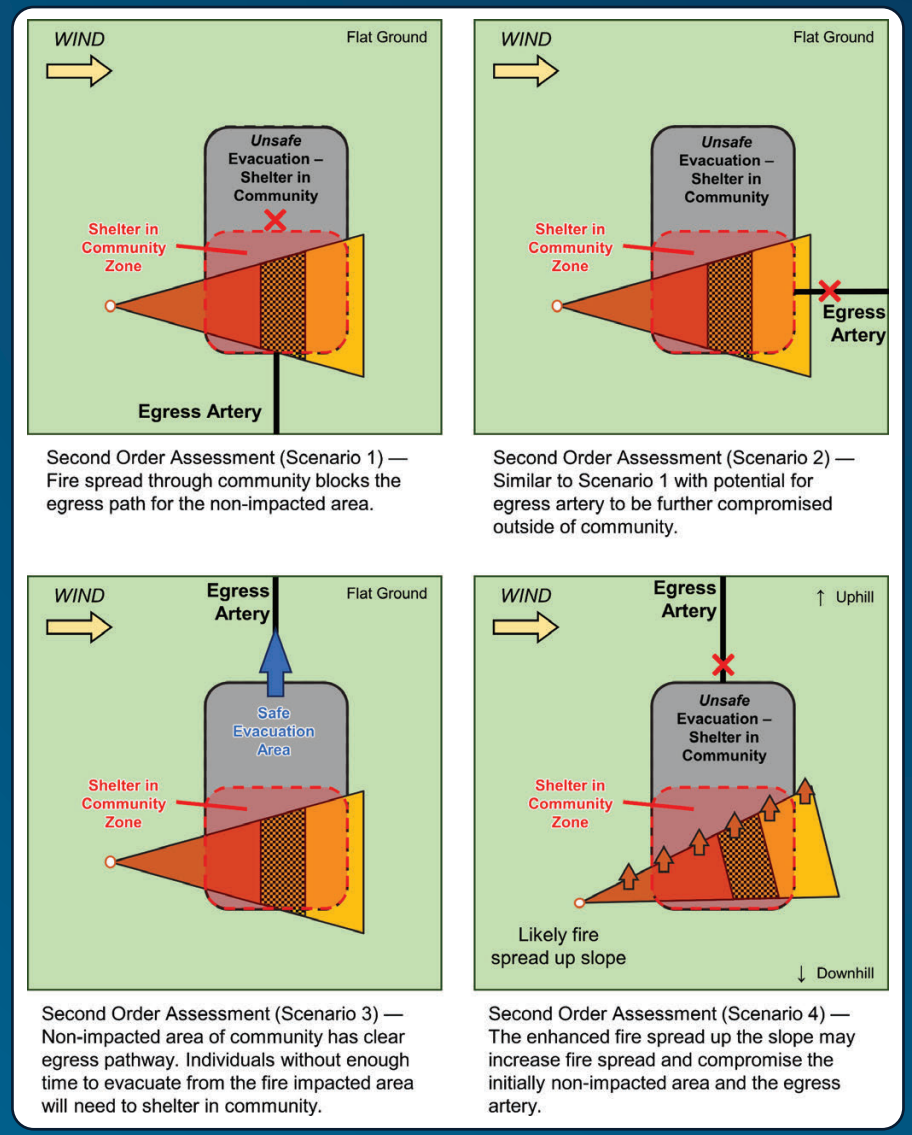


Figure 10 and Figure 11

ESCAPE

Assessment, Planning, and Execution

Assessment – Overview

- NIST Technical Note 2135 Appendix C
- Required time for community evacuation (ITS)
- Status of critical infrastructure hardening
- Fire suppression capacity

Assessment – Data Gathering

- Goal: Collect the community data necessary for the planning and development of the community notification/evacuation plan.

Data Gathering
Wildfire Safety Zones and access
Evacuation destination locations
Hardening of critical infrastructure
Previous evacuation data
Existing evacuation plan and supporting materials
ITS data (previous fires/drills/modeling)
ITA data (previous fires/drills)
First responder and volunteer staffing

The WUI Community Hazard Framework can be used as the foundation for this data gathering and expanded to further accommodate evacuation and sheltering information

Assessment – Appendix C

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- This framework includes information on community size, population, and fuels; on notification and evacuation; and on the community infrastructure and firefighting response potential.
- Aspects of this framework may already be included in various community-level documents, such as CWPPs or evacuation plans.

Community WUI Fire Hazard Evaluation Framework

Community	*Data Type*	*Data Layer in MDS*
Community shapefile, geodatabase, or GeoPackage including topography and geographic attributes, and prevailing weather patterns (e.g., wind)	GIS layer	x
Fuels		
Structure Density (structure separation distances - SSD)	SSD histogram	
Age of structures	Histogram	
Vegetative Fuel Loading: - *Fuel type* - *Fuel loading*	 fuel type tons/acre	
Natural and artificial fuel breaks (including fuel treatments within and around community and year built)	List, GIS layer	x
Community hazards (e.g., hazmat and high fuel load facilities)	Specify, GIS layer	x
Fire History	Frequency of, and most recent, fires in/around community	x
Population		
Population - *Density* - *Permanent/transient ratio*	Number, age distribution Number/acre p/t ratio	
Notification		
Reverse 911 - *Opt-in or Opt-out* - *Percent of population enrolled in Reverse 911*	 Opt-in/Opt-out %	
Sirens or other notification with power backup - *Percent of population within siren coverage range*	List % population	
Notification dissemination w/out phone or internet	y/n	
Evacuation		
Egress Route Capacity (Minimum Throughput Time)	Time (hours)	
Vulnerability of egress arteries: - *Fuel setbacks* - *Hazmat/high fuel load facilities affecting evacuation* - *Other*	 fuel setback data, GIS layer specify, GIS layer	 x x x
Hospitals and senior care facilities	specify, number of persons	x
Community evacuation plan Safety zones and large crowd assembly areas, capacity Evacuation drills	y/n, specify, GIS layer y/n, number, GIS layer y/n	x x
Community in evacuation route of other communities, through-flow number	y/n, identify, number	
Infrastructure / COOP / COG		
Location and needs of key facilities	List	x
Public water, dependence on power, generator backup, community owned water	y/n, y/n, y/n, y/n	
Power lines around primary arteries (above ground or below)	above or below	x
Critical infrastructure that requires fuel to keep operating	specify, GIS layer	x
Fire Fighting Response		
Volunteer vs Career (availability of first responder resources at station)	volunteer/career/combination	
Density of firefighting (ff) responder to number of structures (ff/structure ratio)	ff/structures	
Mutual aid response (engines-hours histogram) and agreements with mutual aid	engines-hours histogram	

Planning

- Developing the Community Notification Plan

  Step 1 – Identify the Green/Red Zone Threshold

  Step 2 – Develop Evacuation Scenarios for Ignitions in the Red Zone

  Step 3 – Identify the Purple Zone

- Account for uncertainties and develop safety factors

Execution

Pre-Planning and Normal Operations

Activities occurring well before the fire season or high hazard conditions include:

- Maintenance of egress arteries and wildfire safety zones.
- Maintenance and upgrades to first responder communication, public notification, and traffic management equipment.
- Establishment of communications channels for the dissemination of fire/notification and evacuation information.
- Training of first responders, including publics works, LE, and volunteers on principles of WUI fire safety.
- PPE for LE, public works and volunteers.
- Updating the evacuation plan, specifically ITS and by extension the Red/Green Zone boundary based on any evacuation route alterations (maintenance/closures). This is particularly important for communities with limited egress routes/lanes.
- Monitoring fire activities in the surrounding region and keeping awareness of scenarios of reduced first responder staffing that may impact early fire containment in non-high hazard conditions.

Execution

High Hazard Conditions

- Red Flag Warnings
- High wind events
- Regional fire storms
- Other disasters that may deplete or reduce local first responder resources

No - Fire

Communications:

- AHJs should inform the community of pending conditions and use the opportunity to **communicate evacuation scenarios and restate where evacuation data will be available**.
- **Communication with surrounding jurisdictions** located within the Green and Red Zones will be critical for rapid and effective situation assessment in the event a fire ignites within or spreads into the zones.

Execution
High Hazard Conditions

- Red Flag Warnings
- High wind events
- Regional fire storms
- Other disasters that may deplete or reduce local first responder resources

Fire

Fire Monitoring:

- **Active fires outside the Green Zone** that have the potential to spread into the zone should be closely monitored for direction and rate of spread.

Communications:

- Communicating changing conditions to the public is critical and AJHs should inform the public using **established communication pathways** and keep information current.

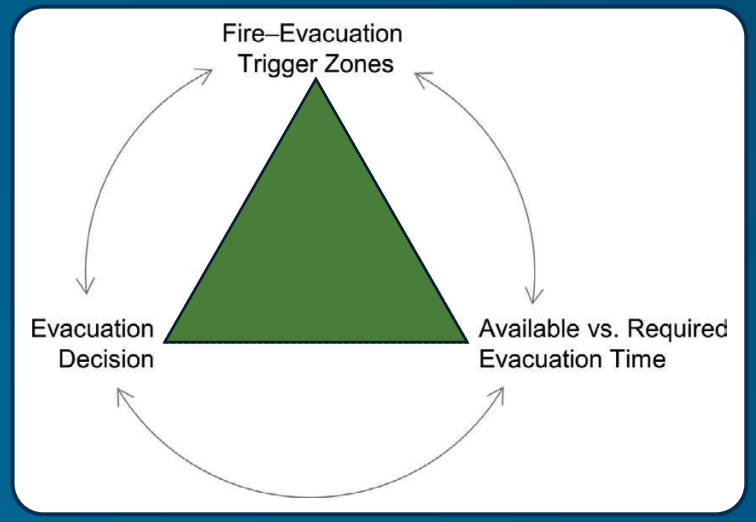
Execution

Using the Zones and the Evacuation Triangle

Fire in Green/ Red or Purple Zone
In the event of an ignition near the community, initial information will include location, accessibility, time of day, availability of resources, weather, and direction and rate of spread (towards the community or not).

Evacuation Decisions
Field observations from both firefighters (IC and engines) and LE channels (911 and deployed officers). Information will be communicated to the public using the established channels and evacuation decisions will be adapted.

Fire Containment
If an ignition in the Green Zone cannot be contained (including spotting) when it reaches the Green /Red Zone boundary, then full evacuation should be considered



Available time
A shift in the Green/Red Boundary may be necessary and drive an evacuation when the fire is further away from the community than initially planned for if the observed fire spread rate is greater than what was used for the development of the zone boundaries.

Recommendations

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ESCAPE

R1. Understand relationship between fire spread and duration of wind events. This may impact evacuation projections in the future.

R2. Understand the relationship between wind events and effectiveness of initial containment.

R3. Develop methodology for assessing the performance of wildland fire spread models using pre-fire predictions and post-fire fire spread data.

R4. Social tools like remote work during high hazard weather events may reduce road congestion and enhance evacuation.

Summary

- The ESCAPE methodology specifically addresses critical temporal/spatial thresholds between fire spread and evacuation.
- Specifically designed to help small and medium size WUI communities develop evacuations plans.
- ESCAPE can be used to help assess a community in the context of notification and evacuation, develop and execute evacuation and notification plans

Thank You

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U.S. DEPARTMENT OF COMMERCE

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