A Wildfire Risk Management System – An Evolution of the Wildfire Threat Rating System

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Abstract
In 2002 the Greater Vancouver Water District began a collaborative project to develop a Wildfire Risk Management System for three municipal watersheds (Capilano, Coquitlam and Seymour) that provide drinking water to the Greater Vancouver Region of Southwestern British Columbia. Wildfire is a natural disturbance agent in these heavily forested coastal watersheds that has the potential to negatively impact water quality, public safety and property, and air quality. Historically these areas have been exposed to low frequency (300-600 years), high severity stand replacement fires that have the potential to significantly alter physical and chemical water properties. Although the probability of large wildfires within these watersheds is considered low, the consequences associated with a large wildfire could be devastating to both the watersheds and the adjacent interface communities.

The Wildfire Threat Rating System has been developed for a number of applications and scales throughout British Columbia over the past six years. In previous applications, all fire related factors (fire risk, suppression capability, fire behavior and values at risk) were rated equally without consideration of traditional risk management theory. The revised system adopts a risk management approach to guide the quantification of separate and discrete landscape-level probability and consequence ratings, using the same underlying data attributes. The resultant Wildfire Risk Management System better enables fire and watershed managers to design strategies and tactics for fire management that vary from high probability-low consequence to low probability-high consequence fire risks across the landscape. As part of the development of the new GIS-based system, a user interface has been incorporated to allow the interactive adjustment of all attribute-rating scales, such that fire managers can develop and analyze fire management scenarios.

The generic approach underlying the Wildfire Risk Management System allows its application in a wide range of fire management planning circumstances from timber supply areas to protected areas and interface communities. In this unique application within the Greater Vancouver Watersheds, quantitative approaches were developed to address a wide range of values at risk including water quality, air quality, visual sensitivity, and community interface zones.

1 Introduction

The past two decades have seen tremendous advances in the use of Geographic Information Systems (GIS) and spatial modelling techniques to support fire management planning (Salazar and Nilsson 1989, Blackwell et al. 2003b). More recently, a variety of GIS applications have been developed to support the specific requirements of wildfire risk assessment and management (Bachmann and Allgower 1998, Gollberg et al. 2001). The goal of these applications is to quantify wildfire risk in a spatially explicit manner, thereby providing managers with a risk management decision-support system.

One promising approach, wildfire threat analysis, was initially pioneered in Australia (Muller 1993, Vodopier and Haswell 1995). The approach was adapted for use in British Columbia (BC), Canada, and has since been applied in a number of different contexts and scales (Hawkes and Beck 1997, Blackwell et al. 2003a). In all applications, the final output of a wildfire threat analysis is a map overlay that is intended to provide a spatial representation of all the critical factors that affect wildfire risk.

As pointed out by Shields (2002) however, the basic approach to wildfire threat analysis and its underlying modelling methodology has several drawbacks, including:

- The final map overlay, which is a mathematical summation of many input factors, can mask the complexity of interactions that occur between input factors.
- The final "threat" output is insufficiently defined or targeted toward specific fire management questions.

To this list, we add the following limitations based on experiences in BC:

- There is a need for greater transparency, flexibility and assessment capability regarding all model inputs.
- There is a need for improved end-user functionality and real-time interactive planning capability to improve effectiveness as a decision-support tool.

With these considerations in mind, we set out to develop an enhanced Wildfire Risk Management System (WRMS) that builds on earlier wildfire threat analysis applications.

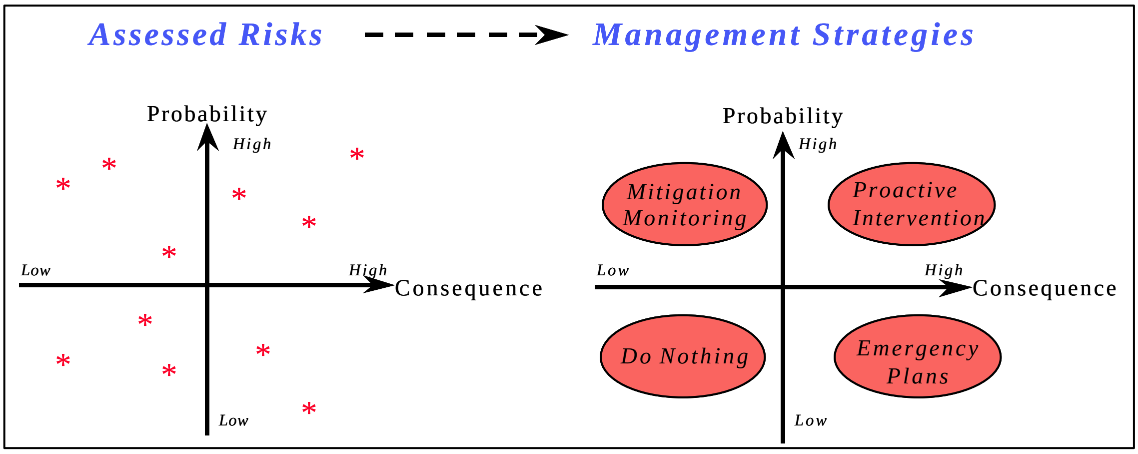
2 Wildfire Risk Management

Definitions of the term "risk" and all its derivatives (i.e., risk management, risk assessment, risk evaluation) are inconsistent in the wildfire literature, perhaps as a legacy of the fact that most wildfire research has been broken down into specialty topics such as fire behaviour, fire effects, and fire history/occurrence. For our purposes we define wildfire risk as the probability and consequences of wildfire at a specified location under specified conditions. This definition, which emphasizes the measurement of risk in terms of the two components probability and consequence, is consistent with the generic definition of risk and its derivative terms being adopted in many jurisdictions worldwide (Canadian Standards Association 1997, Council of Standards Australia/New Zealand 1999, International Standards Organization 2002).

Analytically, our approach to wildfire risk assessment provides a spatial and temporal characterization of risk based on probability and consequence. In simple terms, we want to know at any given location and at any given time, what is the probability of wildfire occurring, and what are the potential consequences (for a given wildfire behaviour) on valued resources.

In other fields of risk management (e.g., hazardous materials management), a single resultant quantification of probability and consequence is often derived mathematically. However, in the case of wildfire risk assessment we find (as in Bachmann and Allgower 1998) that it is more useful to keep these elements separate, since they may imply different management approaches spatially. Conceptually, Figure 1 shows how the various combinations of probability and consequence across the landscape can imply the basic management strategies. In practice, as shown in our application below, the implementation of this risk management approach requires a detailed spatial examination of assessment results across a full continuum from low to high ratings.

Figure 1: Conceptual representation of risk assessment/management as the resultant of two factors, Probability and Consequence



3 The Greater Vancouver Watersheds

The Greater Vancouver Water District (GVWD) manages three watersheds – Capilano, Seymour and Coquitlam – for the purpose of supplying drinking water to two million residents of the Greater Vancouver area. The GVWD has unprecedented control over the utilization of the watersheds, and public access to the three watersheds is denied as a water quality protection measure.

Collectively, the watersheds span 580 square kilometers within predominantly forested mountains, with relief ranging from 150 to 1800 meters in elevation. A comprehensive ecological inventory of ecosystems, geomorphology, disturbance agents (fire, insects and disease), and wildlife habitat exists for the watersheds. Forests in the lower elevations include western hemlock, amabilis fir, western redcedar, Douglas-fir, and some Sitka spruce. With increasing elevation, yellow cedar and mountain hemlock become dominant tree species. In the harsh climate of the highest elevations, vegetation consists of herbs, lichens, and scattered low alpine shrubs and trees.

Wildfire is a natural disturbance agent in these heavily forested, coastal watersheds. Historically these areas have been exposed to low frequency (300-600 years), high severity stand replacement fires (Green et al. 1998). Although the probability of large wildfires within these watersheds is considered generally low, the consequences associated with a large wildfire could be devastating to both the watersheds and the adjacent urban interface communities. Water quality, air quality, urban interface (residential property and recreation use), visual quality and ecosystem integrity are important values that must be considered in a wildfire risk assessment of the GVWD watersheds.

Fire management within the watersheds has historically focused on initial attack and all wildfires have been actively suppressed. However the most recent watershed management plan, which was developed based on extensive ecological studies and public input, has triggered a shift in policy direction. There is now a greater desire to allow more wildfires to burn without intervention, provided there are no significant impacts on valued resources. There is also a desire to improve the cost-effective and efficient allocation of all planning and management resources.

Accordingly, the specific wildfire risk management issues that need to be addressed or supported by the WRMS are:

1. To refine the wildfire management zones within the watershed boundaries.
2. To evaluate all wildfire management resource requirements, and develop cost-effective strategies for initial attack, suppression response, and mitigation activities.
3. To support an effective, multi-agency approach to wildfire preparedness planning.
4. To support ongoing learning and improvement of fire science and management (e.g., evaluation of fuel types and their effect on fire behaviour).

4 Methods

Our goal was to develop a spatial representation of all factors that influenced the probability and consequences of wildfire in the GVWD watersheds. The basic model structure was developed and refined through a series of workshops that involved GVWD staff and fire management specialists and researchers from the BC Fire Protection Branch and the Canadian Forest Service. The model is implemented in a GIS environment using ArcMap 8.2.1 (™ESRI) and ArcInfo 8.0.2 (™ESRI) using a raster grid at 50m by 50m cell resolution.

The final WRMS model structure is portrayed in Figure 2. The final spatial probability rating is derived from three major components: Ignition Probability, Fire Behaviour, and Suppression Response Capability. The final spatial consequence rating is derived from five major components that are significant within the GVWD watersheds: Water Quality, Air Quality, Urban Interface, Visual Quality and Ecosystem Integrity. Each main model component is in turn derived from several subcomponents as shown in the figure.

At the subcomponent level, individual ratings for each raster cell are developed on 0-10 scales that are based on existing biophysical databases and in some cases the application of sub-models (e.g., rate of fire spread calculated using the Canadian Fire Behavior Prediction System and spatial fuel inventory data). An overview of each subcomponent method, database source and/or sub-model is provided in Table 1.

At the component level, the rating for each raster cell is calculated as a weighted sum of all its subcomponents. Figure 3 provides an example of the rating scales and subcomponent weighting for the Suppression Response Capability component. All other components are derived in a similar manner. Similarly, at the overall rating level for probability or consequences, the rating for each raster cell is calculated as a weighted sum of all its components.

Figure 2: GVWD Wildfire Risk Management System (WRMS) Model Structure

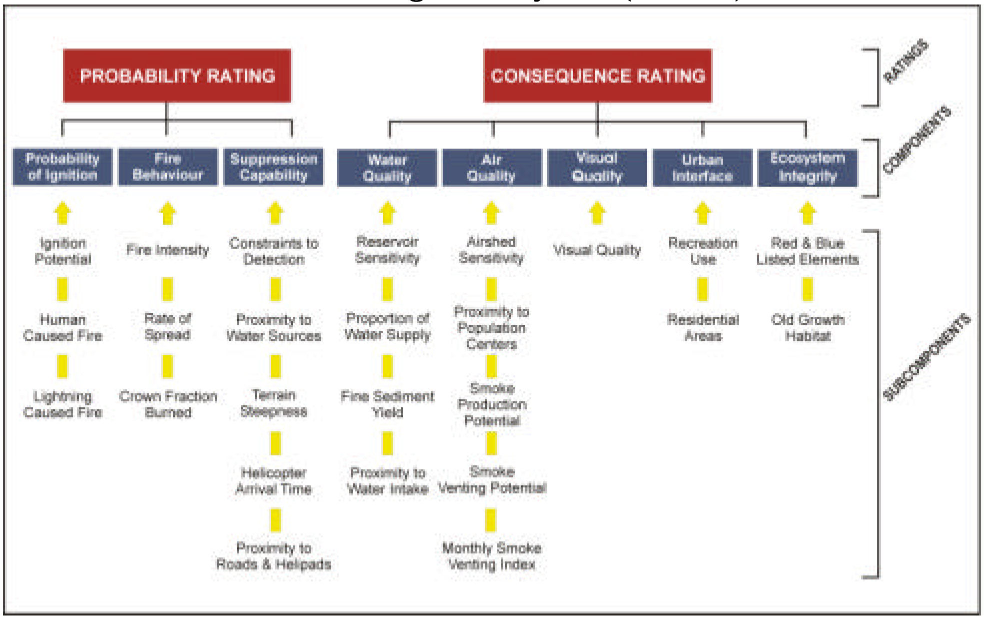


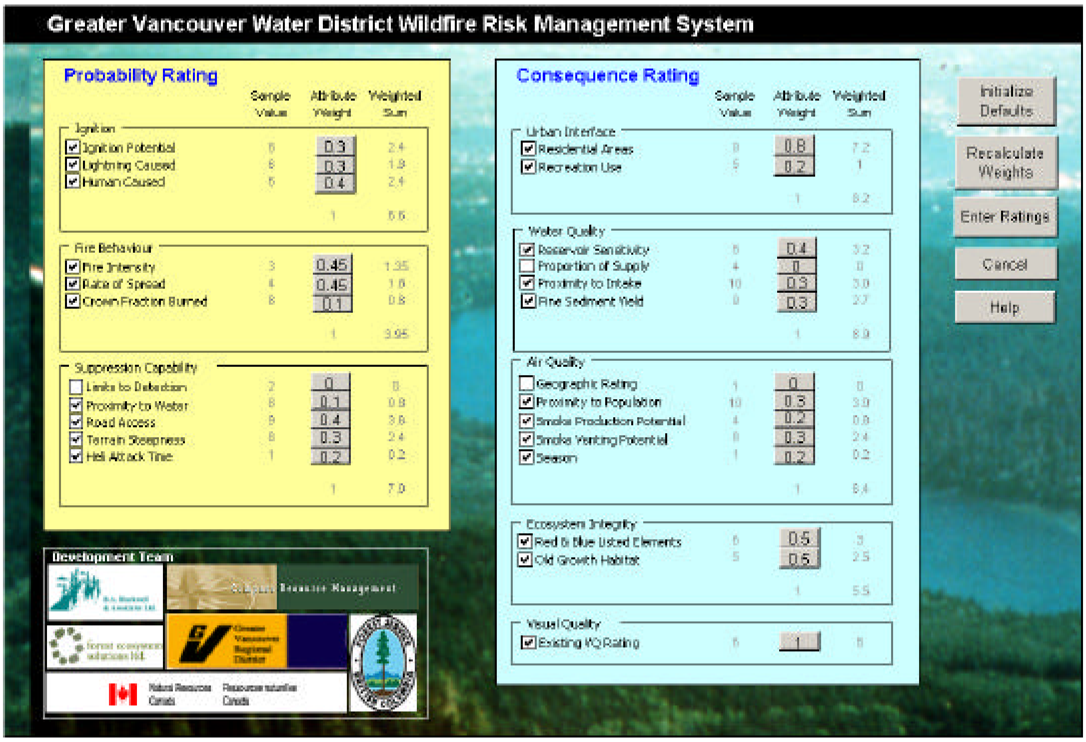
Figure 3: Component Level Rating Example: Suppression Response Capability

Sub-Component	Indicator / Units	Rating Scale		Weight
Constraints to Detection *Indicator of the ability to detect a fire* *(Note: reconnaissance at higher elevations is often constrained by cloud cover)*	Elevation metres	> 1000	10	10%
		500 - 1000	7	
		0 - 500	2	
Proximity to Water Sources *Indicator of the ability to access water quickly for fire fighting. Based on distance from streams and lakes.*	distance metres	>300	10	10%
		101-300	7	
		0-100	2	
Helicopter Arrival Time *Indicator of the time for initial attack, measured as concentric flight time from Seymour base PLUS fixed assumptions about contracted response time to the base.*	minutes	> 70	10	40%
		51 - 70	7	
		31 - 50	5	
		11 - 30	3	
		0 - 10	0	
Terrain Steepness *Indicator of the difficulty of control/contain on the landscape.*	Slope Class %	> 60	10	30%
		41 - 60	7	
		21 - 40	3	
		0 - 20	0	
Proximity to Roads and Helipads *Indicator of the ability to get suppression resources into an area. Based on a bush walking rate of 1 km / hour.*	minutes	> 120	10	10%
		61 - 120	7	
		31 - 60	5	
		16 - 30	3	
		0 -15	0	

From a functional perspective, the WRMS interface provides several unique features (Figure 4). Managers are able to turn on or off various subcomponents or components in the model, which allows the quick and efficient exploration of model interdependencies and the ability to analyze individual spatial ratings. There is also the ability to enter and test various combinations of weights at both the component and subcomponent level, which allows the exploration of specific fire management questions (e.g., what if we increase our suppression resources) and the systematic sensitivity testing of underlying professional judgements that went into the model structure (see section 4 below).

Finally, the model was developed with three user-input functions to support specific analytical requirements. First, users can select from a pre-set list of helicopter attack times that represent different levels of investment into contract resources. Second, for evaluating air quality management scenarios, users can specify a venting index by month of the year. And finally, a full range of potential fire behaviour scenarios can be evaluated by selecting from a range of potential fire weather conditions (i.e., 90th and 70th percentile fire weather conditions for spring, summer or fall).

Figure 4: GVWD Wildfire Risk Management Model Interface



5 Results

Figure 5 presents a compilation of mapping outputs from the initial implementation of the GVWD WRMS. The resultant mapping outputs parallel the structure of the model as described in the previous section, i.e.,

- Subcomponents maps are generated using 0-10 rating scales derived from existing GIS databases and/or sub-model outputs;
- Component maps are generated using user-defined weights on each subcomponent layer;
- Final probability and consequence rating maps are generated using user-defined weights on each component layer; and
- A final probability – consequence overlay map is generated by overlaying the final rating maps.

In overview, the area of highest consequence is located generally within the southern portions of each watershed. This is the area closest to the urban interface where the potential impacts on water quality, air quality, visual quality, property and recreation values are highest. In terms of wildfire probability, there is a relatively large area of moderate to high rating across all three watersheds. These probability ratings are driven largely by terrain steepness and its effect on fire behaviour and suppression response capability.

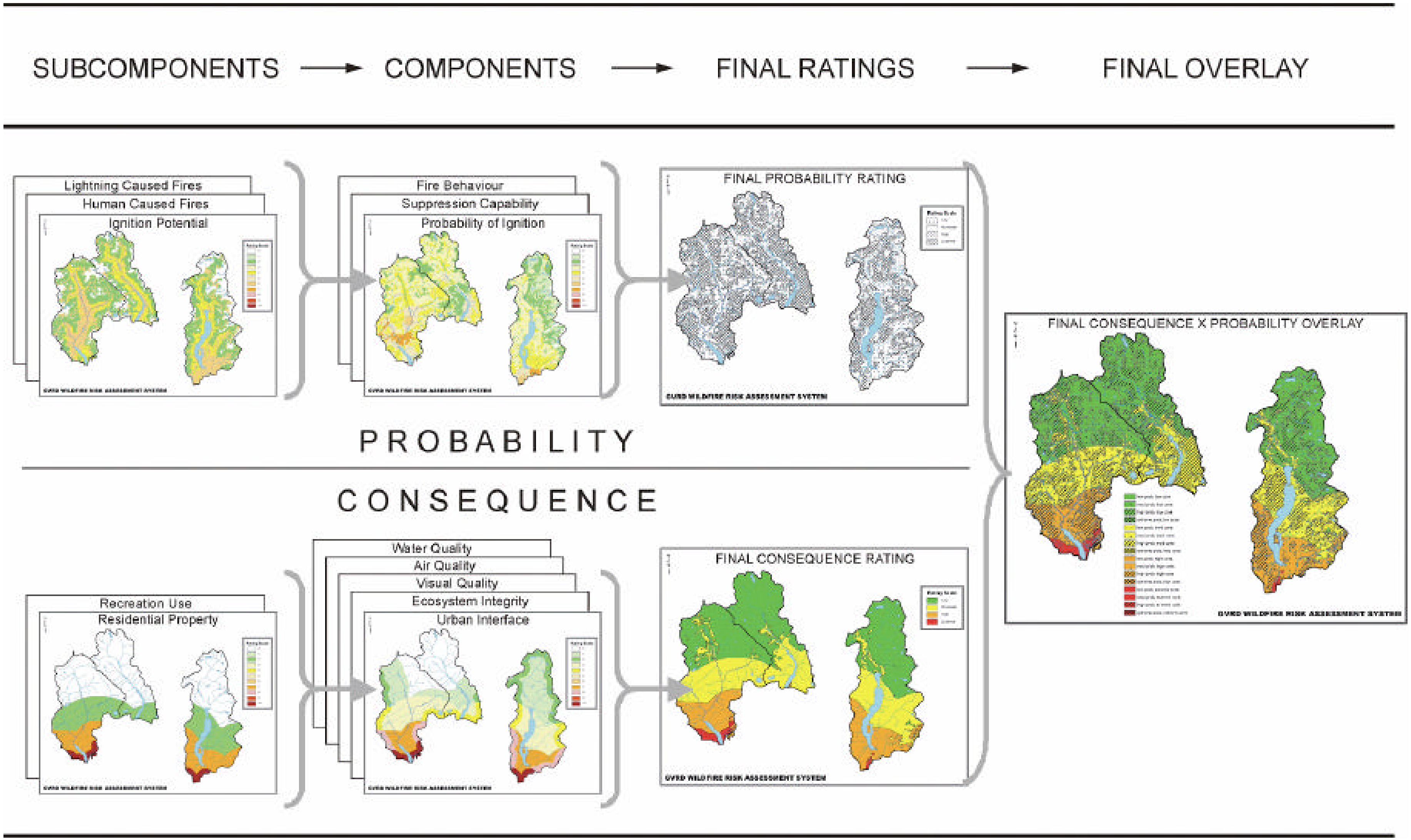
Of greatest interest to watershed managers is the interplay between probability and consequence spatially across the watersheds. Although this overall representation of wildfire risk generally confirms earlier intuition, important refinements to watershed zones and strategies became evident during the planning process (see discussion).

Table 1: Overview of Methods, Databases and Sub-Models for each Subcomponent of the GVWD Wildfire Risk Management System

	Component	Subcomponent	Overview Method	Database/Sub-Model
Probability Rating	Probability of Ignition	Ignition Potential	Calculation based on fuel type and fire weather indices	• Wildfire Ignition Probability Predictor[1]
		Lightning Caused Fire	Inverse distance weighted interpolation of the number of lightning fire ignition points (since 1950) within a 500m buffer	• ESRI Spatial Analyst[2] • GVWD/Ministry of Forests fire records
		Human Caused Fire	Inverse distance weighted interpolation of the number of human fire ignition points (since 1950) within a 500m buffer	• ESRI Spatial Analyst • GVWD/Ministry of Forests fire records
	Fire Behaviour	Fire Intensity	Calculation using fire weather, fuel type and topography	• Fire Behaviour Predictor 97[3]
		Rate of Spread	Calculation using fire weather, fuel type and topography	• Fire Behaviour Predictor 97[3]
		Crown Fraction Burned	Calculation using fire weather, fuel type and topography	• Fire Behaviour Predictor 97[3]
	Suppression Response Capability	Constraints to Detection	Average elevation above sea level of forest inventory polygon	• GVWD topographic database
		Proximity to Water Sources	Buffer distance from perennial streams and lakes	• GVWD spatial data
		Helicopter Arrival Time	Measured flight time (concentric) from helicopter base	• GVWD spatial data
		Terrain Steepness	Average slope of forest inventory polygon	• GVWD topographic database
		Proximity to Roads/Helipads	Buffer distance from roads, helipads, and alpine tundra/parkland	• GVWD spatial data
Consequence Rating	Water Quality	Reservoir Sensitivity Rating	Rating of reservoir sensitivity to adverse fire effects	• GVWD Water Quality data
		Proportion of Water Supply	Rating of each watershed's contribution to regional water supply	• GVWD's Water Distribution Records
		Potential Fine Sediment Yield	Measure of annual fine sediment yield (Mg/ha/year) by subdrainage	• GVWD fine sediment yield database
		Proximity to Water Intake	Buffer distance from water intake	• GVWD spatial data
	Air Quality	Airshed Sensitivity Rating	Location rating of potential impact on the regional airshed	• GVWD's Ambient Air Quality Data
		Proximity to Population	Buffer distance from urban interface	• GVWD spatial data
		Smoke Production Potential	Smoke production as a function of seral stage (i.e., biomass)	• GVWD Ecological Inventory
		Smoke Venting Potential	Average elevation above valley floor of forest inventory polygon	• GVWD topographic database
		Smoke Venting Index	Monthly smoke dispersion rating based on long-term averages	• GVWD's Ambient Air Quality Data
	Visual Quality	Visual Quality	Areas delineated as visually sensitive from local vantage points	• GVWD existing visual quality rating
	Urban Interface	Recreation Use	Buffer distance from recreation areas	• GVWD spatial data
		Residential Areas	Buffer distance from urban interface	• GVWD spatial data
	Ecosystem Integrity	Red & Blue Listed Elements	Areas containing red and/or blue listed species or ecosystems	• GVWD Ecological Inventory
		Old Growth Habitat	Old growth habitat based on biogeoclimatic ecosystem classification	• GVWD Ecological Inventory

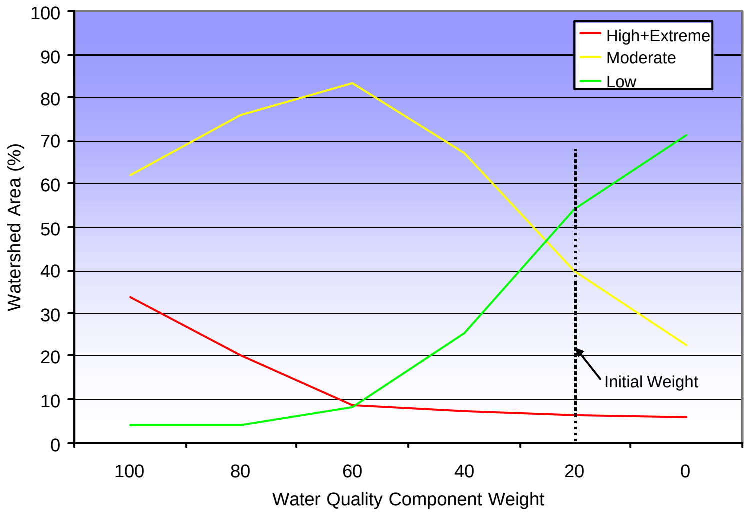
[1] FORTester v1.0 (Canadian Forest Service 2002)
[2] ESRI Spatial Analyst 8.1.2 (™ ESRI)
[3] Fire Behaviour Predictor 97 (™ Remsoft)

Figure 5: Summary Mapping Outputs from the GVWD Wildfire Risk Management System



We undertook a full range of sensitivity analyses on all weights applied within the model as a means of validating the underlying professional judgements and identifying areas where further analysis or data collection might be required. In several cases, we discovered that the overall ratings are highly sensitive to the selection of component and subcomponent weights. For example, the overall consequence rating is very sensitive to the weight applied to the water quality component (Figure 6). As we increase from the 20% weight originally applied, we see that the total watershed area rated as moderate begins to increase significantly. Since the moderate consequence rating will likely be used as a key threshold for determining wildfire suppression zones (when coupled with moderate or greater probability ratings) it is clear that great scrutiny is required in the final determination of this particular weight.

Figure 6: Example of Sensitivity Test on Water Quality Component Weight



6 Discussion

The GVWD WRMS is being used to aid management decisions in several ways. Based on the probability and consequence outputs, the fire protection zones of the watersheds are being refined. All areas with a moderate to extreme consequence rating will be designated within an "active suppression" zone. In contrast, many areas that display moderate to high probability ratings overlap areas of low consequence, and may be candidates for inclusion into an expanded "wildfire prescription" zone. In these areas, under appropriate conditions fires will be allowed to burn with limited or no fire suppression action. Expanding this zone in a scientifically and socially defensible manner has multiple benefits to the GVWD. From an ecological perspective, wildfire will be allowed to play its natural role in ecosystem succession across a larger part of the landscape without undo negative effects. From an economic perspective, suppression response cost savings will accrue over the long term.

The system is being applied to support and evaluate several resource allocation and fire management decisions. For instance, sensitivity analysis identified suppression response capability as one of the key determinants of the overall wildfire probability rating. An important subcomponent of this rating that managers have direct influence over includes helicopter response time. The system provides watershed managers with a formal means of evaluating annual investments in helicopter contracts for use in initial attack, which are based on guaranteed response times. Different investment levels can now be evaluated in terms of their end effect spatially on suppression response capability and, ultimately, wildfire probability.

The WRMS is also providing decision support to an extensive road deactivation program. At issue is a perceived trade-off between potential water quality and ecological gains from road deactivation and potential losses with respect to fire suppression response capability. Using the system, watershed managers are able to show that the use of replacement helicopter landing sites significantly mitigates the spatial impact on suppression response capability due to lost road access. Further, it is now evident that the potential consequences of wildfire are low in some areas where road access is being eliminated.

Unique to this application is the development of GIS themes that quantify wildfire risks to water and air quality. Spatial ratings for these significant values were developed using existing inventories previously established by the GVWD (e.g., terrain, surface materials, etc.). This type of application should be of interest to environmental managers worldwide who are wrestling with the potential impacts of wildfire on these important resource values.

In summary, we believe the GVWD Wildfire Risk Management System provides an increased capacity to make sound and defensible wildfire management decisions, particularly in areas of wildland-urban interface, where planning requirements are the most challenging. It offers several improvements over earlier wildfire threat analysis applications. The ability to spatially analyze and overlay probability and consequence ratings can support both strategic and tactical decision-making regarding suppression resources, suppression priority (multiple fire strike situation), fire hazard mitigation plans in interface areas (e.g., fuel treatments) and road deactivation. The dynamic user interface developed for this application supports both multi-run scenario planning, and sub-component and component sensitivity analysis, which provide an improved understanding of the relationship between the key model inputs that result in the final spatial probability and consequence ratings.

7 Future Directions

The development of the GVWD wildfire risk management system benefited from a collaborative multi-agency approach that supported learning at all levels of government. Opportunities to refine or apply the model more widely have been identified as a result, including:

- Exploit the modular structure and sensitivity analysis capabilities of WRMS to help evaluate alternative fire behaviour models for coastal forests. (Past experience in applying the national Fire Behavior Prediction System, which is based largely on research in boreal forests, has been unsatisfactory.)
- Apply the system to a regional or provincial scale assessment of resource allocation. For example, the optimal placement of air tankers, helicopters, ground crews and other resources may now be possible in the context of a fully spatial assessment of wildfire probability and consequence.
- Incorporate real time (daily) fire weather inputs. This would provide managers with a daily risk profile allowing for more advanced preparedness, detection, and suppression resource allocation. This capability would augment the current use of fire danger ratings to guide closures and burning restrictions associated with both industrial and recreational activities.
- Finally, utilize the interactive capabilities of the wildfire risk management system for activities such as: i) evaluating potential changes in fire behaviour due to fuel mitigation treatments, ii) simulating landscape-level wildfire risk changes related climatic events like El Nino.

6 Acknowledgements

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