The Importance of a Dedicated Fire Weather Network:

Reducing the impact of wildland fires.

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Executive Summary

This white paper argues that a dedicated fire weather network improves prediction, prevention and suppression of wildfires. Effective fire management today requires fire weather data that is accurate, timely, reflective of actual field conditions, and durable enough to ensure a continuous historical weather record. Standard meteorology stations do not meet the modern standard of fire agencies because they are not typically located appropriately for fire weather purposes, do not collect observations for peak fire danger hours, and are not built to withstand harsh conditions. By investing upfront in a dedicated fire weather network, fire management agencies can save lives, reduce damages and decrease emergency response costs.

Introduction

Every year, 35 million hectares —or about 1% of the world's forests— are lost to wildfire.[i] Recently in North America the area burnt by wildfires has increased sharply, while regions like Southeast Asia and South America have seen a rise in the number of land-clearing fires and other escaped wildfires in equatorial forests[ii]. In 1997, Malaysia, for example, spent $8.2 million to put out fires that resulted in major evacuations.

"I don't know how you could protect communities and suppress wildfires without a dedicated fire weather network. It drives all of our operations. When you reach certain thresholds in whatever rating system you have, then you respond proactively and gear up, rather than waiting for the calls to come in and finding you've already got a ground fire jumping to a crown fire."

JOHN FLANAGAN
Wildfire Management Branch, BC Government (Canada)

The extraordinary costs of fire suppression activities are matched only by the damages to property and ecosystems these fire wreak—in South America, this loss is estimated at $1.6 billion annually[iii]. In the US, damages from major fires were found to account for as much as 95% of total costs from fire[iv].

These fires cause a devastating loss of life. Wildfires in Greece in 2007, for instance, caused the deaths of 69 civilians, 9 firefighters and 2 pilots. And a ground-breaking new study estimates that smoke from land fires causes a staggering 339,000 deaths per year[v].

In emerging economies, the default mode of fighting wildfires is reactive—to tackle fires as they arise using whatever resources are available. This approach is both costly and dangerous.

Advances have been made through the use of basic weather data from meteorological stations. In years past, fire agencies used this data to develop fire danger rating systems that helped them predict, prevent and suppress fires. However, there is a mismatch between the specialized, comprehensive data needed for effective fire management today and what is available from rudimentary meteorology networks. This leads to inaccuracy that can cause dangerous errors in decision-making.

How can fire management agencies improve their ability to predict, prevent and fight wildfires? By installing dedicated fire weather networks. A dedicated fire weather network is a finely-spaced grid of remote automated weather stations (RAWS) that is specifically designed for fire weather applications.

"When you're putting people in the field to fight fires, you want them to know what kind of conditions they're going into. Knowing that saves lives. There are times where they shouldn't be going. And if you don't know that, then you're going to have people die."

DON GREEN
Former Chief Fire Meteorologist, Yukon Government (Canada)

Fire Weather Data Adds Critical Insight to Fire Management

Fighting a wildland fire without fire weather data is like walking into a burning building blindfolded. A severe fire can race across the landscape at upwards of 23 km/hr and without accurate fire weather information there is no way of knowing where the fire is going, how hot it will burn, and what it will take to stop it.

Modern fire agencies use fire weather data to make decisions about how many people to send to a fire, where to send them, and how quickly they must arrive. Should the focus be on ground operations, or is aerial support needed? Operations are constantly adapting to fire weather information: imminent rainfall may make fire suppression activities unnecessary; an expected change in the wind direction may inform a shift towards protection of a nearby town; windy conditions may

"We used to have a lot of logging activity fires because businesses want equipment operating 24/7. There were always folks out in the woods wanting to operate on a particular day and we're having to tell them "no" because we believe there's a fire threat. And they're standing there saying "but it's raining." Now we feed the RAWS data into a National Fire Danger Rating System and based on historical fire load and threat, we can take out that intuitive piece and make it based on science that everyone can agree upon."

DAVID GRANT
Smoke & Fuels Specialist, Washington State (USA)

FIRE DANGER RATING SYSTEM USES

- **Public campfire bans**
- **Pre-positioning firefighters**
- **Fire detection planning**
- **Dispatching attack crews**
- **Fire suppression tactics**
- **Active fire behaviour plans**
- **Crew situation analysis**
- **Prescribed fire planning**
- **Fire/fuel modelling**
- **Fire behaviour training**
- **Wildfire research**

make it too dangerous for a helicopter. By understanding the weather's effect on a fire's behaviour, decision-makers can make the most effective use of available resources while prioritizing the safety of their firefighters.

Fire danger rating systems: the key to fact-based decision-making

Perhaps even more important than the ability to predict fire behaviour during a fire event is the ability to identify dangerous conditions *before* a fire starts. By knowing when and where conditions are ripe for fire, fire managers can take measures to reduce ignition risk and increase fire preparedness. That's what a fire danger rating system does.

A reliable fire danger rating system is acknowledged worldwide as the keystone of effective wildfire management. A fire danger rating system removes reliance on experience and intuition, and instead allows decisions to be based on consistent, science-based criteria. An early study of Canada's fire danger rating system found that over an eleven year period the system saved more than $750 million[1] in firefighting expenditures[vi]. In China, implementation of a national fire danger rating system has reduced area burned by 90% since 1987[vii].

Preventative measures are the first step towards reducing wildfire. Fire danger ratings can be used to ramp up public education campaigns, limit open fire burning, and restrict industrial activities in the forest. In British Columbia, Canada, government regulations restrict or place conditions on certain high-risk activities depending on the fire danger level. For instance, when the danger has been 'high' for three days, activities that might throw sparks or start a fire—like railroad grinding, arc-welding, grass-mowing, or use of explosives for road clearing—are prohibited in the afternoons , and require at all times a person nearby to patrol for and extinguish any fire[viii]. This approach takes the guesswork out of restrictions, avoiding legal battles and creating common ground with private landowners who want to protect their land resources while maximizing their operations.

Fire weather data reduces risks during prescribed burns

An excess buildup of fuel caused by ongoing fire suppression can lead to extreme fire conditions. Fire weather data and danger rating systems allow land managers to reduce this fire risk by doing prescribed burns during times when the fire will achieve its objective but the probability of escape is low.

The importance of proactive resource allocation

When it comes to wildland fire, timing is everything. A quick initial attack can make the difference between a fire that is put out before it has the chance to spread, and an inferno that burns for weeks, claiming lives and property. Fire managers can pre-position firefighting resources into areas with the highest danger. It is not feasible to have 100% of staff ready to go at all times, nor is it feasible to have enough equipment and staff to deal with the most extreme fire season. Instead, fire danger ratings can determine the level of preparedness and resources on any given day and during times of extreme risk, resource-sharing agreements can be drawn

[1] All costs in this report are given in $US

"If the weather data is not accurate, then the indices will be off. For example, if the humidity is too high, then it will show a lower index than what is actually representative of the fuels. And when the firefighters go in to attack, the fire behaviour is going to be more extreme than what they were expecting. Same thing if the wind equipment is showing too light a wind, they're going to be in for surprises. And those are never pleasant."

DON GREEN
Former Chief Fire Meteorologist, Yukon Government (Canada)

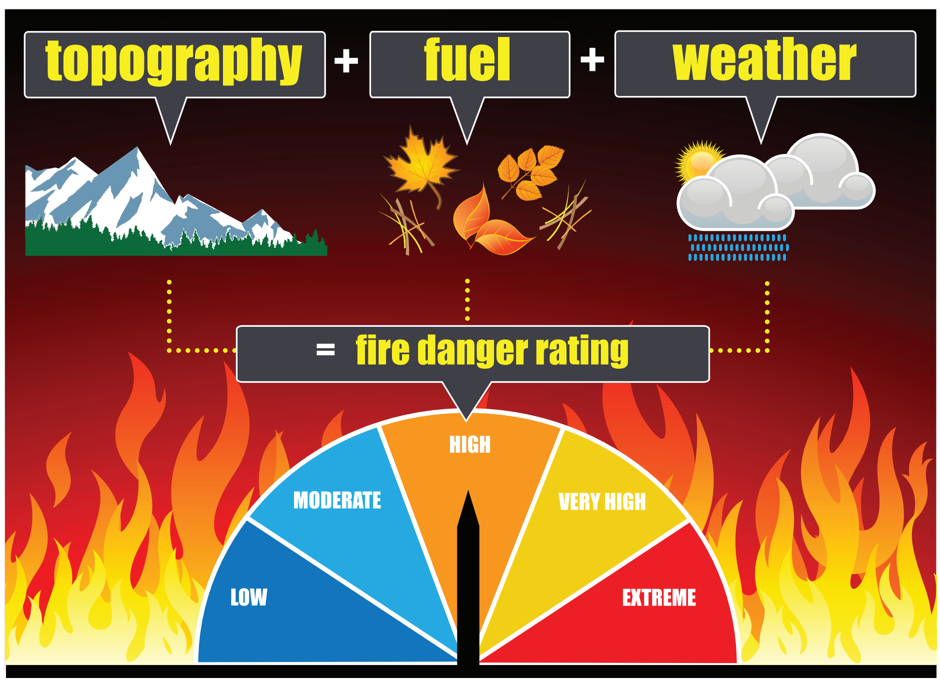
upon with other jurisdictions (both the US and Canada have such agreements in place).

Fire weather data helps post-fire analysis

Fire weather data allows fire investigators to trace a fire's path to its source, while fire danger ratings can help inform whether a fire was the result of natural or human causes —a low ignition risk, for example, could suggest arson[ix]. An accurate historical fire weather record also helps build better decision support systems.

How Fire Weather Data Impacts Fire Danger Ratings

Fire weather observations consist of temperature, precipitation, relative humidity, wind speed, wind direction and sometimes solar radiation and fuel moisture. Fire danger is determined by three elements: topography, fuels, and weather. Of these three, weather is the largest factor in day-to-day changes in fire danger[x].



Fire danger rating[xi] systems use these daily and hourly weather inputs to create multiple "indices" that assess the potential over a large area for fire to ignite, spread, and require suppressive action. Predicting fire behaviour, on the other hand, also assesses this potential but produces more concrete outputs that are site-specific and pertain to existing fires.[xii]

There are a number of fire danger rating systems in use across the globe. Most use a collection of indices that include a summary index indicating the potential intensity of a fire (in Canada, the Fire Weather Index, in the US, the Burning Index), and

> **"The indices are calculated at noon to give a projection of what's going to be the conditions later on in the afternoon during the time when the fire will spread the most. Some airport stations don't report until seven o'clock in the evening, so they're useless to us. If it rains halfway through the day, there's no record of it until the evening. Well, you can't base anything on that kind of information."**
>
> **DON GREEN**
> Former Chief Fire Meteorologist,
> Yukon Government (Canada)

related sub-indices that describe both the potential for ignition based on fine fuel moisture and wind speeds, and the potential for prolonged burning based on the build-up of dry fuel. Forecasted weather data can be used to estimate future fire danger.

Precipitation, temperature, wind speed, and relative humidity all affect the daily wetting and drying of the various layers of forest fuels (such as twigs, needles, and fallen logs). This cycle is cumulative, with each day's moisture serving as an input to the next day's calculations—making a continuous fire weather record a critical factor in attaining accurate fire danger rating results**.**

Fire behaviour prediction systems work on similar principles but rather than producing indices that are simple numeric scales, they produce detailed outputs such as rate of spread, head fire intensity, fuel consumption, and fire type (e.g. ground or crown fire). They incorporate site specific information about vegetation, slope, elevation, and latitude, as well as wind direction.

Accurate Fire Weather Data = Accurate Fire Decisions

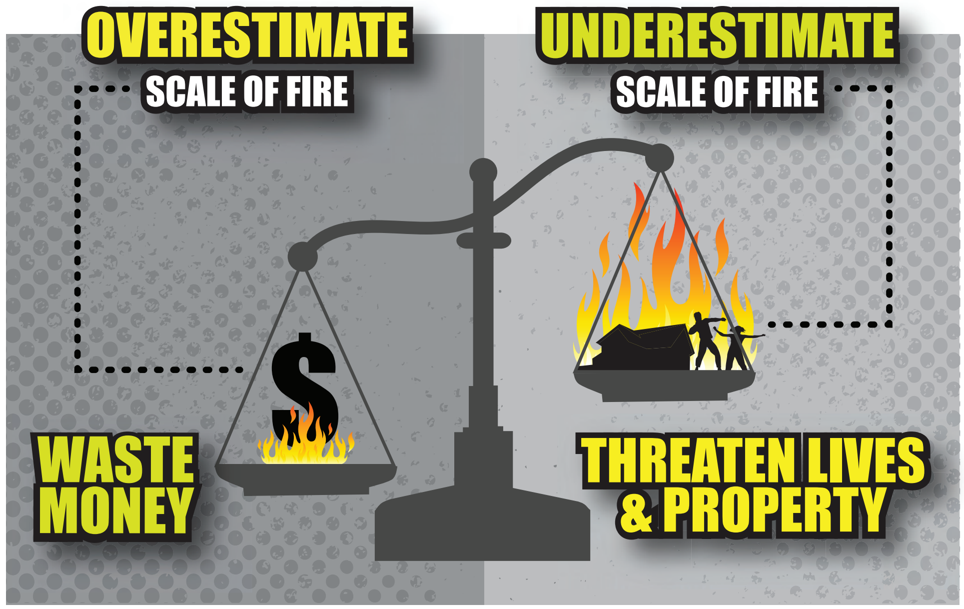
To be useful, fire weather data must be accurate. As discussed above, a fire's behaviour is affected by even small changes in the weather. Likewise, fire danger ratings and fire behaviour prediction systems will produce significantly different results when weather inputs are changed.

Small weather changes have big consequences

A single day's error in weather measurement can result in danger indices that are off-base. In some situations, an underestimation of wind speed by 9 km/hr would result in an underestimation of the rate of fire spread by half. Even a 2 km/hr error in wind speed could produce a difference in the rate of spread that would cover the transition from surface fire to crown fire[xiii]—a dangerous situation that requires significantly more suppression resources. In the same way, just 5 mm of rainfall can bring double the fine fuel moisture content and dramatically lower the risk of spread.

"We have these mutual aid agreements with other provinces and countries. But it's a bit of guessing game because it costs a lot of money to bring those resources in. By using the RAWS network and our fire danger indices, we can look into our crystal ball and predict that in two weeks we're going to be okay, so we can send those crews to Ontario and recover those funds back. "

JON FLANAGAN
Wildfire Management Branch, BC Government (Canada)



The Fire Weather Index can be thrown off by 20%--a significant difference in terms of expected fire weather—by a single day's error of 10% in relative humidity, or a 2 degree error in air temperature. Add in a 6 km/hr error in windspeed and the index will be 30% off. [xiv]

Improper weather station location compounds errors

When a weather station is too far away for it to be representative of an area, such problems are compounded because the error will be repeated daily. The tracking of the drying and the wetting of fuels is done by entering each day's fire weather indices into the next day's. Estimations of fuel moisture—particularly important in the early and late season—can become entirely incorrect.

"If you have the equipment at the right place when severe fire weather is expected then you can respond to reported fire ignition much faster. And a fire that is basically addressed within half an hour or an hour has much less chance to propagate. After that, it becomes very difficult and in some cases impossible to control."

DANIEL POIRIER
Chief Fire Meteorologist
Saskatchewan Government (Canada)

Gaps in fire weather data invalidate historical analysis

Similarly, a gap in the weather data caused, for example, by equipment failure or a staff absence, creates inconsistencies. Since fuel moisture content is established over the course of years, a fire danger rating cannot be properly calculated without a continuous record of fire weather data.[xv]

Late fire weather data is useless data

Fire danger rating systems are intended to predict the worst-case scenario, which for fire is the afternoon when heating peaks. Weather observations must be taken at noon and reported quickly so that ratings reflect *today's* fire danger, not tomorrow's. Hourly data is even more useful, particularly during fire suppression when sudden shifts in weather can jeopardize a crew's safety.

Simply put, poor data leads to poor decision-making.

> **"Helicopters have flight limitations based on wind. The National Weather Service makes a prediction, and then we looking at the RAWS stations to see whether or not that prediction is valid at this location. We ask, do we have an hour before this thing is going to come through here and hit us or has it already passed?"**
>
> **DAVID GRANT**
> Smoke & Fuels Specialist, Washington State (USA)

Inaccurate danger ratings rack up unnecessary expenses

A fire danger rating that has been mistakenly set too high will incur significant costs as a consequence. In the US, higher fire danger ratings trigger a lengthening of staff hours, resulting in overtime pay of 50%. Given the average crew cost of $3,000 per day[xvi], this will quickly add up. Aerial resources are even more expensive: In South Africa, it costs $23,000 a month to keep a helicopter on standby[xvii]. In Australia, a heli-tanker is $20,000 per day on standby[xviii]. And in Italy and France, the average cost for water bombers on standby is $13,000 *per hour*[xix]. Public funds are too scarce to be wasted on being ready for fires that will never happen.

It is particularly costly to bring in resources from other jurisdictions. This can be offset by hiring out those resources at other times, but only if fire danger can be accurately predicted using fire weather indices.

Erroneous danger ratings have public consequences

An overestimated fire danger rating can also incur private costs when restrictions are placed on industrial operations and agricultural activities. Tourist revenue can be lost and public frustration can result from campfire bans and other precautionary steps.

Nevertheless, the worst consequences arise when fire danger ratings are underestimated.

Underestimated danger leads to unnecessary risk

When danger ratings are too low, fire managers will be allowing high-risk activities when they shouldn't be. In British Columbia, a 20% error in the fire weather index will mean the difference between a ban on all high-risk activity, and the restriction in the afternoons. In such conditions just one spark from a forester's power saw could cause a fire.

> **"When you have to start managing wildfire with minimal resources like they have in Argentina, you better make sure you're sending those resources to the right fire. Nothing worse than going to the wrong fire, when you've got another one that shows up and gets away when the one you are on does nothing and the data says so."**
>
> **DAVE MAREK**
> Fire Behaviour Specialist, BC Government (Canada)

Even worse, incorrect danger ratings may lead to prescribed burning at times that aren't safe. Today's cautious attitude towards prescribed burning is in large part due to high-profile incidents where the fire escaped and serious damages resulted. Accurate fire weather data is crucial for the safety of these operations.

Inaccurate danger ratings leads to escaped fires

Fire danger ratings are used to determine crew readiness and resource availability. A delayed or insufficient initial attack will lead to more escaped fires. According to an Australian study, on a bad day, a fire crew delay of just one hour will reduce the probability of containment within 8 hours by 60%[xx]. A Commission found that Australia's Black Saturday in 2009, in which 173 people died and 414 injured, was in large part due to delay in sending aerial resources.

In the US, just 1% of fires account for 94% of suppression expenditure[xxi]. The damages from an escaped fire can be enormous. In India, a single fire in a sandalwood forest in 1997 generated $43 million in damages.

Poor prediction of fire behaviour endangers lives and property

Once a fire gets going, an accurate prediction of its behaviour is needed to safely and effectively allocate firefighting resources and defend lives and property. Weather conditions dictate whether it is safe for aerial resources to come in, where ground crews should be set up, and whether nearby settlements need to be evacuated or not.

Proper resource allocation is a large factor in cost. A study of large fires in the US[xxii] found that geospatial technologies (which are often informed by fire weather data) reduce cost inefficiency by 44%, suggesting there is significant scope for improvement in even sophisticated operations like those found in the US. In countries with fewer resources, judicious placement of those resources becomes even more crucial.

How to Achieve Fire Weather Data Accuracy

To meet the modern standards of fire management agencies, weather data must be accurate, timely, representative of actual field conditions, and durable enough to ensure a continuous historical weather record. These can be achieved by working towards a dense network of Remote Automated Weather Stations (RAWS) that are correctly located, finely calibrated, and robust.

STEPS TO LOCATING A FIRE WEATHER NETWORK

1. Identify priority regions using fire incident records, bioclimatic information and existing weather stations.
2. Equip field rangers to take occasional manual weather readings across the landscape for a few months to identify areas not represented by existing weather stations.
3. Confirm data gaps by installing portable RAWS to collect data for a few years.
4. Install permanent RAWS to cover the data gaps.

Station location is critical

A weather station's location needs to reflect the conditions it's trying to assess. A meteorological station at an airport, for example, will accurately gauge flying conditions in the valley bottom and the approach of broad weather fronts. A fire weather station, on the other hand, needs to gauge what weather conditions are like in the places where wildfires start—within the forest cover, close to the ground, on a level or sunny slope — and embedded in the local terrain. Wind speeds in a forest opening are typically 40% less than those at an airport station[xxiii]. Terrain and elevation can substantially alter temperature, relative humidity, and wind speed and direction.

Existing meteorological networks rarely cover the areas where fire danger information is required, particularly in jurisdictions with large wilderness areas. In British Columbia, for instance, the meteorological network has approximately 90 stations in the province, mostly located in urban areas, while another 260 RAWS are used to collect fire weather data throughout the province, particularly in fire-prone ecosystems.

More density equals more accuracy

The data accuracy of a fire weather network increases with its density. One modelling study set in Spain found that switching from a grid spacing of 100 km to 50 km in just the most critical fifth of an area would reduce annual burned area by 20%[xxiv]. The initial RAWS network in the US had a spacing of 120 km, but an 80 km distance is now considered the minimum necessary for a meaningful network. This reflects a shift in use from only coarse fire danger ratings to support of

"I need to know: did a rain shower actually come through there or did that area get missed? Are the winds really as bad as they say they are 30 kilometers away? I have to make decisions based on the weather at the fire site, and the more RAWS data I have coming in the better."

DAVE MAREK
Fire Behaviour Specialist
BC Government (Canada)

decisions that affect firefighter safety in specific locations[xxv]. A study of the US RAWS network found that, in spite of a median distance of only 29 km between stations, only 5% of stations were redundant, indicating that such a dense network is useful for representative fire weather data[xxvi].

The more varied the terrain is, the more stations are needed for accuracy. Complex terrain also requires greater judgement and analysis to determine station placement. Portable RAWS stations can be particularly useful in confirming or challenging the accuracy of the nearest weather station during a major fire event or during a prescribed burn.

Automation increases reliability and efficiency

According to the World Meteorological Organization, "the benefits of Automated Weather Stations include their cost effectiveness, high frequency data, better ability to detect extremes, deployment in hostile locations, faster access to data, consistency and objectiveness in measurement, and ability to perform automatic quality monitoring."[xxvii]

Timeliness is essential for fire weather, and as discussed in the previous section, rudimentary weather stations don't always report at the right time of day for calculating fire danger indices. Fire suppression operations particularly value having access to hourly data, because it could save lives.

Automated fire weather stations are purpose-built to transmit data without any intervention. Manual weather stations are difficult and expensive to staff in remote areas where few people live. They also require staff time on the receiving end to receive and process the information. Automated fire weather stations reduce human error by cutting out these processes, providing fire managers with peace of mind that observations are correct. Automation also frees up staff time to focus on other tasks, reducing budget expenditures.

Integrating various data sources adds complexity

Having a purpose-built fire weather network allows a fire agency to avoid the integration challenges that come with obtaining data from multiple sources. Standardizing data from different networks can be time-consuming and compromise data quality. When Argentina was setting up its fire weather system, it found its greatest challenge to be resolving communications system disconnects due to variations in hardware and software systems between networks[xxviii].

Low volume vs. high volume precipitation

Fire weather operators have unique needs. Where standard meteorological stations are more focused on accurately capturing high-volume rainfall events, a fire weather station needs to be finely-tuned to gauge minute quantities of precipitation. The faint drizzle in the morning or the overnight dewfall—these small quantities of moisture can have a significant impact on the day's fire behaviour. They are also easy to miss because of their rapid evaporation from a typical rain gauge. The best fire weather stations are designed to prevent this from happening.

"We used to have remote data loggers that we'd pay local guides and outfitters to go out and read the data and phone it in. It wasn't timely. And you never knew for sure that the readings were correct. Because there were tales of people saying "It's pouring rain, I don't want to go out there." They'd just guess. So for not a huge investment, the automated stations give us an hourly report-back with no intervention required. And we know the equipment is calibrated, and the readings are not guessed. "

ERIC MEYER
Wildfire Management Branch
BC Government (Canada)

Tailored to fire weather standards

To maintain data accuracy, stations should be built and maintained to rigorous fire weather network standards. The US fire weather network standards specify everything from sensor accuracy and station placement to calibration and maintenance schedules[xxix]. These requirements are tailored to the unique demands of fire weather applications while upholding standards set by the World Meteorological Organization.

Maintenance simplicity reduces costs

Purpose-built remote fire weather stations are designed to make scheduled maintenance simple enough for a non-technical staff person to do. This reduces costs and makes it more affordable to keep up a regular maintenance schedule.

Durable stations prevent interruptions

A remote automated fire weather station must be virtually indestructible in order to maintain the continuous weather records so necessary for fire danger applications. Lightning strikes, fire, freezing temperatures, bear attacks, and vandalism are just some of the harsh conditions they must withstand.

The Value of a Dedicated Fire Weather Network

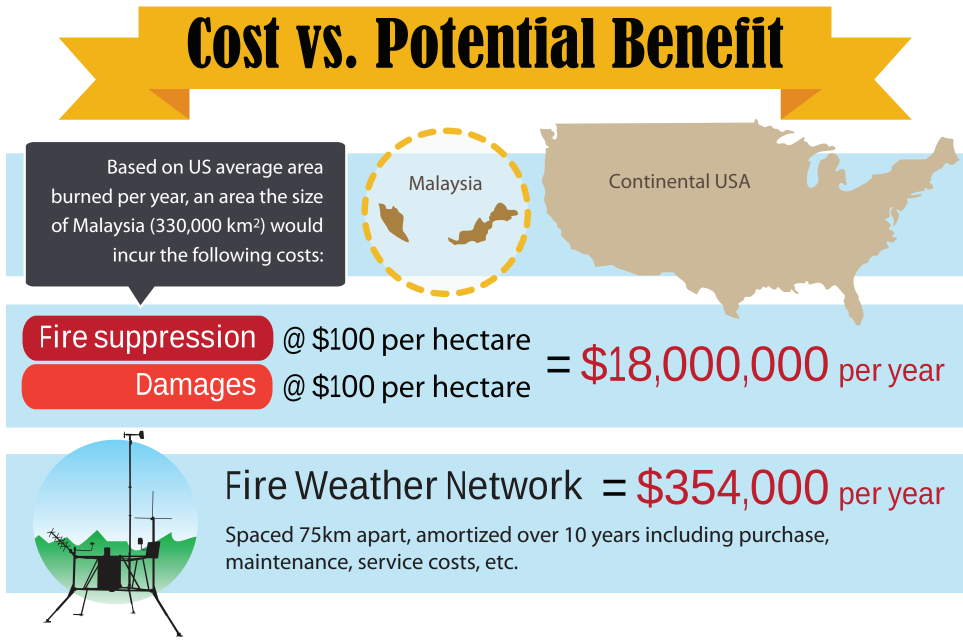
A dedicated fire weather network will result in more accurate, timely, and complete fire weather data. Better data means better decision-making, which in turn leads to lower expenditure on fighting fires and less damage to property, lives, and ecosystems. The cost of a dedicated fire weather network is very small in comparison with the cost of errors in fire suppression. Using very conservative estimates, an agency would need to reduce the area burned by only 2% in order to justify the cost (see box). If reductions are 20% as in the study previously mentioned[xxx], then the costs will be vastly outweighed by the benefits.

"With the national weather service automated stations, it takes us a lot of human interaction to get their observations, edit them and place them into the National Fire Danger Rating System. Our RAWS stations beam that information directly to the national computer so we can make up to the hour adjustments."

DAVID GRANT
Smoke & Fuels Specialist,
Washington State (USA)

“Some of the costs involved in firefighting are extremely expensive—the aircraft, the expenses. From that perspective, the amount to spend on weather is very small. So it’s not something that is even debated. It’s known that you need to put the weather stations out there to be able to get those indices, and we need to maintain them to get accurate indices. It’s pretty well accepted that it’s saving money and saving property and saving lives.”

DON GREEN
Former Chief Meteorologist,
Yukon Government (Canada)



A Cost-Benefit Analysis

Based on data collected between 1985 and 2012[2], the United States sees an average of 76,669 fires per year, impacting 4.96 million acres (20,075 km2). This is roughly .22% of the total land area of the United States.

Using the US average as a reference (which is lower than the global average) an area the size of Malaysia (330,000 km2) could expect to have fires impacting 726 km2 annually. Assuming* a cost of $100/hectare for fire suppression and $100/hectare for damages, this would result in approximately $14.5 million dollars in suppression and damage costs annually. The cost of a fire weather network for an area this size, spaced at 75-km apart and amortized over ten years and including maintenance costs, would be about $354,000 per year. It would only take a 2.5% reduction in annual fire costs to justify this expense.

**Estimates of cost per hectare vary enormously. In the US, the 20-yr average cost of suppression alone is $600/ha[xxxi]. Case studies in the US have shown suppression costs ranging from 53% to more typically only 5% of total costs incurred by fires. In 1997, fires in Malaysia, Indonesia, and Khazakstan incurred damage costs of $609,000/ha, $2,418/ha, and $717/ha respectively. In the Malaysian case, fire suppression only accounted for three percent of the total costs—the bulk were incurred from lost productivity due to evacuations, and lost tourism revenue. Other examples include Sri Lanka, where average damages from 1990-2000 were $60/ha, and Mongolia, where average damages from 1996-1997 were $13,000/ha.*

[2] Based on information available from the National Interagency Fire Center, with annual fires and total acres including all private, state, and federal lands.

Alternatively, a reduction in firefighting costs from better resource allocation would have the same effect: in the hypothetical example used here, this might be achieved with only a 4% reduction in firefighting costs.

Conclusion

A dedicated fire weather network helps fire management agencies improve their ability to predict, prevent and fight wildfires. This white paper has shown how costly and dangerous errors can be made when fire weather data is incorrect or missing. A dedicated network of remote automated fire weather stations ensures fire weather data is timely, accurate, and representative of actual field conditions. This investment will be paid back many-fold in the form of more effective and efficient firefighting, reduced damages to property and ecosystems, and saved lives.

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