Emission Inventories for SIP Development

David V. Sandberg and Janice Peterson
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INTRODUCTION:

This document contains a recommendation on obtaining simple, realistic information for an emission inventory of wildland fires appropriate for State Implementation Plan (SIP) development. The minimum precision for the inventory would be a one-year time period (current and predictive) over an "administrative district" (e.g. National Park or state forest district). The inventory would be used by air quality managers and land managers to compare wildland-fires with other sources and to facilitate proposed increases in prescribed burning. The inventories might also be useful for internal program review, demonstration of conformity, and to measure prescribed-fire/wildfire tradeoffs.

This paper defines the ***default level*** of inventory precision (i.e. Level 0, based only on currently available information); a ***basic level*** (i.e. Level I, the minimum level that would be considered a national norm to support SIP development); and a ***detailed*** level (i.e. Level II, where greater analysis or accountability is appropriate). Emission rates for time periods of less than one day are not discussed, so the inventory procedures described here may not be adequate for dispersion modeling or smoke management decisions.

"Wildland fire" is actually an aggregation of several tens of thousands of individual fires in the United States each year that vary widely with regards to size, loading, consumption, and combustion efficiency. The term includes a variety of intentional fires (i.e***. prescribed fires***) that achieve resource management objectives, and unintentional fires (i.e. ***wildfires***). That distinction has become less clear, because the level of suppression for wildfires is adjusted in relation to the values at risk and the anticipated effects on ecosystem health. Fire management policies and terminology are currently under review.[1]

[1]The National Wildland Fire Coordinating Group recommended a new terminology, effective January 1,1998 that redefines wildland fire as "any non-structure fire, other than prescribed fire, that occurs in the wildland". Prescribed fire would include only fires ignited by management action. If that language is adopted by the agencies, this paragraph all other uses of "wildland fire" and "prescribed fire" will have to be revised.

RECOMMENDATION:

1. All States should implement a "Level I" inventory.

This actually constitutes four "Level I" inventories:

(1) Current emissions from prescribed fires characterized by a 3-year rolling average (e.g. 1998-2000, or whatever three year period is consistent with emission inventories done by States for SIP's to implement new standards for PM2.5).
(2) Current emissions from wildfires characterized by a 10-year rolling average (e.g. 1990-1999).
(3) Projected future emissions from prescribed fires (e.g. 2010).
(4) Projected future emissions from wildfires (e.g. 2010).

2. States should implement a "Level II" or higher inventory for "controversial" programs.

This might be compiled from:

(1) "Level II" input by all burners where it is necessary to justify maintenance of a burn program level of activity when there is public pressure to reduce the program; or
(2) From a mixture of "Level I" input from burners anticipating no change in the level of activity over the next ten years and "Level II or higher" input from burners anticipating an increased program.
(3) "Level II" for wildfires (current and projected future) where there is intent to demonstrate offset of wildfire emissions attributable to an increase in prescribed-fire activity level. Where this is not intended, Level I is adequate for wildfires.

3. States and burners might agree on an inventory with higher resolution than Level II if:

(1) The higher-precision inventory is necessary for some other purpose, such as detailed tracking of emission-reduction goals, internal burning-program review requirements, anticipating land-use changes, and/or the need to reduce emissions but not acres burned.
(2) The inventory will also be used to provide input to dispersion models, or to associate emissions with air pollution impacts.
(3) Information is also to be used in active daily burn allocation processes

DATA SOURCES

As for any source, an emission inventory for wildland fire will be compiled by multiplying an estimate of the ***level of activity*** by an ***emission factor***. For wildland fire, the level of activity is the ***mass of biomass (fuel) consumed***, usually expressed in tons; and the emission factors (from AP-42) are expressed in pounds per ton of fuel consumed. Emission factors for criteria pollutants are derived from an estimate of overall combustion efficiency (i.e. stoichiometric ratio). The mass of fuel consumed is the product of fire ***size*** (acres), pre-burn fuel ***loading*** (tons per acre), and fuel ***consumption*** (percent of pre-burn loading).

The level of activity is not as readily available as one might assume, and must be derived or implied from other information. Even the size of a fire is difficult to inventory precisely because fires commonly burn with irregular severity, often leaving unburned or partially-burned patches within its perimeter. Pre-burn fuels include several components such as duff, litter, herbaceous vegetation and grass, brush, down woody debris, woody tree components, and tree foliage. None of these components except down woody debris are easily or routinely measured in a wildland fire, and each will vary over the area of a fire.

Emission inventories for wildland fires must be compiled in a process that uses raw data collected in the course of fire management or in a separate sampling process. Some information is often available from a prescribed burning plan or permit where those instruments are used, but the practice is widely variable between states and within states. Individual wildfire report data is occasionally available for small fires (less than 10 acres); often available for medium-size (10 to 100 acre) and usually available for large fires (greater than 100 acres). These raw data are usually limited to time, approximate location, fire perimeter area, weather (occasionally) and qualitative description of fuels at point of ignition. The permitting and reporting procedures must either be made more robust and universal to provide sufficient raw data for emission inventory, or they must be supplemented by other data collection.

Raw data must then be processed via expert judgement, scientific algorithm, access to other data sets, or some appropriate combination of these to calculate the level of activity (i.e. the mass of fuel consumed) and assign an appropriate emission factor for each class of fire. Finally, an emission inventory can be completed for an individual fire, a statistical class of fires, a burn program, or a population of fires in a given area over a period of time. In this paper, we do not develop data management or quality assurance strategies. Nor do we discuss the research and development needs required to calculate the level of activity.

Emission inventories measure emissions after control measures are taken. Prescribed fires

are managed to reduce emissions, either by reducing the mass of fuel consumed or by improving combustion efficiency. In some cases, the best available emission-reduction methods reduce the resource management value of the fire(s) or compromise the protection from future wildfires, making it impossible to prescribe emission reduction techniques universally. The use of emission reduction techniques, although they may reduce emissions by a few percent or as much as fifty percent, may not be detectable by sequential emission inventories because of the inherent lack of precision in emission estimates.

MINIMUM TECHNICAL REQUIREMENTS:

Two tables follow, one summarizing the information needed for a prescribed burning emissions inventory and the second summarizes information needed for a wildfire emissions inventory. Each table lists the categories of information needed to inventory emissions, proposes a "minimum requirement" for a Level I inventory, and lists options for increasing precision necessary for a Level II inventory. Definitions follow the two tables.

PRESCRIBED BURNING EMISSION INVENTORY DATA REQUIREMENTS
recommended for all prescribed fires larger than 100 tons of biomass consumed[2]

INFORMATION NEEDED	Units	Minimum Requirement	Overview of Options for Increasing Precision	Comments
1. Time period	time	year	season, month, day	
2. Location	n/a	administrative area	county, latitude and longitude, or watershed	
3. Area actually burned	acres	acres	stratify by fuelbed description	Should be retrospective to get an accurate estimate.
4. Fuelbed description	type or tons per acre	grass/brush/ forest floor/ forest crowns or slash	vegetative type, fuel profile, fuel profile by loading category (high/medium/low), inventoried fuel loadings	Critical for estimating fuel loading and assigning an emission factor but may also be used for estimating fuel consumed. Use of BACM techniques may be detected with refined information.
5. Fuel consumed	percent or tons/acre	expert estimate	site specific information for driving predictive algorithms	Critical variables for gaining precision will vary with fuel type and area, fuel moisture is nearly universal. Use of BACM techniques may be detected with refined information.
6. Emission factor	lbs/ton	burn average (tabular value)	site specific information to allow consumption to be apportioned into flaming vs. smoldering phases	Assigned based on AP-42. *(Note that AP-42 section on wildland fire must be updated)*

[2] This de-minimus level for data collection is just a starting point for discussion. Most likely, there is no single de-minimus value that will be appropriate for every state and across all levels of inventory.

7. Type of burn or fuelbed	category	none	broadcast, pile, right-of way, spot burning	Can increase accuracy of consumption estimates and emission factor assignment.
8. Purpose of Burn	category	none	ecosystem management, waste disposal, habitat enhancement	Can be used if SIP strategies or permitting differs by class of burn

WILDFIRE EMISSION INVENTORY DATA REQUIREMENTS
recommended for all reported wildfires larger than 10 acres and consuming more than 100 tons of biomass[3]

INFORMATION NEEDED	Units	Minimum Requirement	Overview of Options for Increasing Precision	Comments
1. Time period	time	year	season; month; wildfire start, major spread, control, and declared-out dates; activity by day	Finest time resolution for which the inventory results will be used.
2. Location	n/a	administrative area	county; latitude and longitude; watershed	
3. Area actually burned	acres	acres	acres black stratified by other categories of information such as date, fuelbed, area burned in severe, moderate and low intensity, etc.	Currently, reported wildfire area burned is generally perimeter area which results in a systematic overestimation of area burned by as much as one third.

[3]See also footnote 2. A separate effort by the National Wildfire Coordinating Group, the Fire Statistics Project is striving to achieve some consistent formatting of fire reports from all federal agencies and states, and to create a national data base and data management system (John Skeels, personal communication). Fire reports usually contain minimal information for fires less than 10 acres in size, some information for fires less than 100 acres in size, and fairly detailed information for larger fires.

4. Fuelbed description	type or tons per acre	grass/brush/ forest floor/ forest crowns or slash	vegetative type, fuel profile, fuel profile by loading category (high/medium/low), percent of area burned by fuelbed description	Critical for estimating fuel loading and assigning an emission factor but may also be used for estimating fuel consumed. Unfortunately "cover type at point of ignition" is all that is indicated on fire reports. Minimally, acres burned are to be stratified by grass, brush, forest floor, timber crowns, or slash. This is the most critically lacking variable in most current fire reports, and some approach to augmenting the information should be considered.
5. Fuel consumed	percent or tons/acre	expert estimate	more research is needed to develop algorithms to predict wildfire fuel consumption	Very difficult to estimate accurately and likely varies widely throughout a wildfire area.
6. Emission factor	lbs/ton	average value from table	see fuelbed description	Assigned based on AP-42. *(Note that AP-42 section on wildland fire must be updated.)*
7. Control Strategy	category	none	full supression, modified, limited	May be used in some SIP strategies in order to identify sources that are allowed to burn to achieve resource benefits or economic efficiency.

EMISSION INVENTORY PRECISION OPTIONS

LEVEL 0 -- DEFAULT LEVEL OF INVENTORY

Level 0 is based on information currently available in published reports, or in the files and memories of burners. States should resort to this level only if Level I is unattainable.

Part 1. Current Prescribed Burning -- Level 0

Two multiple-state examples are useful in understanding possible approaches to a Level 0 inventory for current prescribed burning.

Peterson and Ward (1992) compiled an estimate of burning that was accomplished during 1989 using simple survey forms that asked burn managers in all 50 states for the approximate area burned in their jurisdiction, the fire-danger-rating fuel model (20 possible), their fuel consumption objective, seasonal distribution of the burning, the reason for burning, and their prediction of fire use trends. Estimates of duff and litter (organic layer) loadings were added to the fuel models using expert judgment. Generalized consumption estimates were made based on either the consumption objective, if reported, or an expert judgment based on the reason for burning. Emission factors were assigned based on fuel model. This inventory remains the best national inventory available, but is quite variable in its accuracy. Also, there has been dramatic change in several states in the amount of burning since 1989 due to changing timber harvests and due to the increase in burning for ecosystem restoration.

It would be possible to repeat this type of study for a more recent period of record with a few months' effort, but it would suffer similar QA/QC problems, and once again be a single snapshot in time rather than an ongoing process.

Lahm and Peterson (in preparation) compiled a spatially-resolved inventory of prescribed burning during 1 current and two future years (1995, 2015, and 2040) for 10 western states as part of the Grand Canyon Visibility Transport Commission study. Fourteen vegetative cover types were spatially mapped throughout the domain using remote sensed data within which up to three levels (high, medium, and low) were specified by field burners and used to characterize fuel loading resulting in 37 unique fuel models. Fuel consumption was estimated using algorithms that relied on an expert-panel-assigned fuel moisture (dry, normal, or wet) believed to be most frequently associated with the burner-reported type of burning (initial entry, maintenance, broadcast, pile, or prescribed natural fire). Emission factors were assigned based on the vegetative cover type.

The Lahm and Peterson inventory provides a good model for estimating emissions from future prescribed burning and future wildfire but the data compiled as part of the Grand Canyon Visibility Transport Commission study needs refinement at the state or local level to gain accuracy.

Part 2. Current Wildfire Activity -- Level 0

No meaningful estimate of recent wildfire emissions exists on a national scale, although the GCVTC inventoried average wildfire emissions for 10 Western states for the period 1986-1992. Wildfire area burned is reasonably available in published statistical summaries and in agency records, but the only information consistently available is area burned, date, and location. Meaningful biomass information is only occasionally available.

An expert could roughly categorize the information available in fire reports into cover types (e.g. forest, brush, and grassland), presume a biomass consumption for each (e.g. 40, 10, and 2 tons per acre) and apply a single emission factor (e.g. 27 lbs./ton). This would not be a huge effort, but it has not yet been done.

Part 3. Future Prescribed Burning -- Level 0

Theoretical, but unspecific estimates of future prescribed fire are available from Hardy (unpublished 1997) These estimates are based on the historic natural frequency of fire, applied to maps of ecosystem distribution, using fuel models and general consumption and emission-factor values. They do not reflect policy or true management intent.

Estimates of future prescribed fire (years 2015 and 2040) are also available from the Lahm and Peterson inventory for 10 western states. These were developed using similar methodology to the 1995 inventory but field managers were asked to estimate future fire use based solely on what they believed ecosystems need to remain healthy and excluding anticipated (and unquantifiable) future political realities, funding, and personnel restrictions (although perceptions of these undoubtedly influenced the process). In the aggregate, results from the FEP agree with what land managers expect for the future role of fire in ecosystems of the West, and with existing land management and fire use goals laid out in major agency planning documents. The accuracy of the input data is inconsistent between and within the 10 states so, although the methodology is useful for developing future inventories of this type, the data needs refinement at the state or local level to gain accuracy.

Although federal land managers have set general goals for increasing prescribed burning, and in fact the increase has already begun in some jurisdictions, no consistently developed, detailed projection of burning planned for the end of the next decade has been compiled. **[SAM, IS THIS STILL TRUE?]** As land management and program plans are completed

over the next few years, these projections will become increasingly available.

An interim step for developing an emissions inventory for future prescribed burning would be to use the Lahm and Peterson methodology (with appropriate modifications and adjustments) and apply it to each individual state. Existing data for the 10 western states must be reviewed and updated, and data for the remaining 40 states needs to be compiled.

Part 4. Future Wildfire Activity -- Level 0

Wildfires have increased dramatically in some regions of the country, especially in the West, during the past decade. There are some speculative efforts that project the frequencies of wildfires under future land-use and climate scenarios (Sampson and Clark, 1996, Lenihan unpublished)

No estimate of future wildfire activity is currently available that would provide a reasonable basis for an emission inventory projection. Our recommendation, in the absence of improved analysis, is to use the period 1987-1996 to characterize the average area burned by wildfire in future years. This inventory needs to be developed.

LEVEL I—BASIC LEVEL OF INVENTORY

Level I is the minimum level that would be considered a national norm to support SIP development**.** Level I inventory relies on information currently available to some states via burn permit programs, smoke management programs, and individual wildfire reports. Existing data collection would be augmented during 1998-2000 (or other three-year period consistent with SIP development) by:

(1) Providing a minimal prescribed-burn report including raw data on the time period, location, fuel type, and fuel consumption for all fires larger than the de-minimus value in all states during the 3-year period,

(2) Providing a small amount of additional information for all wildfires (10 acres or larger) that describes the fuelbed in the burned area (i.e. identifies the predominant fuel as one 5 basic types), and

(3) Providing some additional information for large wildfires (100 acres or larger) that also describes the spatial variability in fuel type and fuel consumed over the area, i.e. stratifies the raw data by fuel type and fire severity.

Part 1. Current Prescribed Burning -- Level I

We recommend that all states compile statistics during the next three years, based primarily on burning permits issued in many states, with some verification and filling-in of data by state forestry offices at the end of the burning season. This will require some states to begin collecting information on prescribed burning for the first time. The minimum information required to produce a Level I prescribed fire inventory is:

Information Needed	Required Data and Source
(1) Time period	Year, (1998-2000)[4] to begin a 3-year rolling average. Date of ignition is strongly recommended because of greater utility and ease of collection.
(2) Location	Appropriate administrative unit (county, park, forest, and/or district)
(3) Area actually burned	Acres, either from a post burn report, or an expert-judgment adjustment of the total of planned permitted burn activity
(4) Fuelbed description	Single characterization of the fuel bed into grass, brush, forest floor, forest crowns, or slash
(5) Fuel consumed	Assignment of averages by a local or national expert
(6) Emission factor	AP-42 assigned based on fuelbed description
(7) Type of burn or purpose for burn	Not required at Level I

[4]The three years following the adoption of any EPA wildland fire policy with development of baseline inventories for PM2.5 SIP's.

Part 2. Current Wildfire Activity -- Level I

The minimum information required to produce a Level I wildfire inventory is:

Information Needed	Required Data and Source
(1) Time period	Year of burn, from fire report. Date of ignition is strongly recommended because of greater utility and ease of collection.
(2) Location	Administrative unit, from fire report
(3) Area actually burned	From fire report (be aware that perimeter acres are generally reported rather than acres actually burned)
(4) Fuelbed description	Fuelbed description, at least to the level of stratification of acres burned by grass, brush, forest floor, forest crowns, and slash, is required. This can be accomplished by augmenting the individual fire reports on all wildfires or by auditing wildfire effects in a separate sampling effort.
(5) Fuel consumed	Assignment of averages by a local or national expert
(6) Emission factor	AP-42 assigned based on fuelbed description
(7) Control strategy	Not required for Level I

Part 3. Future Prescribed Burning -- Level I

Same approach as in Level 0. This level does not provide justification for an increasing prescribed burn program or for maintaining a controversial level of burning.

Part 4. Future Wildfire Activity -- Level I

Same approach as in Level 0. This level does not provide for considering the tradeoffs between prescribed fires and wildfires.

LEVEL II—LEVEL RECOMMENDED FOR BURN PROGRAMS WHEN ADDITIONAL ANALYSIS IS WARRENTED

A Level II inventory may be indicated in states where pressures on burn programs require greater accountability by the burners and the state, where the public and/or elected officials need better justification of why burning is necessary, where tighter restrictions are desired on certain types of burning to allow for more of another type, and/or where projected increases in burning in or near non attainment areas requires conformity analysis. A Level II inventory does not provide enough information to perform dispersion model analysis so does not provide enough information to link wildland burning quantitatively to

air quality or to specific air quality events or impacts.

Prescribed burning is a very diverse activity and the information required to describe it in detail can be very complex and unique by vegetative cover type and area of the country. Therefore it is not possible to describe exactly the data that should be collected in every state that wishes to implement a Level II inventory. States will need to start with the general recommendations given below and work with experts from the burning and fire science communities to custom design the data needs specific to the local vegetation types, available science, and fire use patterns in their area of interest.

Level II precision requires more information than is generally required for burning permits and fire reports in most states. The additional information will allow improved precision to gain greater confidence in the results of the inventory, understand and describe how and why prescribed fire is used across the state and within various vegetative types, detect use of BACM techniques, track emission reduction progress due to BACM, and allow a limited (circumstantial) ability to link impacts to prescribed burn activities.

Part 1. Current prescribed burning -- Level II

Information Needed	Required Data and Source
(1) Time period	Finer resolution than one year, in order to apply better algorithms for biomass consumed and to enable SIP strategies targeted to specific time periods during the year. Recording specific dates is strongly recommended.
(2) Location	Additional information, such as legal description or latitude-longitude and elevation; in order to apply better algorithms for biomass consumed and
(3) Area actually burned	Pre-burn estimates may not be used alone, but must be verified after the burn is completed.
(4) Fuelbed description	Include cover type, fuel condition class, or loading profile. Fire behavior model alone is insufficient.
(5) Fuel consumed	Report sufficient fire weather and fuels information to infer a) threshold of flammability (e.g. spreading, crowning, and smoldering) and consumption (e.g. fuel moisture, etc.)
(6) Emission factor	From AP-42, based on fuel and fire type
(7) Type of burn	Pile or Broadcast burning
(8) Purpose for burn	Some indication of whether burning is for production efficiency, fire safety, or ecosystem management.

Part 2. Current Wildfire Activity -- Level II

Information Needed	Required Data and Source
(1)Time period	Date of ignition, from fire report. Date of control would also be useful.
(2)Location	Administrative unit, from fire report
(3)Area actually burned	Because only perimeter acres are reported on individual fire reports, this assessment of actual blackened area must be made by augmenting the fire report on all fires for a period of 3 years, or by auditing wildfire effects in a separate study.
(4)Fuelbed description	For fires grater than 100 acres, stratification of fire area by fuel type or fuel condition class, such as by assigning one of several dozen available stylized fuelbed profiles or conducting a coarse fuel inventory at individual fires, is necessary. This can be accomplished by augmenting the individual fire reports on all wildfires or by auditing wildfire effects in a separate sampling effort.
(5)Biomass consumed	Biomass consumption must be modeled on the basis of weather information collected on or near individual wildfires (as is routinely done) and the fuelbed description in block 4. In some fuel types, this will require upgrading of the "CONSUME" algorithms through additional field research.
(6)Emission factor	From AP-42.
(7)Control Strategy	Full, Modified, or Limited suppression[5]

Part 3. Future Prescribed Burning -- Level II

The anticipated prescribed burn program must be described as the average, maximum, and minimum annual program for the next ten year period. The information must be stratified according to each of the categories of information included in Part 1.

Part 4. Future Wildfire Activity -- Level II

There is no standard procedure currently available to anticipate reduction of wildfire activity due to prescribed burning or climate fluctuations. Such analyses must be individually tailored to the specific situation, and must consider the changes in each of the

[5]This terminology is subject to change. See also footnote 1.

categories of information included in Part 2.

DATA MANAGEMENT ISSUES

Thus far, we have only described the minimum level of raw data that must be collected for individual fires, but have not described the analysis that must be done to convert the raw data into realistic estimates of the level of activity (i.e. emission tons) from each fire, from a burn program, or at a location over time. All of these issues, including the development of algorithms required to convert the raw data into emission estimates, must be addressed before these data requirements have any real meaning.

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