Appendix L-O
[from the State of New Mexico Smoke Management Program, Appendix J]

Emission Factors & Calculations
The table below was developed using vegetation type and loading or quantity, and emission factors. The Air Quality Bureau (AQB) used emission factors from EPA (AP-42) and from research done at the Pacific Northwest Research Station of the USDA Forest Service (C.C. Hardy et al.) to develop the table. Additional tables that list these emission factors are included below. As science improvements are made, the best available emission factors will be used in the New Mexico Smoke Management Program.

NM Smoke Management Program Emissions Table		
Vegetation Type	One Ton PM10	
Field Crops	65	Acres
Orchard trimmings	5000	Cubic feet piled material
Shrub land	34	Acres
Forest	23 Acres	
Shrub/forest piles	5000	Cubic feet piled material
Grass	100 Acres	

Table J.1. Method to determine, by general vegetation type, what acreage or pile volume produces one ton of PM10.

Emission factors have been developed for certain vegetation (fuel) types and represent the mass of pollutant (particulate matter) produced per mass of fuel consumed. Emission factors are different for various fuel types, and are different for different phases of combustion. Generally, the flaming phase of combustion produces fewer emissions than the smoldering phase. Accordingly, the emission factor for the flaming phase is of a lesser value than that for the smoldering phase. Emission factors allow the calculation of emissions in pounds of pollutant, if vegetation type and loading is known.
Emissions are determined for a particular vegetation or fuel type by multiplying acres burned times fuel loading in tons per acre by percent consumption times the emission factor for that fuel type.
Thus, the standard algorithm for estimating emissions is:

Acres X tons per acre X percent consumption X pound per ton = pounds of pollutant

For example: 100 acres x 10 tons/ac x 0.5 (50%) x 22 lbs/ton = 11,000 lbs or 5.5 tons.

For Emission Factors, see the tables on the following pages, along with the Chapter 13.1, Wildfires and Prescribed Burning, in AP-42, Fifth Edition, Volume 1, 10/96 (www.epa.gov/ttn/chief/ap42)

	Forest and Rangeland Emission Factors (Hardy et. al.)							
Fuel or Fire	**Combustion**	**Emission Factors**						
Configuration	**Phasea**	**PM PM10b**		**PM 2.5**	**CO**	**CO2**	**CH4**	**NMHC**
				(pounds emission per ton fuel consumed)				
BROADCAST BURNED SLASH1								
Douglas fir/	flaming	24.7 16.6	14.9	143	3385 4.6	4.2		
Hemlock	smoldering	35.0 27.6	26.1	463	2804	15.2	8.4	
	fire average 29.6	23.1	21.8	312	3082 11.0	7.2		
Hardwoods	flaming	23.0 14.0	12.2	92	3389 4.4	5.2		
	smoldering 38.0	25.9	23.4	366	2851 19.6	14.0		
	fire average 37.4	25.0	22.4	256	3072 13.2	10.8		
Ponderosa/	flaming	18.8 11.5	10.0	89	3401 3.0	3.6		
Lodge pole pine	smoldering	48.6 36.7	34.2	285	2971	14.6	9.6	
	fire average 39.6	25.0	22.0	178	3202 8.2	6.4		
Mixed conifer	flaming	22.0 11.7 9.6		53	3458 3.0	3.2		
	smoldering 33.6	25.3	23.6	273	3023 17.6	13.2		
	fire average 29.0	20.5	18.8	201	3165 12.8	9.8		
Juniper	flaming	21.9 15.3	13.9	82	3401 3.9	5.5		
	smoldering 35.1	25.8	23.8	250	3050 20.5	15.5		
	fire average 28.3	20.4	18.7	163	3231 12.0	10.4		
PILE-AND BURN SLASH1								
Tractor piled	flaming	11.4 7.4 6.6		44	3492 2.4	2.2		
	smoldering 25.0	15.9	14.0	232	3124 17.8	12.2		
	fire average 20.4	12.4	10.8	153	3271 11.4	8.0		
Crane piled	flaming	22.6 13.6	11.8	101	3349 9.4	8.2		
	smoldering 44.2	33.2	31.0	232	3022 30.0	20.2		
	fire average 36.4	25.6	23.4	185	3143 21.7	15.2		
"Average Piles"	flaming	28.4 19.0	17.1	169	3207 16.6	11.6		
BROADCAST BURNED SLASH2								
Sagebrush	flaming	45.0 31.8	29.1	155	3197 7.4	6.8		
	smoldering 45.3	29.6	26.4	212	3118 12.4	14.5		
	fire average 45.3	29.9	26.7	206	3126 11.9	13.7		
Chaparral	flaming	31.6 16.5	13.5	119	3326 3.4	17.2		
	smoldering 40.0	24.7	21.6	197	3144 9.0	30.6		
	fire average 34.1	20.1	17.3	154	3257 5.7	19.6		
FOREST WILDFIRE3								
	fire average	30.0	27.0					

1 Ward, D.E.; Hardy, C.C.; Sandberg, D.V.; Reinhardt, T.E. 1989. Part III-emissions characterization.
In: Sandberg, D.V.; Ward, D.E.; Ottmar, R.D., comp.eds. Mitigation of prescribed fire atmospheric pollution through increased utilization of hardwoods, piled residues, and long-needled conifers.
Final report. U.S. DOE, EPA. Available from: U.S. Department of Agriculture, Forest Service,
Pacific Northwest Research Station, Seattle, WA.
2 Hardy, C.C.; Conrad, S.G.; Regelbrugge, J.C.; Teesdale, D.T. 1996. Smoke emissions from prescribed burning of southern California chaparral. Res. Pap. PNW-RP-486. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 37p.
3 Hardy, C.C.; Ward, D.E.; Enfield, W. 1992. PM2.5 emissions from a major wildfire using a GIS 1 2 rectification of airborne measurements. In: Proceedings of the 29th annual meeting of the Pacific Northwest International Section, Air and Waste Management Association: 1992 November 11-13; Bellevue, WA. Pittsburgh, PA: Air and Waste Management Association.

a Fire average values are weighted-averages based on measured carbon flux.
b PM10 values are calculated, not measured, and are derived from known size-class distributions of particulates using PM and PM2.5.

Emission Factors for Field Crops *		
Vegetation Type	PM10 **	PM2.5 **
Alfalfa	31.8 30.4	
Barley	15.4 14.9	
Corn	12.4 12.0	
Cotton	17.7 17.0	
Hay	31.8 30.4	
Oats	22.9 21.8	
Peanuts	17.7 17.0	
Pecans	11.0 10.3	
Pistachio	11.0 10.3	
Sorghum	21.4 20.4	
Wheat	11.5 10.9	
Weeds (ditches/ditch banks)	17.7	17.0
Average field crops	17.7	17.0
Average orchard crops	11.0	10.3

* From Integrated Assessment Update and 2018 Emissions Inventory for Prescribed Fire, Wildfire, and Agricultural Burning. (draft) Western regional Air Partnership, Fire Emissions Joint Forum by Air Sciences Inc. August 27, 2002.
** Pounds pollutant per ton of residue consumed.

J.1. Definitions

Broadcast burning – intentional burning within well-defined boundaries for reduction of fuel hazard, resource objectives, or both.
Combustion – the rapid oxidation of fuel in which heat and usually flame are produced. Combustion can be divided into four phases: pre-ignition, flaming, smoldering, and glowing
Emission factor – the mass of particulate matter produced per unit mass of fuel consumed (pounds per ton, grams per kilogram)

Flaming Phase – this phase follows the pre-ignition phase and precedes the smoldering combustion phase. It is the luminous oxidation of gases evolved from rapid decomposition of fuel in which water vapor, soot, and tar comprise the visible smoke.
Percent Consumption – the amount of a specified fuel type or strata expressed as a percentage that is removed through the fire process.
Pile – materials that have been relocated either by hand or machinery and heaped together.
Pyrolysis – the thermal or chemical decomposition of fuel at an elevated temperature
Slash – debris resulting from such natural events as wind, fire, or snow breakage; or such human activities as road construction, logging, pruning, thinning, or brush cutting. It includes logs, chunks, bark, branches, stumps, and broken understory trees or brush
Smoldering Combustion Phase – combined process of dehydration, pyrolysis, solid oxidation, and scattered flaming combustion and glowing combustion, which occur after the flaming combustion phase of a fire; often characterized by large amounts of smoke consisting mainly of tars. Emissions are twice that of the flaming combustion phase

J.2. References

Regional Haze Rule
Published in the Federal Register on July 1, 1999, 64 FR 35714.
http://www.epa.gov/ttn/oarpg/t1/fr_notices/rhfedreg.pdf 35 36 37 38
WRAP Policy on Enhanced Smoke Management Programs for Visibility
Approved by the Western Regional Air Partnership, November 12, 2002.
http://www.wrapair.org/forums/fejf/documents/esmptt/policy/030115_ESMP_Policy.pdf

Integrated Assessment Update and 2018 Emissions Inventory for Prescribed Fire, Wildfire, and Agricultural Burning. (Draft), August 27, 2002.
http://www.wrapair.org/forums/fejf/documents/emissions/WGA_2018EI_Draft.pdf

Estimating Fuel Loading
[from State of New Mexico Smoke Management Program, Appendix K]

Fuel, in the context of wildland or agricultural fire, refers to all combustible material available to burn on an area of land. Grass, field crops, brush, timber and slash or thinning residue are the most common fuels found in New Mexico. Each fuel has its own burning characteristics based on several inherent factors. These factors include its moisture content, volume, arrangement and the plant's genetic make up. All of these contribute to how a fire spreads, its intensity, and its smoke production and emissions.
Fuel loading is measured in tons per acre. Grass is considered a light fuel with approximately ¾ tons per acre. On the other end of the spectrum, thick brush, a heavy fuel, can have a volume of over 21 tons per acre. The intensity of the fire is directly related to fuel loading. Grass burns rapidly with a short period of intense, maximum heat output; brush, on the other hand, has a long sustained high heat output making it more difficult to control.
There are several way to estimate fuel loading. One is to take measurements of the current vegetation or debris. Browns transects can be used for woody fuels and clip, dry and weigh can be used for grass fuels. Other methods include using fuel models (Fire Behavior or NFDRS, others), photo series, or ocular estimates. There are numerous other methods of measuring vegetation, but the most common are listed here.
See the list of publications in sections K.5.1. and K.5.2. that follow for further guidance in determining fuel loading.

K.1. Broadcast Burns

Procedures for use of the photo series to determine gross woody fuel (there are currently no photo series specifically just for grass although they are being developed) loading are:

1. Observe each specific fuel size class of residue on the ground (for example, three to nine inch diameter size class).
2. Select a photo or photos that nearly match or bracket the observed fuel class.
3. Obtain the quantitative value for the characteristic being estimated from the data sheet accompanying the selected photo (or interpolate between photos).
4. These steps are repeated for each fuel size class or fuel characteristic as needed.
5. The total gross woody fuel loading can then be calculated by summing the estimates.
6. If the general area being inventoried has areas with obvious differences in residue loading, the user should make separate determinations for each area and then weigh and cumulate the loading for the whole area.

The procedures for inventorying downed woody material are provided in two U.S. Forest Service technical reports published by the Inter-Mountain Forest Range and Experiment Station in Ogden, UT. The "Handbook for Inventorying Downed Woody Material" by James K. Brown (USDA General Technical Report INT-16, 1974) and the "Graphic Aids for Field Calculation of

Dead, Downed Forest Fuels" by Hal E. Anderson (USDA General Technical Report INT-45, August 1978) are the reference documents to be followed when doing a planar intersect sample.

K.2. Grass/Non-Woody Fuels

Direct Measurement Method

1. Harvest or Clip-and-Weigh Methods:

a. Clipping vegetation to ground level and then weighing it is the most direct and objective way to measure herbaceous biomass.

b. Clipping can be accomplished with grass shears, sheep shears, power grass shears, sickles, and hand lawnmowers equipped with grass catchers.

c. Though "clip-and-weigh" methods are highly accurate, they are very time consuming.

d. Before clipping some things to think about are:

i. Are you clipping plants rooted in the plot or those that occur within or above the perimeter of the quadrat?

ii. Will species be clipped and weighed separately or will all plants be clipped and weighed together?

iii. A general rule of thumb is one quadrat per 10 acres. (For the purposes of the NM SMP)

iv. Quadrats (a 3ft x 3 ft square or 1 yard x 1 yard square) should be randomly located.

v. Are the plants evenly distributed across the area or is there a lot of variability? The more variability the more quadrats you may want.

vi. The NM NRCS recommends at least 800 lbs./acre for prescribed burning in grassy fuels.

2. Weighing and Drying Harvested Material:

a. The weight of plant material includes inter- and intra cellular water and external water such as dew and precipitation. Therefore the weight of freshly harvested plant material is highly variable and depends on recent weather, atmospheric conditions, and the water status of the plant.

b. Once a sample is dried the percent dry matter equals dry weight divided by fresh weight, multiplied by 100. The dry weight is the weight of the sample after oven drying, and the fresh weight is the weight of the sample after it was just clipped.

c. Recommended drying procedures:

i. Dry sample within 24 hours of clipping

ii. Place samples in paper bags (grocery bags, lunch bags). Know the weight of the bag. One quadrat or species per bag.

iii. A forced air oven is best at 60-70° C. and will take 24-48 hours to dry.

iv. The samples can be checked every 4-8 hours until there is no change in weight.

v. If an oven is not available the samples can be air dried and placed in a dry room until the weight stabilizes. A drying room can be established by simply turning the heat up in a room.

vi. Once you have the dry weight, subtract the weight of the bag.

vii. To estimate the pounds per acre use the following formula:

Dry Weight in pounds per square yard X 2.42 (conversion factor) = tons per acre

For example, a square yard of pasture was clipped, producing two pounds per square yard of totally dry material. The following calculation provides the tons per acre.

2 lbs per square yard x 2.42 = 4.84 tons per acre

K.3. Pile Burns

To determine tonnage in units that will be (but have not yet been) piled, the transect method or photo series method as described above can be used.

If units have already been piled, one of the two following methods can be used:

1. Visual estimates of piles.
2. Statistical sample of pile volume.

These methods are described in a publication form the Pacific Northwest Research Station, Fire and Environmental Research Applications, “Guidelines for Estimating Volumes, Biomass, and Smoke Production For Piled Slash,” 1996, by Colin C. Hardy.

A simpler, but less accurate method in determining pile volume is length multiplied by weight multiplied by height. This will provide the cubic feet of the pile. Multiplying this by the number of piles will give an estimate of the piled volume on the unit.

K.4. Definitions

Biomass – the amount of living matter (as in a unit area or volume of habitat).

Broadcast burning – intentional burning within well-defined boundaries for numerous objectives.

Brush – a collective term that refers to stands of vegetation dominated by shrubby, woody plants, or low growing trees.

Dead fuels – fuels with no living tissue in which moisture content is governed almost entirely by absorption or evaporation of atmospheric moisture (relative humidity and precipitation).

Forest residue – accumulation in the forest of living or dead (mostly woody) material that is added to and rearranged by human activities such as harvest, cultural operations, and land clearing.

Fuel – combustible material.

Fuel Loading – the amount of fuel present expressed quantitatively in terms of weight of fuel per unit area usually tons per acre.

Fuel Model – information describing a particular combination of vegetation, represented in numerical terms, that is used to simulate fire activity in that vegetation type.

Fuel Size Class – a category used to describe the diameter of down dead woody fuels. Fuels within the same size class are assumed to have similar wetting and drying properties, and to preheat and ignite at similar rates during the combustion process.
Herbaceous – having little or no woody tissue and persisting usually for a single growing season.
Photo Series – a collection of photos that provides a basis for quantifying and describing existing fuel loads based on vegetation type and fuel size class.
Pile – materials that have been relocated either by hand or machinery and heaped together.
Planar Intersect – involves counting intersections of woody pieces with vertical sampling planes that resemble guillotines dropped through the downed material.
Quadrat – a two-dimensional sample unit of any size or shape.
Slash – debris resulting from such natural events as wind, fire, or snow breakage; or human activities as road construction, logging, pruning, thinning, or brush cutting. It includes logs, chunks, bark, branches, stumps, and broken understory trees or brush.
Transect – a specific area of predetermined size used for sampling, for example, a narrow strip (measuring tape) used for point-intercept sampling (i.e., sampling points along a line).

K.5. References

This list is not complete and new photo series are being developed at this time.

K.5.1 Photo Series

Blonski, Kenneth S. and Schramel, John L. 1981. Photo series for quantifying natural forest residues: Southern Cascades, Northern Sierra Nevada. USDA Forest Service general Technical Report PSW-56. Pacific Southwest Forest and Range Experiment Station, Berkeley California. 145 pages. (Ponderosa Pine, mixed conifer, lodgepole, white fir, red fir, mountain hemlock)
Fischer, William C. 1981. Photo guide for appraising downed woody fuels in Montana forests: grand fir – larch – Douglas fir, western hemlock, western hemlock – western redcedar, and western redcedar cover types. USDA Forest Service General Technical Report INT-96. Intermountain Forest and Range Experiment Station, Ogden, Utah. 53 pages.
Fischer, William C. 1981. Photo guide for appraising downed woody fuels in Montana forests: interior ponderosa pine, ponderosa pine-larch-Douglas fir, larch-Douglas fir, and interior Douglas fir cover types. USDA Forest Service General Technical Report INT-97. Intermountain Forest and Range Experiment Station, Ogden, Utah.133 pages.
Koski, Wayne H. and Fischer, William C. 1979. Photo series for appraising thinning slash in north Idaho: western hemlock, grand fir, and western redcedar timber types. USDA Forest Service General Technical Report INT-46. Intermountain Forest and Range Experiment Station, Ogden, Utah. 49 pages.
Maxwell, Wayne G. and Ward, Franklin R. 1976. Photo series for quantifying forest residues in the ponderosa pine type, ponderosa pine and associated species type, lodgepole pine type. USDA Forest Service General Technical Report PNW-52. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. 73 pages.
Maxwell, Wayne G. and Ward, Franklin R. 1976. Photo series for quantifying forest residues in the coastal Douglas fir—hemlock type, coastal Douglas fir—hardwood type. USDA Forest Service General Technical Report PNW-51. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. 103 pages.
Maxwell, Wayne G. and Ward, Franklin R. 1979. Photo series for quantifying forest residues in the Sierra mixed conifer type, Sierra true fir type. USDA Forest Service General Technical Report PNW-95. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. 79 pages.
Maxwell, Wayne G. and Ward, Franklin R. 1980. Photo series for quantifying natural residues in common vegetation types of the Pacific Northwest. USDA Forest Service General

Technical Report PNW-105. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. 230 pages. (Douglas –fir hardwood, hardwoods, Douglas –fir hemlock, sub alpine fir, mixed conifer, lodgepole pine, ponderosa pine and associated species, ponderosa pine, brush, juniper, grass)

National Wildfire Coordinating Group. 1997. Photo series for quantifying forest residues in the southwestern Region: Data compiled from Black Hills ponderosa pine and spruce type 1990; GTR-PNW-105; GTR_PNW-52, 1976; GTR-PSW-56, 1981. PMS 822. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center.227 pages. (ponderosa pine pre-commercial thinning, partial cut, natural, white fir, juniper, mixed conifer)

Ottmar, Rodger D. and Hardy, Colin C. 1989 Stereo photos series for quantifying forest residues in coastal Oregon forests: second growth Douglas fir-western hemlock type, western hemlock-Sitka spruce type, and red alder type. USDA Forest Service General Technical Report PNW-231. Pacific Northwest Research station, Portland, Oregon. 67 pages.

Ottmar, Rodger D., Hardy, Colin C., and Vihnanek, Robert E. 1990 Stereo photo series for quantifying forest residues in the Douglas fir –hemlock type of the Wilamette National Forest. USDA Forest Service General Technical Report PNW-258. Pacific Northwest Research Station. Portland, Oregon. 63 pages.

Ottmar Rodger D., Vihnanek, Robert E., and Wright, Clinton S. 1998. Stereo photo series for quantifying natural fuels. Volume 1: mixed conifer with mortality, western juniper, sagebrush, and grassland types in the interior Pacific Northwest. PMS 830. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 73 pages.

Ottmar, Rodger D. and Vihnanek, Robert E. 1999. Stereo photo series for quantifying natural fuels. Volume V: Midwest red and white pine, northern tallgrass prairie, and mixed oak types in the Central and Lake States. PMS 834. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center.99p.

Ottmar Rodger D.; Vihnanek, Robert E. 2000. Stereo photo series for quantifying natural fuels. Volume III: Lodgepole pine, quaking aspen, and gambel oak types in the Rocky Mountains. PMS 832. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 85 p.

Ottmar Rodger D., Vihnanek, Robert E., and Wright, Clinton S. 2000, Stereo photos series for quantifying natural fuels. Volume IV: Pinyon-juniper, chaparral, and sagebrush types in the Southwestern Unites States. PMS 833. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 97 p.

Reeves, Hershel C. 1988. Photo guide for appraising surface fuels in east Texas: grass, clearcut, seed tree, loblolly pine, shortleaf pine, loblolly/shortleaf pine, slash pine, longleaf pine, and hardwood cover types. Center for Applied Studies, School of Forestry, Stephen F. Austin State University, Nacogdoches, Texas. 89 pages.

USDA Forest Service. 1990. Photo series for quantifying forest residues in the Black Hills ponderosa pine type, spruce type. USDA Forest Service publication A-89-1-90. Rocky Mountain Region. 80 pages.

K.5.2. Fuel Models

Anderson, Hal E. 1982. Aids to Determining Fuel Models for Estimating Fire Behavior. USDA Forest Service, Intermountain Forest and range Experiment Station General Technical Report INT-122 Boise, ID.22 pages.

Burgan, R. E.; 1988. 1988 Revisions to the 1978 National Fire-Danger System. USDA Forest Service, Southeastern Forest Experiment Station, Research paper SE-273, Asheville, North Carolina, 39p.

Deeming, J. E., R. E. Burgan, and J.D. Cohen, 1977: The National Fire Danger-Rating System-1978. USDA Forest Service, Intermountain Forest and Range Experiment Station, General Technical Report INT-39, Ogden, Utah, 63p.

K.5.3. General References

Bonham, C.D. 1989 Measurements for terrestrial vegetation. John Wiley & Son, New York, NY.

Daubenmire, R. 1959. A canopy coverage method of vegetational analysis. Northwest Science 33:43-66.

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K.5.4. Web References

Regional Haze Rule

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http://www.epa.gov/ttn/oarpg/t1/fr_notices/rhfedreg.pdf

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Approved by the Western Regional Air Partnership, November 12, 2002.

http://www.wrapair.org/forums/fejf/documents/esmptt/policy/030115_ESMP_Policy.pdf