

# THE DEVELOPMENT OF A REAL-TIME FOREST FIRE MONITORING AND MANAGEMENT SYSTEM

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## ABSTRACT:

Understanding wildfire behavior is critical for maintaining the safety of fire-fighting crews. Understanding wildfires can also result in significant fiscal savings through improved planning and resource allocating. Currently, wildfire monitoring techniques are not accurate or efficient enough to optimally monitor this natural disaster. To help remedy this, the mobile multi-sensor research group of the University of Calgary is designing an innovative, real-time, internet based wildfire monitoring and modeling system. This system has the potential to impact the process of predicting wildfire propagation, resulting in reduced damage to the environment, enhanced safety and appreciable financial savings. This paper will discuss the design and functionality of the system which integrates four components into a data acquisition/processing system and accompanying GIS based web browser. The four components are: a thermal infrared imaging sensor, wireless communications, an inertial navigation system and a wildfire prediction model based on algorithms used by *Prometheus* (designed by the Alberta Government in 2003). The final system is able to locate hotspots of fires within five meters, predict where a fire will most likely propagate with time, detect smoldering fires underneath surface vegetation, and detect fires through smoke, haze and darkness with the highest possible accuracy and efficiency of any commercial wildfire model available today.

## INTRODUCTION

Wildfire management agencies have a need for a system that can estimate the propagation and intensity of spreading wildfires. Understanding the behavioral characteristics of wildfires and how they spread through various vegetation types and terrains are a major concern for environmental agencies, government officials and the general public. If unmonitored or poorly modeled, manageable fires can grow out of control, potentially devastate entire ecosystems and alter local weather patterns (Johnson, 2001). Wildfires can also destroy thousands of acres worth of prime revenue growing lumber resources that are essential to the economies of some countries (Johnson, 2001). Furthermore, wildfires can rage near cities and towns and consume the homes and treasures of the citizens (O'Brian, 2003).

Currently, Canada lacks a standard fire modeling software program. Each fire agency in each Canadian province, and even districts within provinces, use different programs to predict wildfire behavior and how to orchestrate suppression attacks. This can create difficulty when trying to fight fires that cross provincial borders and creates a gap in communication when trying to learn from fires that occurred in other provinces. This research paper explores the design and implementation of a robust, near real time, internet based, wildfire monitoring and modeling system that meets the standards of all the fire districts within Alberta, Canada. This system could be used province-wide to help different agencies and districts communicate more efficiently with each other and could also allow the public to view current provincial fire situations from their personal computers.

## 2.0 SYSTEM ARCHITECTURE DESIGN

This wildfire monitoring and modeling system (WMMS) can be broken down into three main sub-systems. These sub-systems can be identified as the data Acquisition System, Control Center System and Response System. The functionalities of each sub-system are shown in Figure 1.

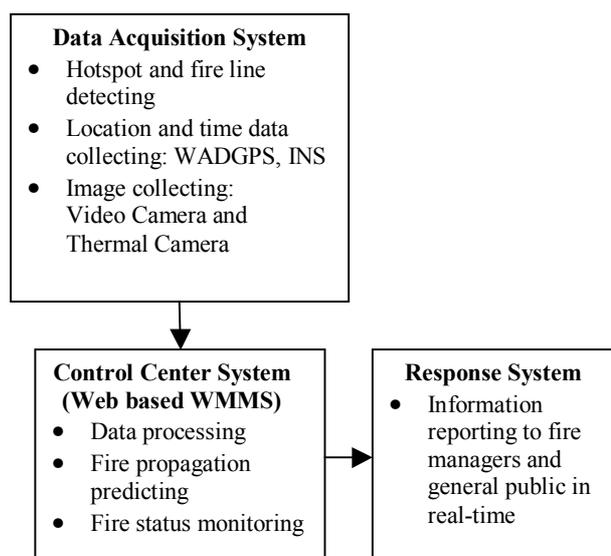


Figure 1: Logical Model Design for the Mobile Mapping System

The Data Acquisition System integrates an Inertial Measurements Unit (IMU) receiver of the Wide Area Differential GPS (WADGPS), and a thermal camera. The WADGPS and IMU data are used to georeference the thermal images. The use of a thermal camera, which senses heat emitted in the form of infrared radiation, enables early detection and location of forest fires that could not be sensed by the human eye. The camera will also provide accurate images of the fire in reduced visibility due to haze, smoke or darkness. The real-time data acquisition system, designed to upload this data in real-time to the internet site, will sufficiently aid fire managers to effectively determine where to allocate resources and to quickly detect where hidden, smoldering fires are located. The accuracy obtained by this system is two to five meters and facilitates the acquisition of accurate reports on position, size and direction of the fire. For further information about this Data Acquisition System, see Wright and El-Sheimy, 2003.

The Control Center System houses the webpage. It has many responsibilities. The first of three main responsibilities is processing all information that is obtained by the Data Acquisition System. The second responsibility is performing the fire behavioral modeling functions. The last major responsibility is displaying the fire status monitoring information. More detailed information about these processes and functions will be given in the next section.

The last sub-system, the Response System, enables the results of the Control Center System to be displayed to the user. This system allows the system user to view the results obtained from the Control Center System.

All three sub-systems are linked through the Web based WMMS which organizes all functions of the Control Center System for use by the operator. A flow chart outlining the structure of the WMMS can be seen in Figure 2.

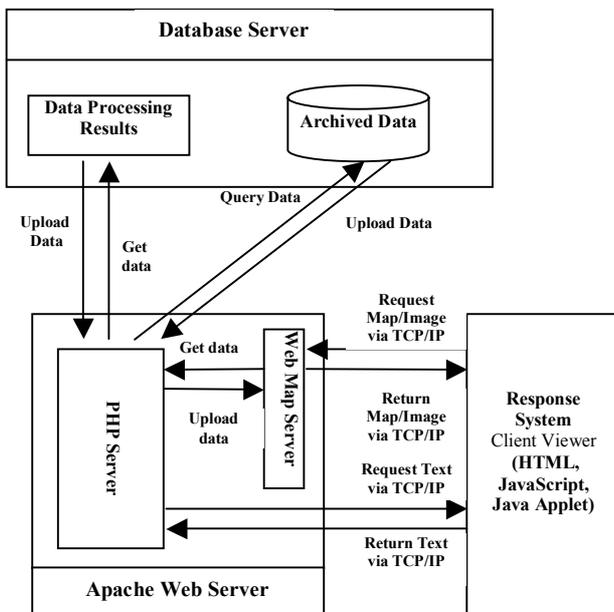


Figure 2: Control Center System: Client/Server Communication

The Database Server obtains the data from the Data Acquisition System and all data processed in the Control Center System can

be viewed by the client through the Response System. The WMMS has five main components, as shown in Figure 2 that allow the three main sub-systems to communicate seamlessly. These components are listed below:

- Apache Web Server
- Web MapServer
- Hypertext Preprocessor Server (PHP)
- Database Server
- Transmission Control Protocol and Internet Protocol (TCP/IP)

## 2.1 Apache Web Server

The Apache Web Server is a computer platform that hosts the Web MapServer and the PHP server. The role of the Apache Server is to connect the client's personal computer to the stored wildfire data on the server via the MapServer and PHP servers.

## 2.2 Web MapServer

The Web MapServer is a public domain development environment from the University of Minnesota that is used for building spatially enabled Internet applications. This software works on any Linux, UNIX and Windows platform and has many GIS features which make it the most attractive option to use for the WMMS Webpage. MapServer also allows the clients to browse GIS data and to create geographic maps (Lime, 2003). It is responsible for all spatial data operations and publications in this system.

MapServer works by configuring each application using a text file called a "mapfile". Anything associated with a particular application is defined in the mapfile as an object. In a single file there can be many objects used to build an entire interface, or just a single object used to build a simple legend or scale bar. To add to the functionality of the system, one can use and modify these objects through an HTML form. The program results are then run through a series of templates depending on the application (i.e.: data browse or feature queries) and the results are displayed to the user.

## 2.3 PHP Server

PHP is a general purpose scripting language that is particularly useful in Web development and can be easily embedded into HTML. The PHP server facilitates the transfer of image and textual data between the server and the client. It performs the searching techniques of the spatial and textual data. The user can thus access the newly published data processed by the control center through the Apache Web Server. However, since this web based fire modeling system is capable of publishing information in real-time, the data server must be accessed frequently. If textual, real-time data is transmitted, the PHP server can directly transfer the data from the database to the client via the TCP/IP protocol, which is explained later. If the data is a general image such as fire photos, the PHP server can automatically retrieve it from the database and pass to the client.

## 2.4 Database Server

Multiple types of data sets are used in this application such as text, spread sheets, general and georeferenced images, GIS data and GPS coordinates. This application uses the Standard Query Language (SQL) to organize the database. The SQL standard

makes it easy to separate the logical layer and data layer thus increasing its flexibility. This database was also chosen because it can easily be transferred to a more powerful database when extra functionality is needed.

## 2.5 TCP/IP Protocol

The TCP/IP protocol is the communication protocol that is used in the system to transmit data between the server computer and any number of client computers over an Internet connection. The TCP part of the protocol establishes the connection between computers and exchanges streams of data. The IP part of the protocol addresses the packages of data and drops them into the system so that they can be delivered to the appropriate computer.

the capability to use this system like a public user but also have the added ability to control, update and monitor the system. When an authorized user is logged onto the system, the program will check the user's access rights and make available the appropriate toolbars. For example, when a manager is logged onto the system, the Manager's Toolbox will be available in addition to the tools available to the public user. The tools reserved for managers are under the heading labeled Manager's Toolbox on the main page of the website.

A sample screen capture of the WMMS is shown in Figure 3. This screen capture depicts the setup for a user with managerial capabilities. This sample can be accessed from the following Internet site:

- [http://cfei.geomatics.ucalgary.ca/firepub\\_com/firepub.php](http://cfei.geomatics.ucalgary.ca/firepub_com/firepub.php)

## 3.0 INTERFACE FOR INTERNET USER

### 3.1 User Access and Main Page Layout

The general public and forest fire managers are the two potential users of the WMMS. The forest fire managers have

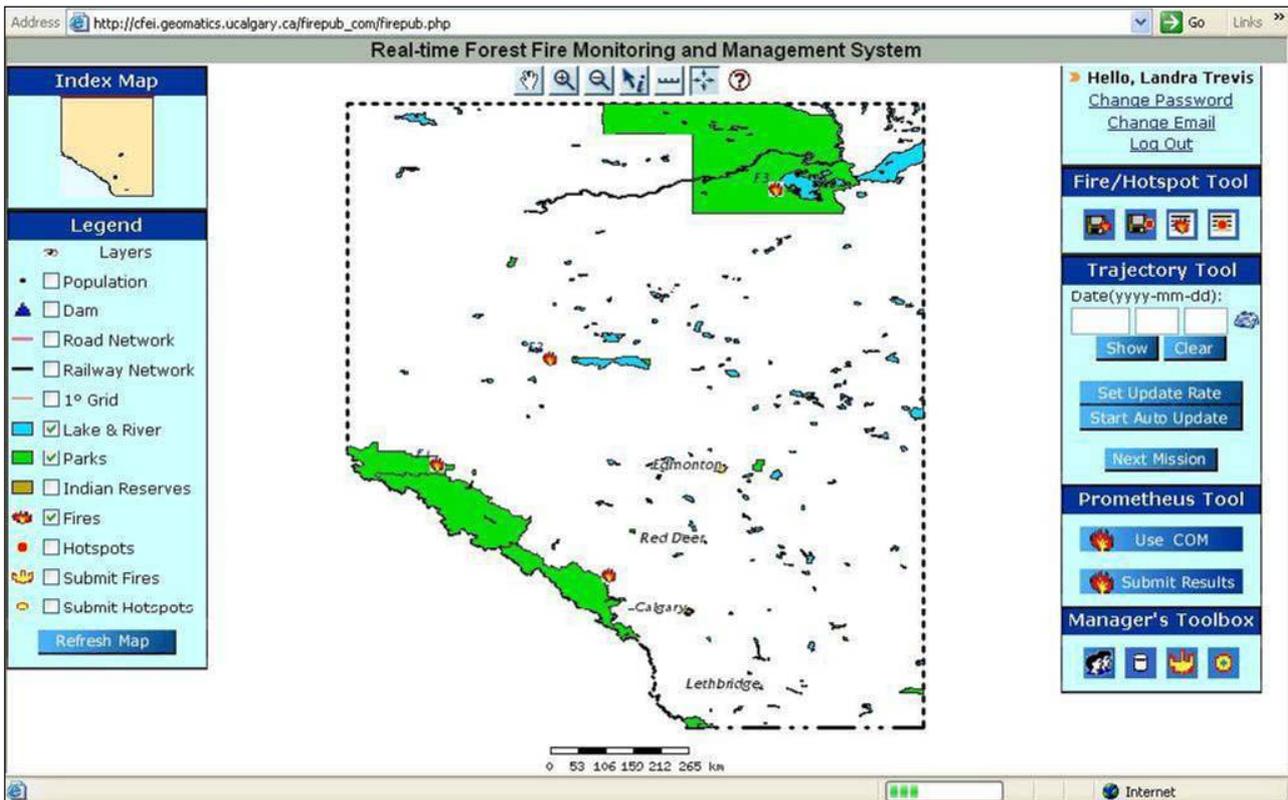


Figure 3: Screen Shot of the “Real-time Fire and Hotspot Publishing System”

The left hand side of the screen shows the reference map and legend which contain the possible layers that can be added to the display. The center of the screen shows the province of Alberta which can be panned or zoomed into in order to show the user a more detailed map. The right hand side of the screen displays the possible tools that can be used to assist in modeling wildfires. A list of all possible tools includes the Fire/Hotspot Report Tool, Trajectory Tool, Prometheus Tool and Manager's Toolbox. In the example shown in Figure 3, four fires are depicted on the map of Alberta.

## 3.2 Tools

**3.2.1 Fire/Hotspot Reporting Tool:** The reporting tool enables the user to view the Fire Summary Reports for the different districts in the province. After clicking this button, the number of active fires, cause of fire and fire status is shown for the different fire management districts throughout the province.

This information is displayed in the report pages which can be viewed based on year or by management district. Any fire that is currently burning can be selected from within the fire reports and a fire status page will be displayed containing the real-time information relevant to that fire.

The fire status page shows the real-time location of the center of a fire or hotspot. In addition, the location of the fires can be viewed on a reference map of Alberta, shown on the same screen. Other information such as fire status, fire management district and most up to date aerial photos are also shown on this screen.

**3.2.2 Trajectory Tool:** The second tool that is currently available on the WMMS is the Trajectory Tool. This tool is capable of reporting the real-time trajectories of a spotter aircraft's flight path and displaying on the webpage the locations of any spotted fires or hotspots along that flight path. Points along the plane's trajectory are collected using the WADGPS receiver that is mounted on the spotter aircraft and transferred to the system in the same manner used by the Fire/Hotspot Reporting Tool. The trajectories are then displayed on the base map. Fires and hotspots are also recorded during this process and any incoming fire coordinates are uploaded to the website and marked on the base map with a fire icon. If the fire has been extinguished but is still smoldering, the locations of hotspots within the smoldering area will also be automatically uploaded to the web site as the spotter aircraft passes over.

**3.2.3 Prometheus Tool:** The third tool that is available on the WMMS is the Prometheus Tool. This tool allows fire managers to determine how a current or hypothetical fire will propagate across the terrain. Prometheus is a wildfire modeling program which is the result of a national interagency project endorsed and administered by the Canadian Interagency Forest Fire Center (Prometheus, 2004). Alberta Sustainable Resource Development is the lead agency for this project and has permitted the Geomatics department of the University of Calgary to use Prometheus as a tool in its wildfire prediction system. Prometheus is currently able to model wildfire behavior based on topography, the Canadian standard fuel types and the Canadian standard weather index system from the Canadian Forest Fire Danger Rating System (CFFDRS) (Prometheus, 2004).

Prometheus was chosen for this system since it possesses three key advantages that no other available model has. The first advantage is that Prometheus provides an intuitive pictorial view of the spread of fire though the landscape. This enables users to quickly view how the fire is spreading instead of having to interpret textual values of rate of spread and fire intensity. The second advantage is that Prometheus uses the two working sub-systems of the CFFDRS in its prediction model. This helps standardize the model since the CFFDRS is a national system for rating the risk of forest fires in Canada. Finally, Prometheus can be integrated into the WMMS using its Microsoft COM (Component Object Model) interface. The COM interface allows easier integration of Prometheus with other Microsoft applications, permits additions to be made to the model and allows the model to work seamlessly through a web browser. The CFFDRS and Prometheus COM will be discussed in more detail in the following sections.

**CFFDRS:** The CFFDRS is the Canadian standard for predicting wildfires, which was initially developed in 1968 (Hirsch, 1996). Since then, two sub-systems have been developed to handle

fuel types, topography and weather. A third sub-system is being developed to include risk of lightning and human caused fires but is not operational yet. Currently, only the Fire Weather Index (FWI) and Fire Behavior Prediction (FBP) Systems are being used by the Prometheus COM.

The FWI system is composed of six components that model fire behavior based on daily fuel moisture and wind effects. The first three components deal with the moisture content of the different layers of fuels on the forest floor. The layers are defined as scattered litter and other fine fuels, loosely compacted organic layers at moderate depth and deep, compacted layers. The three remaining components of the FWI system include predicted rate of fire spread, fuel available for combustion and predicted head fire intensity. These six components are calculated using the equations from (Van Wagner, 1985) to produce qualitative FWI grid maps.

The FBP system uses fuel types and topography to calculate quantitative predictions for select characteristics of fire behavior (Hirsh, 1996). To use this model, input from the following five sources is required:

1. Fuel type
  - o Determined using a list of sixteen general fuel types that are some of the major fuel types in Canada
2. Weather
  - o Encapsulated using output from the FWI system, plus hourly data on wind speed and direction
3. Topography
  - o Defined by percent slope and aspect
4. Foliar moisture content
  - o Determined using elevation, latitude, longitude and date
5. Type and duration of prediction
  - o Determined using the elapsed time since the fire began and whether it began by a point or line ignition.

Once these parameters are entered into the FBP system, the system produces the primary outputs of rate of fire spread, fuel consumption, head fire intensity and fire type. From these parameters two dimensional views can be produced to illustrate the fire spreading as a function of time. Once the results of both the FWI and FBP systems are obtained they can be combined to create a complete view of predicted fire propagation.

*Prometheus' Component Object Model:* To create the Prometheus COM, the Prometheus application has been programmed into various components where each component is capable of performing a certain task. Components are reusable pieces of software in binary form that can be plugged into other components from other vendors with relatively little effort. Software components must therefore adhere to a binary external standard. A COM builds a foundation that enables the creation and use of reusable components by making them "component objects". An object is a piece of software that contains the functions that represent what the object can do and state associated information for those functions. Objects are made up of a data structure and some functions to manipulate that structure. These mechanisms are independent of the other applications that use object services and of the programming languages used to create other objects. The COM also provides methods for code reusability without the problems of traditional language style implementation inheritance. To use the COM the client must tell an object when they are using it and when

they are finished and the objects must delete themselves when they are no longer needed. COM uses operating systems and application permissions to determine if a particular client can load the object.

To use the Prometheus COM, one must first check the consistency between the user data and the Prometheus data. If the data is not consistent a conversion must be completed. This would be performed in the user's application. The converted data can then be used as input into the Prometheus COM. The Prometheus COM Model is built using five separate low-level COMs. Since low level COMs are very difficult to use directly, a higher level Prometheus COM has been built by the Alberta Sustainable Resource Department to access the five separate low level COMs. The Prometheus COM architecture is shown in Figure 4:

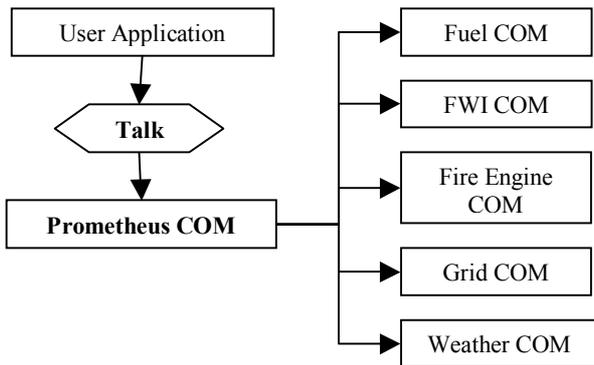


Figure 4: Prometheus COM Architecture

With this set up, all the functions available in the low level COMs can be called individually and used by this system. To activate the COM on the WMMS Webpage one would click the "Use COM" button seen in Figure 3. Next, the user must go through a sequence of five screens to enter the necessary parameters for all of the low level COMs. On the web page these screens are designed to look like a file folder with five separate tabs. The defining name of each screen is written on the tab of the file folder. This was done so that the user can quickly flip back and forth between screens to enter in all the necessary information. The first of the five screens is shown in Figure 5.

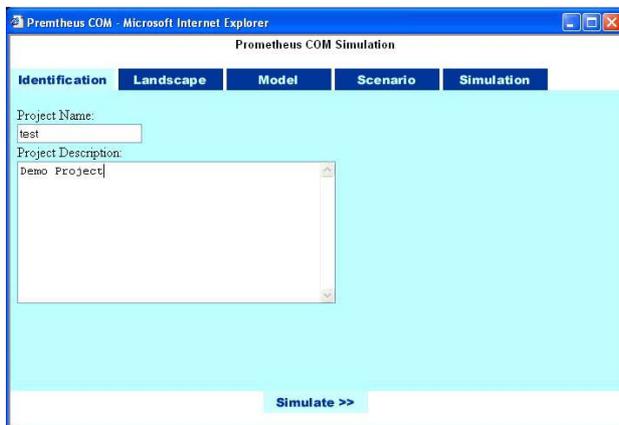


Figure 5: Screen Shot of COM Interface

The information requested for each screen of the COM interface is illustrated in the following flow chart.

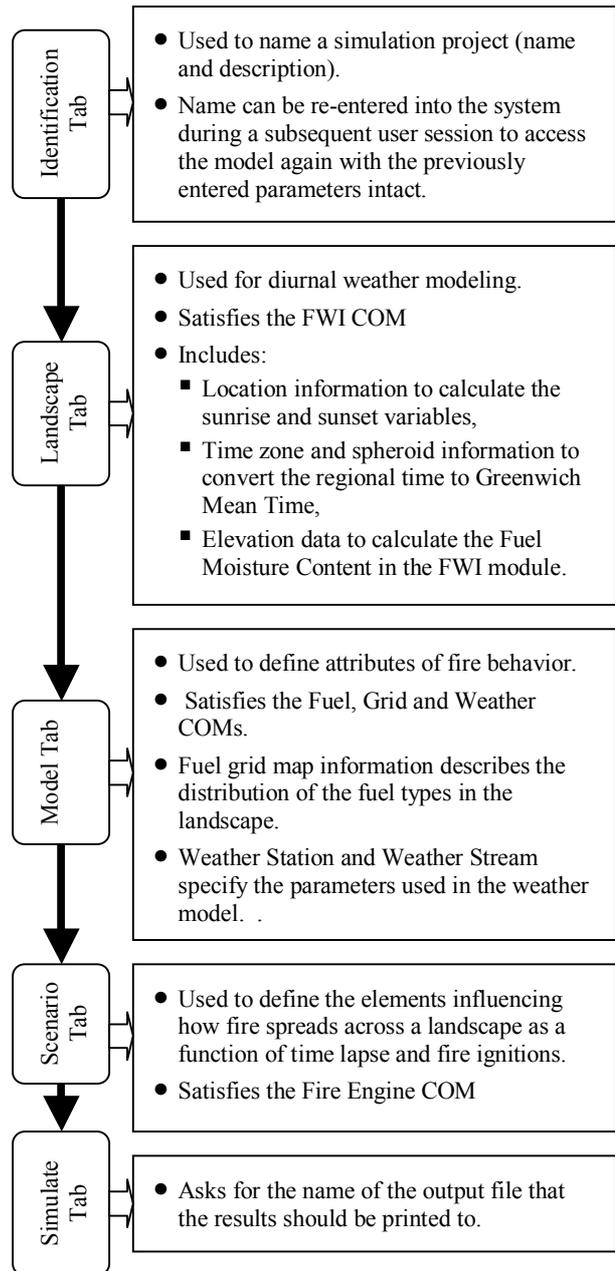


Figure 6: Flow Chart Describing Steps of COM Interface

Pressing the "Simulate" button on the Simulate page allows the COM to compute a fire perimeter on the map of Alberta that is displayed on the main page of the website.

All the variables used by the Prometheus model can be entered in real-time to the system. This allows users to simulate fire propagation scenarios at any time and location. After all the necessary information is entered (projection, fuel grid, weather condition, etc.), the website will link to the necessary components of the Prometheus COM via the PHP Server and MapServer to display an image, on the main map, of the predicted growth perimeter for the fire.

It must be noted that Prometheus's COM is still under development. Version 2.0.1 is currently being used in this application. Some functions and capabilities are currently unavailable in the COM. One such function is that fire lines that define fire barriers are not available. Ideally, ignitions

should be specified as points, lines or polygons; however the current version of the COM limits fire line specifications to points only.

**3.2.4 Manager's Toolbox:** Using the tools in the Manager's Toolbox, the user can update user accounts, update database data, update user submitted fires and hotspots.

*Update User Accounts:* This tool allows a manager to see information about the users who have accessed the site. Information about the users includes:

- their user status,
- name and
- Email.

Only an existing manager can upgrade a general user to manager status. Similarly, only a managerial user can demote a user to general status or delete a user from the system.

*Database Management Tool:* This tool is still under development. Once finished, this tool will allow users, with managerial status, to access or update the fire information database. Data in the fire information database will include fire weather information, provincial fuel type information and fire location information.

*User Submit Fires and Hotspots Tool:* This application provides some tools for managing and monitoring fire and hotspot situations. Using these tools, managers can view the new fire information that has been submitted by other fire managers and edit or update information about fires as it becomes available.

Wildfires and hotspots need quick response times. This system provides the manager with the ability to work on any computer at any time, and from any location. To ensure quick fire response times, the system will send an email to the fire managers the instant a user submits new fire or hotspot information to the system. In addition, having the detection software, reporting functions, fire simulation model and decision-making support tools available on the same website provides a seamless fire report and management tool that will help mitigate wildfire disasters.

## 4.0 CONCLUSION AND FUTURE RESEARCH

This research has the potential to greatly benefit fire managers in predicting and managing fires. The WMMS could help minimize suppression efforts by directing the supplies to the areas of active heat emissions via real-time thermal images and modeling techniques. As a result, this system could not only save time and money but also improve the safety of the ground based fire-fighters. This system will also be updated and improved as future versions of the Prometheus COM are released. Additional functions will also be created to supplement the Prometheus COM. Proposed functions will be designed to incorporate additional variables that affect fire behavior. Two additions are currently being researched. One addition will involve the incorporation a resource location/allocation function. The second addition is to include a danger vs. economic loss rating variables into the Prometheus model.

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