Author Biography:
The authors of this article are a group of five wildfire experts from different geographic parts of the west: Doug Campbell, author of CPS and retired fire manager, USFS, R-5; Will Spyrison, InciNotes Cofounder, division chief, USFS R-5; Jerry Chonka, retired fire manager, USFS, R-2 & 3; Paul Orozco, retired fire manager, USFS, R-2 & 3; and a preferred to be anonymous retired fire manager, USFS, R-3 (reviewed fatality site). Each have a unique wildfire specialty and combined boast 200 years of combined fire experience. Ruth Harrison was the editor for this article.

The Yarnell Fire – Part One: A Cry For Help

The Granite Mountain Hotshots' last moments, before they were overcome and perished in a wall of fire, were punctuated by a cry for help as they deployed fire shelters. This last cry for help is representative of the Yarnell Fire itself. Fire managers and leaders on the fire were also overwhelmed by the fast-moving and rapidly changing fire. From the start of the Yarnell Fire there was a sequence of lost management opportunities to keep up with or stay ahead of the fire, beginning with misreading the severity and potential of the fire environment, to not having enough right-place, right-time resources, and finally, not engaging in critical planning. In order to clearly identify how and when these missed opportunities might have mitigated the situation as it unfolded, we should first look at the sequence of events, followed by specific recommendations for more effective management considerations.

The Fire "Size Up"

Immediately prior to the Yarnell Fire start, a large fire burning close by, the Doce Fire, offered important information about the current fire environment. The Yarnell area, along with the Doce area, had already been issued a red flag alert for extremely low live and dead fuel moistures. When the Yarnell Fire was discovered, this was the "size up" given by the air attack first over the scene: "It's one half acre in size and 80% out." This incomplete size-up, the lack of recognition of the red flag alert, and the failure to gather critical information from the nearby Doce Fire were significant oversights. Because of this inadequate size-up, the Yarnell Fire was determined to be a minor fire threat unnecessary to engage at night, since there was potential for a lightning hazard to firefighters. Due to the lightning risk and helicopter duty schedule, the fire was not engaged until 17 hours later, despite the fact that easy access was available through a jeep trail leading to the initial fire start. (Ironically, with a growing awareness of the fire's potential and need to contain the fire, and after failing to contain the blaze the next day, firefighters spent the following night on the fire despite the same threat for lightning.)

The Fire Escapes Control as Alignment Factors are Misread

Later in the day of June 29, the Yarnell Fire escaped from the suppression efforts of 13 firefighters led by a lone Type IV Incident Commander. Even though the hottest part of the burning period for that day had passed, the fire continued to burn and move into better alignment with wind, slope, and preheated fuel. It grew quickly to 35 acres, increasing to an estimated 100 acres later that day. The Incident Commander on the fire requested a Type II Incident Management Team, noting that the fire would likely threaten the community of Yarnell. An order for a Short Type II Team was placed, scheduled to arrive the next morning.

Once again, as the Yarnell Fire escalated, information was added and situational awareness became clearer. The fire burned aggressively into the night, and by morning on June 30 was no longer a small fire, but a large fire with no anchor points. Remarkably, the fire had demonstrated out-of-alignment behavior by exhibiting aggressive growth at night despite the absence of heating from solar radiation. This atypical behavior of forces should have alerted management to expect radical fire growth when conditions were again aligned during the next burning period.

In addition, the fire was ruled by topography until the wind increased to the point it overcame the variations of slope and became a wind driven fire. The fire was now large enough to be aligned with fuels, slope, and wind from any direction. To make matters worse, the weather forecast for June 30 was for triple digit temperatures, with low relative humidity and thunderstorms, creating the possibility of dangerous, changeable winds. Additional alignment factors included the red flag alert for low live and dead fuel moistures as well as the ERC value in the 97th percentile, and alarmingly low thousand- hour-fuel-moisture readings from the nearby Stanton fire weather station. The resulting effect of this alignment of extreme thresholds contributed to the explosive fire behavior the afternoon of June 30. These extreme conditions had created a fire poised to explode into a major fire event and burn into the Yarnell community. The conditions necessitated a much greater response than a Short Type II Team to transition. Apparently, the magnitude of the situation was inaccurately assessed, resulting in management's under-reaction. Efforts from the State's fire management group and Short Type II Team to manage the Yarnell Fire simply were too far behind the severe conditions and escalation of the fire. The Type II Team had not marshaled enough and the right kind of resources, which added to the confusion and cycle of missed opportunities that led to the entrapments and fatalities.

June 30: Transitioning Command in a Severe Fire Environment

In response to the worsening situation, the incoming Fire Overhead Team, with its variety and number of fire suppression resources, brought hope that the Yarnell Fire would be controlled and become just another lightning- sparked wildfire statistic. In typical firefighter fashion, the crew looked forward to meeting an exciting challenge, while providing a public service in responding to a fire. However, the piecemeal way these fire resources came together would soon change the mood from enthusiasm to frustration. Evidently, two type II incident commanders, one operations section chief, and a logistics chief (to arrive at 1600 on June 30) were ordered as separate individual resources rather than as a unit to comprise the fire overhead team. We know the team's briefing with the Arizona State Division of Forestry included only a few team members. The rest of the team members and resource orders would be filled and arrive at different times during the operational period. These additional resources coming in at different times would create briefing problems, in turn, leading to confusion and havoc out on the fire line.

As the make-shift incident management team gathered and tried to organize, the fire continued to increase in size and intensity, responding to hotter and drier environment. Influenced by the alignment of severe fire conditions, the fire had grown during the night to an estimated 300 to 500 acres with no control points. Daybreak found the fire poised in full alignment with dense pockets of fuel, with steep slopes, canyons and ravines acting as chimneys, amplifying hotter and drier aspects. All these conditions signaled danger reminiscent of the Dude Fire, July 26, 1990, that claimed the lives of 6 of the 11 firefighters who deployed fire shelters on that day. In addition to the known conditions on the Yarnell Fire, the energy release component, coupled with live and dead fuel moistures, constituted extreme fire severity, but the values of these measurements were unknown to the incident management team and firefighters.

Confusion and Frustration

Once incoming fire suppression resources began working on the fire, confusion, and frustration became the "norm." Below is an excerpt from the Arizona Republic article citing interview notes from Serious Accident Investigation conducted by the State of Arizona.

- Throughout the interviews, key figures in the fire-suppression effort criticized almost every aspect of planning, oversight and execution.
- Members of the Blue Ridge crew said they dealt with a leadership dispute among supervisors and got no instructions, records show. They characterized the overall operation as “total non-stop chaos” and “Swiss cheese” because it was so full of holes.
- The Blue Ridge members said that they witnessed “a near miss” with aircraft, whose pilot and crew sounded, “overwhelmed”, adding, “the air show seemed troublesome.”
- Blue Ridge described overhearing the last transmissions from Granite Mountain and then sitting in a truck to “listen for anything on the radio.”
- At fire headquarters after the fatal burn-over, Blue Ridge hotshots had a conversation with Roy Hall, the incident commander who had taken charge seven hours earlier. “They never knew (he) was the IC,” an investigator noted. “They never heard it over the radio” (Wagner & Sanchez; Arizona Republic; December 13, 2013).

Reading the Fire Environment and Fire
At this point in the narrative, we must acknowledge pockets of excellence within fire organizations that have demonstrated sensible responses under these circumstances, observing the highest professional standards for public and fire fighter safety. For example, even as the Yarnell Fire raged toward disaster, the Blue Ridge Hotshots successfully escorted both the Lookout stationed at Granite Mountain, and a dozer operator caught in harm’s way, to safe haven.

Furthermore, the Superintendent of the Blue Ridge Hotshots questioned the Granite Mountain Hotshots about their escape route, out of concern for their safety. He worried that the Granite Mountain Hotshots’ escape path would lead them straight through the fire. Unfortunately, through miscommunication, he felt satisfied that they had laid out a clear route to safety, and sadly, did not pursue the matter further.

Meanwhile, Chuck Maxwell in Albuquerque, New Mexico, was poised to perform another lifesaving intervention, from his post leading the Regional Fire Behavior Predictive Center. From his remote location, he wondered if he should forcefully intervene, after seeing the alignment of severe environmental factors which, when accelerated by predicted micro-bursts of out-flow winds from thunder storms, would make the Yarnell Fire explosively dangerous. However, due to management protocols, he could not offer his observations and concerns without a formal request from the proper officials. Previously the Fire Behavior Predictive Center had appropriately issued a red flag alert for extremely low live and dead fuel moistures, providing an added component in evaluating a severe fire environment, magnifying the risk for extremely dangerous fire behavior in the Yarnell area. While individual hotshots were aware of Maxwell’s warnings, management leadership failed to recognize his assessment.

In the next issue – The Yarnell Fire – Part Two: Better Use of Resources.

THE YARNELL FIRE - PART TWO: AN EXAMINATION OF WORKLOAD and TOOLS TO PREDICT FIRE SEVERITY

What went so wrong on the Yarnell Fire, where 19 elite members of the Granite Mountain Hotshot crew died? Our team, which consists of five wildland experts from different geographic parts of the west, believes that to answer this question, it is necessary to examine whether fire management and leaders were prepared to manage the severity of the fire and its environment. This sort of examination leads to learning from the fatality fire, and represents a departure from the traditional fire investigation process, which primarily focuses on the fatality event itself. This same fire team believes an effective analysis of the fire conditions and environment leads to properly managed workloads, effective mitigation of fire risks and hazards, and an increased margin for error.

Fire Workload
We begin with the relationship between workload, management, and fire severity. We believe that increasing fire workload can lead to compromised management, which in turn increases hazards and risks, and reduces the margin for error in maintaining safety. Interestingly, a 1957 Forest Service Report illustrates an emphasis on management's relationship to fatality fires, claiming that "fire fatalities are the result of a series of management misjudgments, errors," and something they called "sins of omission that happen in a severe fire environment." Simply put, the severity of the fire danger invariably leads to increased fire workloads. Without an adequate response to the increased workload, management oversights, errors, and omissions begin to surface. Therefore, it is critical to understand the severity of the fire and be able to quantify fire risk in order to effectively manage the workload, reduce hazards, and increase margin for error.

"Reading" a Fire is Critical
Reading and understanding fire conditions in order to quantify hazards and develop mitigation tactics cannot be overemphasized. Why is it important to know the fire conditions? Doesn't everyone already know about fire danger? Although we are all familiar with the ubiquitous "Smokey the Bear" fire danger signs, it is nevertheless apparent there are significant deficits in the ability to read the fire conditions and site-specific fire behavior. In the Yarnell fire, for instance, both the fire environment and the fire itself were grossly underestimated. The results were catastrophic.

Knowing with accuracy the severity of the fire environment and intensity of the fire allows leaders to effectively match the management and fire strategies to the intensity of the fire. This, of course, ensures safety for firefighters and communities. On the other hand, failure to do so will likely result in missed opportunities to provide command and control for safety, as well as successful management of the fire. Once again, we saw this failure in the management of Yarnell.

We believe that not having a system or process to methodically read the fire's risks and hazards compromises safety, particularly when fires become larger, hotter, and more explosive due to either climate cycles of drought or global warming.

The current system of fire assessment, which uses mostly prior fire experiences and some academic training, has been somewhat effective in the past. This system has proven grossly inadequate, however, in managing current fires, which have increased in severity, intensity, and explosiveness as the result of long-term droughts.

Knowing Thresholds

When working on the Thirty-Mile Fire Fatality Investigation Board of Review, one of our team members was asked to develop a set of thresholds that would accurately predict explosive fire danger in order to keep firefighters safe on the fire line. Unfortunately, it is not that simple. There is no such set of magic thresholds which guarantee an accurate prediction of fire explosiveness, although some fire managers have tried to use temperature, relative humidity, and other environmental factors to determine when to "disengage" from an unsafe fire environment. The challenge is that fire environments vary and change continually. Firefighters will always confront parts of any given fire that are relatively safe and other portions which are dangerous. In addition, the safety or danger of any particular section of a fire changes continually.

Energy Release Component: A Predictive Tool

Regardless, it is obvious to us and most fire managers that tools to understand the fire environment and fire conditions are essential in effectively managing firefighting strategies and work load. We call the use of these tools *fire preparedness*. The best tool to accomplish this sort of preparedness is the use of the National Fire Danger Rating System or (NFDRS). Without explaining details of NFDRS, we suggest that the system, although mandated procedurally, is not being used effectively nor universally. As an example, one component of the NFDRS is knowing and responding to the Energy Release Component (ERC) value and using "pocket cards" to indicate red flag fire dangers and fire season severity. Unfortunately, pocket cards are rarely used. We surmise a lack of training and understanding of ERC are to blame for the fact that fire managers and fighters do not use ERC information and pocket cards.

The ERC (G model) was developed as a basic level of standard assessment of the fire environment. In some parts of the country, this model worked effectively. National fire policy mandated, however, that each agency, region, and unit find its own best predictors for the fire environment from NFDRS. This simply did not happen. As a result, the ERC model was not successful, since it was not systematically taught, enforced, nor adapted to local conditions. This is unfortunate, given the fact of knowing that intricacies of ERC offers a precise prediction tool for fire severity.

For example, an ERC reading of a 90th percentile can have two different meanings, depending on whether the value is increasing or decreasing. If the ERC value is increasing, it indicates that the moisture in the fuel is decreasing, which signals an increase in fire severity. If that same 90th percentile ERC value is on its way down, this indicates that the moisture in the fuel is increasing, suggesting the fire severity is declining.

Fine Fuel Moistures and ERC Values

Understanding this relationship of changing fine fuel moistures and ERC values is extremely helpful to fire managers. As firefighters know, fine fuel acts as kindling to start the fire. Whether fine fuel moisture is increasing or decreasing indicates a change in the severity of the fire environment, even though the ERC values may be the same. In this example of the ERC value at a 90th percentile, if fuel moistures are increasing (because a wet air mass arrives or a high dew point occurs), then the severity of the fire is declining despite the fact that the 90th percentile is itself a high value. In the Southwest, there have never been large fires when ERC values were dropping, even though the values themselves may be high.

When fine fuel moisture values are examined in conjunction with historical ERC averages, the result is a much more precise prediction of fire severity. Fire policy mandates that fire managers compare current ERC values in a fire environment to historical averages. If a current measured ERC value is significantly higher than historical averages for that time of year, then it is extremely likely for fire conditions to be severe. Add the fine fuel moisture to this algorithm, and fire managers can quite accurately predict the severity of fires that are being battled on any given day.

ERC values are just one of many fire danger threshold indicators, for indicating whether a fire will act with the force of a Sunday stroll or a speeding train. The US Forest Service threshold value for extreme fire danger is the 90^{th} percentile ERC. So why is this information not being used? The first Yarnell Fire Serious Accident Investigation (SAI) did not even mention ERC in its report. The Arizona Department of OSHA Yarnell Fire Investigation Report mentioned ERC values, but did not consciously link them to an alignment of forces that signaled precisely defined dangerous and explosive fire conditions.

Thousand Hour and Live Fuel Moistures
Thousand hour fuel moisture values are another important environmental condition to monitor. Thousand hour fuel moisture values are a reliable threshold indicator for fire severity. Statistically, when thousand hour fuel moisture values in the Southwest are 12% or lower there is high probability for a large fire occurrence. Live herbaceous and woody fuel moistures are also important conditions to monitor. One of our team members has spent over thirty years developing and using a system to monitor live and dead herbaceous fuel moistures. In doing so, he has developed fuel moisture thresholds for when crown fire is most likely. For example, conifer <75% live fuel moisture corresponds to potential for independent crown fire when in alignment with wind and slope. There is also a corresponding live fuel moisture value for crown fire in brush to consider. (see appendix 1)

When ERC, live fuel moisture values, and dead fuel moisture values are in alignment, and determined to be more severe than historical averages, fire managers, leaders, and firefighters can assume without doubt that the fire will be dangerous and explosive.

Reading Site-Specific Fire Forces
We have talked about how fire conditions set the stage for how a fire will burn. We want to remind readers that conditions influencing the fire environment, especially as measured by NFDRS, are mostly unseen. Conversely, once a fire begins, the forces affecting the fire, such as fuels, slopes, shading, and aspects, are visible. Fire managers, leaders and firefighters know this and through experience get very good at *reading* the fire. Once again, the ability to read the fire is largely based on experience and some academic learning. Unfortunately, as we mentioned earlier, there appears to be no widespread systemic application of these skills and knowledge.

The Campbell Prediction System (CPS) offers a systematic method to read the fire, as well as language to describe alignments and thresholds that affect the fire. Firefighters using CPS to methodically assess fire alignments and thresholds can more precisely predict where changes in the fire will happen. In addition, CPS predictions provide coherent and consistent communication between firefighters, because all are using the same language to describe the fire.

CPS works by looking at alignments of slope, fuel, and preheat (aspect, shading and or solar heating). In addition to CPS assessments, wind and weather must also be assessed, given their dramatic effects on the direction and force of fire. (We point to the Yarnell Fire, when strong winds developed and disastrously altered the already severe fire environment, causing the fire to blow up on June 30, 2014.)

CPS and the Yarnell Fire

In CPS language, what was the Yarnell Fire saying as it escalated from a fairly docile fire to a deadly inferno the afternoon of June 30th? To begin, the aggressive fire growth the night before, without solar preheating, was revealing a *signature*, indicating the fire would threaten to significantly intensify the next day when alignment of slope and fuel would align with solar heating.

CPS reads the fire head, flanks and heel. CPS looks for fire signatures on all sides of the fire examining the forces of solar preheating, fuel, and slope. Once a fire signature is observed, firefighters are able to infer the same fire behavior will likely occur under similar conditions. Had CPS been used during the Yarnell fire, managers and firefighters would have recognized predictive information about the fire as solar preheat increased. Fire behavior escalated dramatically on all sides of the fire as solar preheating intensified. These changes in fire behavior are clearly described by the Blue Ridge Hot Shots in their testimony during the Yarnell Fire investigations (flame lengths increasing, fire chewing through retardant, winds increasing and changing directions, spot fires occurring, spot fires increasing in size and frequency, etc.). Firefighters will agree this is how the fire must be read to determine thresholds for safety.

CPS descriptions of the fire signature also offer the ability to predict fire behavior if a wind shift occurs. For example, it is common knowledge among firefighters that if the fire head is making a strong explosive run with wind and a wind shift occurs to either flank of the fire, the same intense explosive fire behavior will occur if the fuel, slope, and solar preheat conditions remain the same. This is exactly what happened during the Yarnell Fire when wind shifts occurred. A less intense flanking fire turned into a deadly head fire as the winds from the outflow shifted directions.

The Yarnell Fire: An Absence of Fire Prediction and Assessment Tools

In the wake of the Yarnell tragedy, the question on the minds of families, members of the fire community, and news services was, "What could have possibly gone so wrong?" Our team attempted to answer said question in Part I of this series, when we described the fire events and decisions made by managers and firefighters as they confronted the deadly fire.

This article has taken a closer look at the fire assessment and predictive tools that should have been utilized by fire managers and firefighters in the Yarnell Fire. Clearly, before the Yarnell fire erupted, forest service personnel were aware of the severe drought conditions throughout the entire area. Unfortunately, however, the Arizona State Forestry/Fire Management and the Type II Team seemed not to have recognized the extent to which those drought conditions had dangerously impacted the fuel bed and entire fire environment.

The fire assessment tools we have described in this article, if utilized by the Yarnell fire team, would have offered opportunities to a) control a harmless fire early on, or b) maintain command and control of the fire later. There is no reasonable doubt that the initial fire could have and should have been easily extinguished. The fact that the early fire was growing significantly in size during the night offered a signature that cried out to be extinguished early on, in light of the severe fire environment.

A study of the historical severity of the fire environment for the Yarnell area during the last week of June confirms the potential for an explosive fire for which a "Short" Type II Team would be ill prepared to manage. (R-3 fire severity map) The confusion, mistakes, conflicts, and near misses that occurred when the Yarnell Fire blew up on June 30th confirm that the Short Type II Team was not using the tools necessary to maintain command, control, and safety for firefighters and the public. The peaking fire behavior and urgent need to protect the local communities simply and quickly overwhelmed the initial Type IV Team, Short Type II Team and Granite Mountain Hot Shots.

In summary, a small fire began in the Yarnell area at a time when drought had created dangerously explosive conditions in local fuel beds. The explosive nature of the fire fuels was *predictable*, given standard fire predictive tools (ERC, thousand hour fuel moistures, etc.). Overnight the small fire morphed into an aggressive fast-running inferno as the typical forces we've described (solar pre-heat, fuels, topography, wind) aligned. The aforementioned transformation, too, was *predictable*, had fire assessment tools like CPS been utilized. In fact, the testimony of the Blue Ridge Hotshots indicated that their assessments of the fire had kept them and others they notified safe. Finally, the devastating shift in fire direction, which eventually caught and overwhelmed the Granite Mountain Hot Shots, was also *predicted*. Chuck Maxwell, who led the Southwest Fire Behavior Predictive Center, had sent warnings of a bank of thunderheads likely collapsing, creating an outflow event, and sending the fire directly toward firefighters. The unfortunate point here is that every behavior of the devastating Yarnell fire was foreseeable, had fire assessment and predictive tools been better utilized.

In Closing

We want to acknowledge once again the tremendous work and high level of professionalism of many fire managers, leaders, and firefighters. Many fire teams have successfully managed for fire safety in extreme fire environments. Our team will continue to question why effective fire management cannot be assumed in all geographic areas, and in all fire environments. We believe systematic training, the consistent use of effective fire assessment tools, and the demand for a culture of professional learning from fire events are essential to improve safety. The probability of safety in stressful changing fire conditions depends upon an accurate assessment of fire hazards and risks.

In addition, we recognize the importance of matching appropriate strategies and tactics to fire severity, as well as matching fire management teams to the fire workload. We therefore place great emphasis on transitioning fire teams effectively to meet an escalating fire, for maintaining command and control of the fire. In short, management of the fire must match the severity of the fire to ensure safety. An effective well-trained fire team, equipped with appropriate fire assessment tools, is capable of managing fire risks and hazards and safeguarding firefighter and community safety.

In Part III, our fire team will examine training models that equip fire teams to manage fire hazards and risks with measurable proficiency.