

Development of a commodity-based fire emissions tracking system

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ABSTRACT

Because of Regional Haze Rule requirements and Smoke Management Programs' (SMP) reliance on near-real time fire emissions data, many states and Tribes in the Western U.S. need a fire activity and emissions tracking system. This paper introduces the Western Regional Air Partnership's (WRAP) Fire Emissions Tracking System (FETS), a web-based fire data management system developed to fulfill the needs of states, Tribes, and the WRAP as they utilize fire emissions data for a variety of air quality planning purposes. The FETS provides routine fire data acquisition (planned and unplanned fire events), stable data storage, and real-time regional coordination among SMPs. The FETS was developed using commodity products, existing hosting services and hardware, and open source development tools. The fire science and other technical services of the FETS were developed modularly using Python and GRASS GIS, taking advantage of available tools such as CONSUME 3.0 for emissions calculations and the online WIMS dataset for fuel moisture. Users access and use the FETS via a standard Internet connection. This paper describes the features of the FETS, including: multiple methods of data acquisition (designed to minimize redundant efforts by SMP personnel), on-screen Quality Control (QC) tools, a mapping tool, and reporting tools including custom queries to download summaries of acres burned, emissions, Natural vs. Anthropogenic burns, and the application of emission reduction techniques (ERTs). The FETS serves the immediate needs of the public and SMP personnel, data analysts from agencies, and Air Quality Planners. Further development of the FETS is planned for 2008 and beyond.

INTRODUCTION

The Regional Haze Rule requires a statewide emissions tracking system (spatial and temporal) of emissions from fire (51.309.d.6.ii)¹. In addition, the WRAP's Enhanced Smoke Management Program Policy² identifies several program elements for addressing visibility impacts due to fire. For all states and Tribes in the WRAP to effectively meet the requirements of the Rule and goals of the ESMP policy, it is crucial to have a reliable, near real-time method to track fire activity and emissions.

The Fire Emissions Tracking System (FETS—www.wrapfets.org) has been developed by Air Sciences Inc. and Wingate Design with support from the Cooperative Institute for Research in the Atmosphere (CIRA), WRAP, and the WRAP's Fire Emissions Joint Forum (FEJF). It is a fully operational fire activity tracking and emissions estimating tool that is part of the WRAP's Technical Support System (TSS—vista.cira.colostate.edu/tss). The FETS is one of the many technical projects the WRAP has developed to effectively compile a regionally consistent and comparable body of technical data. It is part of the transparent and open

network of interrelated data support web systems and the WRAP's technical decision support system. The FETS reflects the ten years of fire-related technical and policy work done by the FEJF. It supports several user groups including the public, fire activity data providers, Smoke Management Programs, state and tribal air quality planning agencies, and the WRAP's TSS Team and Regional Modeling Center (RMC).

The FETS was developed to meet the WRAP's minimum needs and is intended to be flexible enough to undergo modifications to accommodate evolving needs of data providers and users, and expansions to augment the FETS with additional features. The intent was not to create a "brilliant, new design" but to draw on commodity products and existing systems as appropriate. The primary emphases during the development of the system were:

- Efficient data acquisition;
- Stable data storage and availability;
- Real-time data import and export capabilities;
- An interface to allow for enhanced coordination of planned and unplanned events among regional smoke managers;
- A system that accommodates cost-effective development of fire emission inventories.

BODY

FETS Architecture

A distinct server hosts each of the key pieces of the FETS: web interface, database, and data processing tools (Technical Node). Communication between the three components is secure and virtually instantaneous. The web interface is hosted at an inexpensive commercially provided server. The database (SQL) server is hosted at the Cooperative Institute for Research of the Atmosphere (CIRA), host of the WRAP TSS. This hosting arrangement is deliberate in order to streamline the integration of the FETS and the TSS and to take advantage of CIRA's existing infrastructure. The Technical Node is a Linux-based system hosted at Air Sciences that handles GIS processing (see below), emissions calculations using CONSUME 3.0, and quality control of batch data acquired via automated routines.

The FETS system configuration is depicted in Figure 1. The diagram identifies the three distinct servers that make up the FETS, as well as interaction with users and various commodity tools both internal to the system and drawn from the Internet.

Data are stored in the FETS in a way that reflects the structure of existing prescribed fire databases. A Project table stores information about a burn such as the name, location, and type of burn—e.g., information relating to a pre-season permit for a prescription. A Burn Day table is linked to the Project table and stores specific information about each day of a burn including date, fuel type, fuel moisture, and area burned—e.g., information related to individual requests to burn on a particular prescription.

There are three levels of user permissions in the FETS: the general public, TSS registered users, and FETS data providers. Features of the FETS available to each type of user are outlined in Table 1. Data Providers must be approved by the WRAP before access is granted.

Figure 1. Diagram of the FETS system. Grayed text depicts functions not yet implemented.

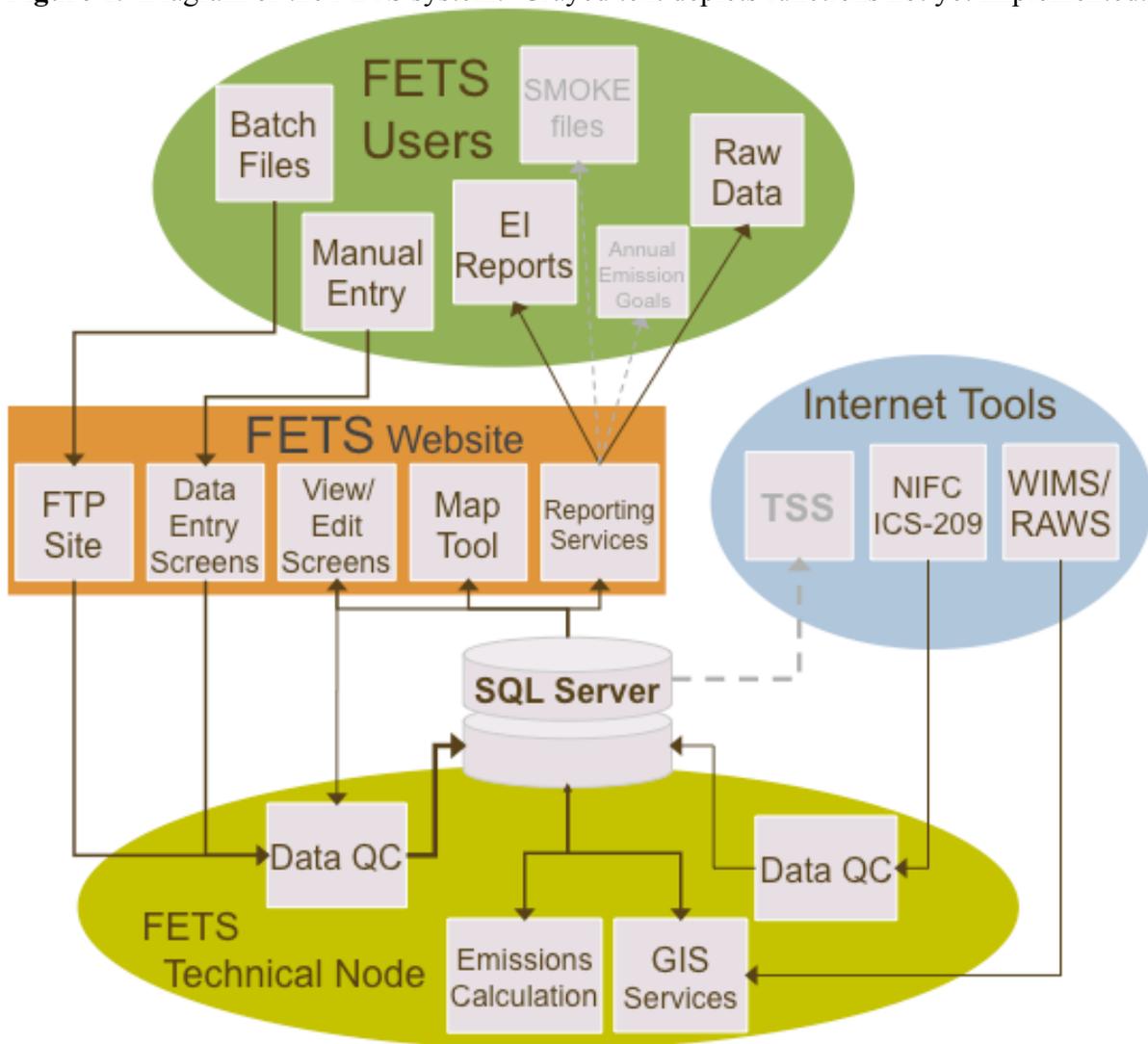


Table 1. User permission hierarchy.

<i>Users</i>	General Public	Data Analysts	Data Providers
<i>FETS Features</i>			
Home Page	✓	✓	✓
Map Tool	✓	✓	✓
Methods and Resources	✓	✓	✓
Reporting Tools		✓	✓
Read/Write/Revise Data			✓
Registration	none	via website	via website w/ approval
User Name/Password	none	Assigned by admin.	Assigned by admin.

Technical Services

Much of the underlying functionality of the FETS relies on operations performed in the Technical Node. All operations are controlled and executed by the Python scripting language. There are three groups of scheduled Python scripts:

- *Morning Downloads.* Scheduled to run at 1 am every day, this series of tasks includes several automated data downloads from other tracking systems, batch files submitted to the FETS FTP site, and weather data from the Weather Information Management System (WIMS) for the past 14 days.
- *Daily Tasks.* Scheduled to run every 15 minutes from 0700 to 1900, this module looks for new or updated records generated through the website that are flagged for an FCC code or FIPS code from the GIS overlay. In addition, the module looks for new batch files on the FETS FTP site to download and process.
- *Weekend Tasks.* This module is run every Sunday at 5am, and includes two tasks: applying fuel moisture and rain event data to records in the database with a date within the past 365 days, and running CONSUME 3.0 for records marked as 'Accomplished' in the database.

Emission Calculations

The WRAP-modified AP-42 method of emissions calculation³ was implemented as the default and instantaneous option for calculating emissions in the FETS. As burn days are entered into the FETS database, emissions are calculated instantaneously by a database trigger and made available to mapping and reporting services for use in regional coordination. This emission estimation accommodates direct comparison of events in the database and comparison to previous inventories built using this method⁴.

CONSUME 3.0 is used to estimate emissions as accomplished acres and other post-burn reporting becomes available. CONSUME 3.0 requires certain ancillary information to calculate emissions for a fire event that is beyond the minimum required data elements⁵. Some of these data elements are available directly from data providers, while others were obtained from other sources or through established defaults. More detailed information on this process can be found elsewhere⁶.

Pollutants and User-provided Emission Estimates

CONSUME 3.0 calculates emissions for total particulate matter (PM), particulate matter $\leq 2.5\mu\text{m}$ (PM_{2.5}), particulate matter $\leq 10\mu\text{m}$ (PM₁₀), carbon monoxide (CO), carbon dioxide (CO₂), non-methane hydrocarbons (NMHC), and methane (CH₄). The WRAP-modified AP-42 method calculates emissions for additional pollutants, including elemental carbon (EC), organic carbon (OC), SO₂, NO_x, ammonia (NH₃) and particulate matter $> 10\mu\text{m}$ (PMC). In addition to performing emissions calculations within the database, the FETS accepts user-provided emissions values. User-provided emission estimates may not include all pollutants available in the complete suite. Therefore, a complete suite of emissions for each fire event may contain estimates from user-provided data, WRAP-modified AP-42 calculations, and CONSUME 3.0 calculations. All three methods of calculation are stored concurrently in the database, and users may access each method through Reporting Services on the FETS website.

Fuel Classification Layer

A common feature among all emissions calculation methods is the need for information pertaining to vegetative cover/fuel classification and estimates of fuel loading and fuel consumption. The FETS uses the Fuel Characteristic Classification System (FCCS) (continental United States), and the Canadian Forest Fire Danger Rating System (CFFDRS) cross-walked to FCCS for Alaska. For users entering data via the web interface of the FETS, users can select a fuel class directly from a pull-down menu and enter a custom fuel loading for a burn or choose to have the FETS choose a fuel class automatically (see below). This automatic method also applies to burn provided in batch mode or mined from other databases. At this time, a single fuel classification and associated fuel loading is assigned to a given set of fire event coordinates. At this time, fire perimeter information is not incorporated and deriving a fire-wide fuel loading value from a variety of vegetation types is not the method used to estimate fuel loading. Details about this and other GIS services are outlined in the next section.

Emission Reduction Techniques

The FETS handles the storage and application of reported use of Emission Reduction Techniques (ERTs). A default option requires only confirmation that any ERT was used. In this instance, estimates of emissions averted (equal to the emissions from a fire with no ERTs minus emissions from the same fire with ERTs applied) are based on the FEJF's Seasonal Suites of ERTs based on location, fire date, and vegetation type (See www.wrapair.org/forums/fejff/documents/ert). Optional inputs include assigning a specific ERT applied to a burn, and/or assigning a custom reduction factor based on information provided to an SMP by the burn manager.

GIS Services

GRASS 6.2 is implemented in the technical node to perform spatial overlays of fire data onto other map layers, and create interpolated surface maps of fuel moisture for the WRAP region.

Fuel Moisture Interpolation

The United States Forest Service Wildland Fire Assessment System (WFAS) reports daily fire weather observations (www.wfas.net) from the Weather Information Management System (WIMS). Ten- and 1000-hour fuel moistures are reported at each of several hundred stations throughout the WRAP region.

Fuel moisture data from WFAS is downloaded and interpolated by a 2nd-order Inverse-Distance-Weighted (IDW) transformation into gridded surface moisture maps by the Technical Node on a daily basis for use in the FETS. Maps for each day of the calendar year are stored in the Technical Node.

Number of Days since Rain Interpolation

The "Days since Rain" parameter as an input to CONSUME 3.0 is used to determine one of three moisture regimes—wet, moist, or dry—which then determines the extent of duff layer consumption (duff layer parameters, such as depth, are stored internally in CONSUME 3.0 by FCC code).

The daily WIMS dataset, described above, reports precipitation at each station in the WRAP region, and is used to determine "Days Since Rain" for fire events. Similar to fuel moisture,

precipitation values are interpolated into a gridded surface map to estimate precipitation throughout the WRAP region. Then, the map may be recoded such that grid cell values greater than 0.25 (representing >0.25 inches of rain in 24 hours; this threshold was determined based on the CONSUME 3.0 algorithm⁷.) are set to 0.0; values 0.0 – 0.24 are set to 1. If two or more maps are created in this manner, they may be combined together successively to obtain a cumulative “Days Since Rain” map for anywhere in the WRAP region. The map combination equation is as follows:

$$\begin{aligned} \text{Equation (1)} \quad & \text{DSRmap1} = (\text{mapDay1} \times \text{mapDay2}) + \text{mapDay2} \\ & \text{DSRmap2} = (\text{DSRmap1} \times \text{mapDay3}) + \text{mapDay3} \\ & \dots \end{aligned}$$

Since some areas of the WRAP region receive very little precipitation each year, the initial cumulative “Days Since Rain” map (DSRmap) had its start date one year in the past to initialize each grid point (i.e., each point on the grid will have seen rain sometime in the last year and reset to zero). On the occasion that WIMS data are not available for a particular day, the previous day’s map is used.

Map Overlay Operations

Fuel classification, 10-hour moisture, 1000-hour moisture, and Number of Days Since Rain are determined automatically by the FETS using a 1-km FCCS fuelbed map (or equivalent CFFDRS map for Alaska) and the maps described above. An automated routine pulls fire events from the database (with a spatial location), drops the data onto a map layer, and inserts the resulting fuel class, moisture, or rain event information back into the database for each fire event. Fuel classification overlays are done immediately upon entering a new fire; moisture and rain event overlays are done when the fire is listed as Accomplished. Occasionally WIMS data are not available for a particular day; in these cases, the fuel moisture and Days Since Rain maps for the previous day are used to derive values for accomplished fire events. In addition, each day the routine looks for WIMS data in the previous two weeks and retroactively interpolates maps for missing days. This means that, if a map is missing in the previous week, the DSR map is re-calculated for every day starting with the day of the missing map, following Equation 1.

Data Acquisition and Exchange Interface

Several methods were developed to assimilate data into the FETS as alternatives to manual entry. For Smoke Management Programs (SMPs) that have or are developing a database for tracking and permitting purposes, streamlined, automated methods of data transfer were investigated. Currently, the following methods are used to gather data from outside systems:

- Oregon Dept. of Forestry Database – Pulls data files that are sent daily to a FTP server intended for BlueSky – RAINS.
- Washing Dept. of Natural Resources Database – Pulls data files that are sent daily to a FTP server intended for BlueSky – RAINS.
- MT/ID Airshed Group Database – Queries the database via a web service.
- AZ Smoke Management Database – An email containing activity data is sent from the AZ system and read by the FETS Technical Node. To date, a test data set was

been sent and the processing module is in place. However, the AZ database system is not yet online.

The other primary alternative to manual entry is to submit data via an FTP site. Instructions are provided to registered Data Providers on the website, as well as a template that must be followed. Currently, accepted file formats are comma-delimited (.CSV) and Microsoft Excel (.XLS). All acquired, submitted, and manually entered data are processed similarly in the Technical Node.

Database Quality Assurance / Quality Control

QA/QC focuses on several aspects of data entry and storage in the FETS. Every data field in the database tables populated by user data carries basic constraints, including

- Data type
- Length (if text)
- Minimum and Maximum (if numeric and applicable)

Effective quality control within the FETS relies upon built-in, automated checks and QC review by Data Providers. Automated QC checks for each style of data acquisition are summarized in Table 2. Data input via batch files (which applies to direct data streams outlined in the previous section) go through a more robust set of automated QC checks than manually entered data: upon submittal, a user will receive a confirmation email with a detailed, record-by-record error report. Any errors in a submitted file results in rejection of the entire data set; the user may re-submit after addressing any errors. For manual entries, the FETS includes a confirmation page after submitting data to allow for review, including a map showing the location of the fire. In addition, for data fields with a limited set of possible choices (such as State), pull down menus (created directly from lookup tables in the database) are used in lieu of keyboard entry.

Table 2. Summary of automated QC procedures for different methods of data submittal.

<i>Internal QC Procedure</i>	ICS-209	Batch Files	Website
Duplicity	X	X	
Data types (e.g. proper date formats)	X	X	X
Range checks (e.g. max. total acres)	X	X	
Location checks		X	

Web-Based Tools

Data Entry

Manual data entry consists of a two-step process, reflecting the structure of the database, and is geared toward planned burn events. A user must first define a “project”, which defines the following (required inputs are italicized):

- *Source Type*
- Fire Name
- Responsible Agency
- *State*
- *Location (latitude and longitude)*
- *Fuel type*
- *Burn Type (e.g. broadcast)*
- *Burn Category*
- Start and End Dates

A separate page allows a user to then define individual days of burning for that project:

- *Acres (planned and actual)*
- Fuel Loading
- Pile data (Volume and quantity)
- *Date of Burn*
- Fuel Type (may use Project value)
- *Emission Reduction Techniques*
- Emissions

Data may also be submitted in batch form via FTP. A page on the website, available only to Data Providers, instructs users on the procedure. A template Excel file is provided and must be followed for submittal to succeed, although the template may be converted to CSV format if desired.

Mapping

The FETS includes a mapping tool to allow real-time access to fire activity in the WRAP region. The mapping tool makes use of the Google Maps API. Control features of the mapping tool include,

- The ability to Zoom in/out of a desired region and pan to adjacent areas.
- Advance or retreat the date period in one day increments.
- Sum fire activity by county or by state for the chosen date range; new icons appear at the centroids of the chosen political boundaries.
- Center the map over Alaska or the contiguous WRAP States.

By default, the map displays all fire activity for today and yesterday for the contiguous WRAP States. Double-clicking on a fire event displayed on the map opens an information window with data about the burn including,

- Area—planned acres for the period as well as cumulative accomplished acres.
- Estimate of emissions
- Source of data (e.g. ICS-209; MT/ID Airshed Database)
- Number of burns to which ERTs were applied

Reporting Services

The FETS has three downloadable reports, two of which are also viewable from a web browser. Fire events accessed to comprise these reports are limited to those listed as ‘Accomplished’ in the database (which includes all wildfire activity by default).

The first report, Quick QC, is a series of tables summarizing fire activity:

- Fire Summary by Source Type by Burn Type.
- Source of Fuel Loading, by Source Type, by FCC derivation (e.g., user-provided, GIS point overlay, or GIS buffer overlay).
- Number of Natural/Anthropogenic Events By Month and by Source Type.

Only burns that have a valid latitude/longitude are included in this report.

The second report, EI Summary, produces a table of daily emissions for all ‘Accomplished’ fire events, including those with invalid location values. Both reports have the following query options:

- Date Range
- State (All or one)
- Agency (All or one)
- Emissions Calculation Method (WRAP-modified AP-42 or CONSUME 3.0)

These two reports may be viewed on-screen in HTML format, or downloaded as a MS Excel spreadsheet.

In addition, users may download fire data into the XML format used by Google Earth (.KML). Fires are organized by type, and information about each day of a fire is viewable, similar to the online mapping tool, by double-clicking a fire location on the map. Unlike the online map tool, the date range is fixed, and summaries for each day of a fire may be viewed simultaneously.

FETS Applications

The FETS is intended to serve several distinct user groups. Web-based seminars are planned for 2008 that will focus on topics related to unique needs of each group.

Smoke Management Personnel

The web-based mapping tool contains real-time information about current wildland fire and planned prescribed burns throughout the WRAP region. Thus, smoke managers may use the FETS on a daily basis as one tool out of many to assist in making burn decisions in their region by having access to information about potential burning occurring outside of their own jurisdiction. This may mean burns occurring in a neighboring state, but also burns of a different type, such as agricultural burns, which may be tracked or regulated by another agency.

Essential to making this effective an effective regional coordination tool is comprehensive data acquisition for all fire types across the WRAP. See below for a discussion on data acquisition.

Data Analysts and Modelers

The reporting functions of the FETS are intended in part to enable analyses on data stored in the system. The quality control procedures in place provide confidence that ‘Accomplished’ fire information is accurate and can be used for comparative source analysis or modeling efforts. In addition, data downloaded into Google Earth may be viewed in conjunction with satellite-derived fire detections available from the USDA Forest Service (activefiremaps.fs.fed.us/wms.php).

Currently, fire data are available as daily activity reports in a spreadsheet-type format. Development work in the future will focus on providing outputs tailored to specific applications, such as generating generating input files for modeling (such as the Sparse Matrix Operator Kernel Emissions (SMOKE) format).

Air Quality and Regional Haze Planners

The reporting functions of the FETS target specific needs of Air Quality Planners. Planners can retrieve QC'd daily fire activity data to assemble emissions inventories for State Implementation Plans (SIP) or other purposes. In addition, the FETS stores information regarding the use of ERTs; tracking ERT application and effectiveness is an integral part of Enhanced Smoke Management Programs mandated by the Regional Haze Rule. Similarly, the FETS allows States' to easily track progress toward meeting Annual Emissions Goals (AEG)⁸ for fire by providing a source of comprehensive fire activity across all source types, tracking the application of ERTs or use of alternatives to burning, and by utilizing consistent methods for estimating emissions.

Current and Future Development of the FETS

2008 Development

Current development of the FETS focuses on data acquisition for prescribed, agricultural and rangeland burning across the WRAP. The success and effectiveness of the applications and features described above depend on acquiring fire activity data across all fire types in all states and tribal lands within the WRAP region. A few smoke management programs, such as those in Montana and Idaho, are sophisticated and enable one-stop shopping for acquiring most fire activity. In other areas, such as Oregon, fire activity is tracked based on the responsible agency (e.g. Federal, State Department of Forestry, State Department of Agriculture) or by the county in which burning takes place. Consequently, in many cases comprehensive data acquisition will require identifying and initiating contact with several entities within a single state.

Future Development

Enhanced data acquisition

- Coordinate with other developers of methods to use satellite imagery to quantify fire size and fire emissions, such as NOAA's Hazard Mapping System (HMS) (www.firedetect.noaa.gov). A promising development is the SMARTFire system (www.blueskyrains.org) being developed under BlueSky-RAINS program that integrates ground-based information from ICS-209 reports with HMS.
- Identify methods to QC fire occurrence (i.e., did an event occur at a certain location on a certain date) and to QC fire characteristics (e.g., fire size, vegetation type, emissions quantity). For example, integrate Monitoring Trends in Burn Severity (MTBS) data as a next level of QC'd inventories (historical).

Enhanced Fire Science

- Augment the FETS with calculation methods to provide emission estimates for additional pollutants (e.g., carbon dioxide [CO₂], subspecies of particulate matter, mercury (Hg), acid deposition pre-cursors).
- Integrate a rudimentary fire-forecasting tool into the FETS.
- Evaluate if and how the FETS will address smoldering emissions.

Enhanced Applications of the FETS

- Integrate the FETS with WRAP's Technical Support System (TSS). This could include importing FETS data into the TSS for use by TSS tools or modifying existing TSS tools to work within the FETS.
- Develop a Regional Haze SIP planning tool to track AEGs based on the consideration and implementation rates of ERTs on planned fire events and utilization of alternatives to burning.

- Integration of the FETS with other forecasting and planning tools such as BlueSky-RAINS and ClearSky/AIRPact (www.airpact.wsu.edu) by exporting comprehensive real-time fire activity data.

CONCLUSIONS

The development of the FETS is the culmination of over ten years of work by the WRAP its Fire Emissions Joint Forum. It is currently operational and capable of accepting data for all types of fire activity at a daily resolution, and offers a flexible submittal process to accommodate the wide variability among agencies and Tribes who track fire data. There is work to be done to develop a comprehensive fire data set for the entire WRAP region, but data acquisition continues to increase and new potential sources of data sought out. The FETS will serve members of the WRAP as a stable, quality-controlled, comprehensive source of fire activity to aid with regional coordination and as the basis of future emissions inventories. In addition, the modular commodity design of the FETS will allow for efficient continued development to augment and enhance the existing tools in the system.

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