Chapter 1 : Methods to Reduce Forest Residue Volume after Timber Harvesting and Produce Black Carbo

Guidelines For Estimating Volume, Biomass, and Smoke Production For Piled Slash. Hardy, Colin C. Guidelines for estimating volume, biomass, and smoke production for piled slash.

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The model-based population estimate of C stocks from CWD pieces was 17 percent In general, models overestimated the C density per-unit-area from slash piles early in stand development and underestimated the C density from CWD pieces in young stands. This resulted in significant differences in CWD C stocks by region and ownership. Based on the results of this study, it is suggested that the U. Introduction The ecological importance of trees in forest ecosystems extends well beyond their biological life in both space and time [1] , [2]. When trees fall or shed components e. The benefits of DWM in forests and, indirectly, to society can be at odds with the fact that DWM may also hinder forest management activities, provide habitat for forest pests, and increase wildfire risk [1] , [7]. Much of the research on DWM is regionally specific and has been conducted at varying scales to assess fuel loads [8] , [9] , wildlife habitat [1] , [3] , [10] , [11] , or carbon C [12] â€" [14]. The results from such studies have been used to develop relationships with other forest ecosystem attributes e. Forest C stocks in the U. Estimates of live and standing dead tree C stocks are based on biomass estimates obtained from inventory tree data [18] , [19]. Estimators have been developed to compute DWM volume, biomass, and C [22] ; however, since DWM inventories have been initiated by individual states at varying times over the last decade, before now there has been insufficient data to generate consistent national population estimates that meet the precision standards established by the FIA program [23]. The latest compilation also provides an opportunity to examine the models used to estimate plot- and population-level estimates of DWM C stocks and compare model- and field-based estimates. As DWM models have been used for over a decade [22] to inform the U. Beyond the borders of the U. Given the costs associated with field-based C inventories and difficulties in achieving the statistical power to detect C flux [27] , the evaluation of DWM field inventory efficacy is paramount to monitoring forest ecosystems in the context of global change. The goal of this study is to examine the effect of incorporating field-based estimates of DWM C stocks into the U. The specific objectives of the analysis are to: Coarse woody debris as defined in Woodall and Monleon [22] must be separate from a standing dead tree and have a lean angle greater than 45 degrees from vertical. Coarse woody debris amassed in piles i. When reporting DWM in the U. Plot-based Sampling Protocol The FIA program maintains a three-phase inventory program, where Phase 1 is designed to reduce variance through stratification using satellite imagery to assign Phase 2 plots to strata [23]. Site and tree attributes are measured at regular intervals on Phase 2 plots that contain a forest land use. Phase 2 plots are quasi-systematically distributed every 2, ha across the U. Coarse woody debris attributes are typically measured on every 16th Phase 2 plot 38, ha as part of the Phase 3 sample. In a few regions, states e. Phase 2 and 3 plots are comprised of four 7. Coarse woody debris is sampled on transects radiating from each Phase 3 subplot center at angles 30, and degrees, respectively. Each subplot has three 7. Data collection involves recording every CWD piece intersected by a transect, and measuring transect diameter, length, small-end diameter, large-end diameter, decay class, and species. Transect diameter is the diameter of a downed woody piece at the point of intersection with a sampling transect. Decay class is a subjective determination of the amount of decay present in an individual log. Decay class 1 is the equivalent of a freshly fallen log the least decay , while decay class 5 is extremely decayed [30]. Fallen logs are identified to species using species-specific bark, branching, bud, and wood composition attributes excluding decay class 5. Coarse woody debris found in piles â€" regardless of cause â€" with the pile center coinciding with a subplot is sampled using pile protocols rather than sampling transects. Field crews assign the pile a shape category i. Study Regions and Data Field data for this study were taken entirely from the FIA database [30] , [31] , sampled from â€" in the 48 conterminous states of the U. The data were organized by region and ownership i. As CWD inventories were initiated at varying times from â€", sample intensities vary by state. In addition, states have the opportunity to increase the sample intensity of both Phase 2 and Phase 3 plots. Furthermore, states also have the opportunity to increase the size of the fixed-area sample plots from 7. Changes in both fixed-area subplot size and CWD sampling transects were incorporated into estimation procedures to allow seamless comparison across the entire U.

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Guidelines in the form of a six-step approach are provided for estimating volumes, oven-dry mass, consumption, and particulate matter emissions for piled logging debris. Seven stylized pile shapes and their associated geometric volume formulae are used to estimate gross pile volumes.

Advanced Search Logging residue is currently one of the largest underutilized residues potentially available for biomass energy production. The cost of collection, processing, and transporting this material is high in proportion to its value; the result is that there are potentially small profit margins. Therefore, managers must develop and execute efficient supply chains. The first step in developing an efficient supply chain requires a reliable estimate of pile volume because this will allow the manager to deploy the appropriately sized transportation and processing operations. This article compares two methods used to measure logging residue piles to terrestrial light detection and ranging LiDAR -generated estimates; one uses a geometric base and the other uses a laser rangefinder. The geometric method, which has been used since the s, derives volume by first ocularly estimating the simplified geometric shape of the pile. The second step measures the parameters to compute the volume of that shape. The other method uses a laser rangefinder with an electronic compass that collects coordinates of the pile and then computes a volume. The laser rangefinder produced results that were closer to the LiDAR-generated estimates than the geometric shapes, which showed larger deviations from the LiDAR-generated estimate for larger piles. We believe that the consistency of the laser rangefinder along with its improved reliability makes it the superior method for estimating volume of biomass stored in piles. These can come from one of two sources. One is logging residues generated from harvest operations. The second is mill residues generated from various manufacturing processes. Mill residues are generated from lumber, pulpwood, and plywood manufacturing. The products include bark, sawmill trimmings, pieces too small for any other solid wood use, sawdust, and veneer shavings. However, much of these mill residues is currently consumed by other manufacturing products that offer much higher returns to the mill than energy production. For example, Douglas-fir Pseudotsuga menziesii bark is sold in large quantities in the Pacific Northwest for a variety of products including soil amendments and decorative landscaping products Thomas and Schumann Coarse residues such as trimmings, slabs, and veneer clippings may be used as raw material for pulp, and a variety of engineered wood products Parikka Planar shavings are popular for animal bedding and are used widely in the commercial livestock and pet industries Thomas and Schumann Logging residue is the material left on site after harvest. This material consists of tops, limbs, needles, stumps, and low-grade wood from breakage or defects. It is considered the lowest value material and is often burned on site to facilitate more efficient reforestation. The high cost to collect, process, and transport this material can limit its use as a viable fuel source. Managers hoping to use this material as fuel will need to efficiently manage the logging residue supply chain if they want to generate competitive energy rates. Thus, the first step that is needed for efficient management of the supply chain is to accurately measure the supply to plan the most efficient operations for the collection, processing, and transportation of this material. Logging residue supply can be estimated from standing volume using allometric models or by measuring the volume of piled residue after harvest. Allometric models can estimate the volume in various components of standing trees. The sum of these individual components produces the total potential volume of biomass available. However, a portion of the potential biomass available from standing trees is used for higher value products, is lost during collection, or is left on site for erosion control and soil maintenance. As a result, the actual logging residue volume that ultimately resides in piles and is accessible for biomass collection and processing operations will need to be determined. This study considers biomass as a byproduct of harvest and compares techniques that directly measure the volume in the piles after harvest. The volume in these piles is an important component in the forest biomass supply chain to inform the choice of the logistical system used to collect, process, and transport biomass. For example, if the volume of material is large, but the current road is too narrow for the largest of chip vans, the volume in the piles is a significant element in the economic analysis to determine whether to modify the road and allow for larger trucks that have lower hauling costs. Misapplication of these logistical choices can result in unprofitable operations. Thus, reliable techniques to measure pile volumes need to be developed. Measuring stock pile volumes is not a problem that is exclusive to forestry. There are a number of traditional surveying techniques that have been deployed in the construction industry to measure stockpiles of gravel or sand. These have required that a person climb on the pile to position an instrument, which can be dangerous. Laser rangefinders with electronic compasses have been used to estimate stockpile volumes of various materials including coal, sand, and gravel while avoiding placing the person in a hazardous position. Previous studies found an improvement in volume estimation using techniques similar to those for conventional survey methods that used a total station. However, these piles are composed of relatively uniform material compared with logging residue, which contains a mixture of materials from small branches to tops or large limbs that may not form as consistently as other materials. The purpose of this study is to compare two measurement techniques that are used to measure the volume of machine-piled logging residue. The first method, the geometric method, will estimate the shape and parameters necessary to calculate the volume using methods described by Little , Hardy , and Wright et al. The second will use a laser rangefinder with an electronic compass to collect coordinates for the piles. Similar methods have been used to measure the volume of hand piles Wright et al. Both estimates will be compared with light detection and ranging LiDAR -generated estimates of pile volumes as the terrestrial LiDAR analysis will serve as the control for the study. Logging residue supply is more frequently expressed in terms of mass rather than volume. However, weighing even the smallest of machine piles is much more difficult than measuring volume. Pile volume can be converted into pile mass by estimating packing ratio the ratio of solid wood to total pile volume. For example, Hardy provides general guidelines for estimating the packing ratio for various species, size classes, and piling methods, with typical values ranging from 0. However, the actual mass of each pile depends on additional variables such as moisture content and size class distribution. As a result, variation in volume measurements may not directly reflect the actual mass. Methods For the purposes of this project, a packing ratio of 0. Thirty-three piles of varying shape and size from recent clearcut sites from western Oregon were used for this study in Data were collected using three different measuring techniques. The geometric method followed the procedure described by Hardy and Wright et al. The second method was laser rangefinders using a TruPulse laser rangefinder. The results from both methods were compared with volume estimates generated from terrestrial LiDAR scanning. Figure 1 shows the types of piles that were encountered in this study. The geometric volume estimates were determined using two steps. First, each pile was visually classified as one of seven geometric shapes shown in Figure 2 Hardy Then, the necessary dimensions were recorded to the nearest tenth of a foot to determine volume. In the case of irregular shaped piles, the sum of the individual components was computed. Volumes were computed using the equations provided for the various shapes Figure 3. For example, the pile in Figure 1 was classified as a half-sphere Figure 3 , and the parameters measured were height and width. Three-dimensional image of piled logging residue produced from terrestrial LiDAR. Seven generalized geometric shapes used to represent residue pile configuration Hardy Half-sphere model of piled logging residue using geometric measurements. View large Download slide Half-sphere model of piled logging residue using geometric measurements. The second method was to measure the piles using the laser rangefinder equipped with an electronic compass. Coordinates were collected using a TruPulse laser rangefinder mounted on a tripod. These data were stored in a handheld computer in conjunction with MapSmart software. A minimum of points were collected from each pile. The average number of points for the 33 piles was Once a sufficient number of points were collected, traditional surface analysis techniques were used to transform the points into a surface using a triangular irregular network TIN. The volumes were determined using the TINs that were computed by the Mapsmart program. The same pile, which is shown in Figures 1 and 3 , is represented as a laser rangefinder-produced TIN Figure 4 as well as a complex surface in Figure 5. TIN of piled logging residue produced from laser rangefinder measurements. Three-dimensional model of a mesh and pipes fitted to a point cloud. View large Download slide Three-dimensional model of a mesh and pipes fitted to a point cloud. To establish the control, a FARO Focus3D three-dimensional terrestrial laser scanner was used to gather three-dimensional point information for each pile. A minimum of three images were collected using a scan rate of 10 minutes per image. The images were merged into a single scene Figure 1 to create a three-dimensional point cloud of the pile surface. Using Leica Cyclone software, the points were used to develop a three-dimensional mesh surface of the basic pile. To capture the volume in the overhanging branches, a pipe-fitting process was added to model the large material that is beyond the smoothed surface of the pile. This volume was added to the mesh surface to compute the total volume calculation Figure 5. Two types of statistical analysis were completed. The first used a paired t-test to determine whether the measurements were significantly different from the LiDAR-generated estimates. The second analysis was used to determine whether each measurement technique produced reliable results similar to those for the control method. Concordance correlation analysis has been used in many fields, especially medicine, to determine whether two measurement techniques result in similar estimates Lin Measurements with perfect repeatability would result in a concordance correlation coefficient of 1. Thus, one technique would be completely substitutable for another. This will determine whether either of the two measurement techniques is a reasonable substitute for the control method. Results The piles ranged from Although 30 of the piles measured ranged from The laser rangefinder produced results that were closer to the LiDAR-generated estimates in more than two-thirds of the samples measured in this study Figure 6. It generated volume estimates by measuring the complex shell shape of the pile Figure 4 , but it did not have the capabilities to measure the protruding branches as it is limited to convex shapes. Laser rangefinder and geometric volume estimates expressed in terms of deviation from control volume estimates. View large Download slide Laser rangefinder and geometric volume estimates expressed in terms of deviation from control volume estimates.

Chapter 3 : State of Oregon: Fire - Burning & Smoke Management

Hardy, Colin C. Guidelines for estimating volume, biomass, and smoke production for piled slash. General Technical Report PNW-GTR Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 28 p.

This is an open access article distributed under the Creative Commons Attribution License , which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. Abstract Forest restoration often includes thinning to reduce tree density and improve ecosystem processes and function while also reducing the risk of wildfire or insect and disease outbreaks. However, one drawback of these restoration treatments is that slash is often burned in piles that may damage the soil and require further restoration activities. Pile burning is currently used on many forest sites as the preferred method for residue disposal because piles can be burned at various times of the year and are usually more controlled than broadcast burns. In many cases, fire can be beneficial to site conditions and soil properties, but slash piles, with a large concentration of wood, needles, forest floor, and sometimes mineral soil, can cause long-term damage. We describe several alternative methods for reducing nonmerchantable forest residues that will help remove excess woody biomass, minimize detrimental soil impacts, and create charcoal for improving soil organic matter and carbon sequestration. Introduction Many forest stands in the western United States are in need of restoration for a variety of attributes e. Although there is broad agreement that some form of restoration of fire regimes, habitat, fish, and wildlife populations, or disturbance patterns is necessary in many areas of the western United States [4], there is disagreement about the objectives and implementation strategies [3]. In this paper we will consider slash disposal activities resulting from thinning operations that are used to reduce the volume of standing timber on a site. Stand density restoration activities usually involve cutting and removing small trees with little merchantable value [3]. Residues created from thinning activities designed to reduce wildfire were estimated to be approximately 0. To reduce the risk of wildfire, residues are often removed and transported to a bioenergy facility, dispersed across the harvest site by masticating or grinding them, or piled and burned [6 , 7]. Slash pile burning can be an economical method for disposing of harvest residues on National Forests following timber harvesting operations [8] and an effective method for reducing the volume of unmerchantable material. However, the impact of pile burning on soil processes is highly variable and can result in either relatively small impacts for a short period of time or long-term residual soil damage [9], but the ecological impacts are not well understood [2 , 10 , 11]. The high variability of soil impacts from pile burning impacts can be attributed to differences in soil texture, fuel type and loading, soil moisture, and weather conditions during burning e. Often, slash piles leave only localized soil impacts; however depending on postharvest woody residue abundance, pile size, amount, and type of fuel in the piles, soil type, fire duration, and the distribution of piles within an activity area larger-scale impacts are possible [2 , 15]. Alternatives to slash pile burning are limited and broadcast burning is often restricted by weather conditions, stand species composition, availability of expert fire crews, or air quality regulation that limit seasonal burning. Some areas are not suited for pile or broadcast burning and therefore, mastication reducing the size of woody residues is gaining popularity in many areas because it can be less expensive than burning. However, it does not remove fuels, it just rearranges them [16]. We briefly discuss the impacts of slash piles, how slash piles are currently built, and then discuss alternative methods for using waste woody residues to create biochar. Our paper is designed to provide information on the usefulness of making and applying biochar or black carbon , purposefully made charcoal for land application. Purposeful biochar applications can be a vehicle for carbon sequestration made from renewable and sustainable woody biomass, but it can also help improve soil conditions by improving soil water and nutrient holding capacity [11]. Slash Pile Impacts Determining the impacts of pile burning on soil health is complex because of the wide variability in how piles are constructed and distributed within a harvest area, amount of biomass to dispose, piling method, species composition, and pile location. In addition, soil is not a particularly good conductor of heat owing to its high internal porosity [17]. In northeastern Oregon, estimates for whole tree yarding and bulldozer-built piles are one on 4 ha 10 acres while processing trees within a harvest area may result in one bulldozer-built or hand-built pile in every 0. Because slash is concentrated into piles, heat is concentrated into a small area where it can alter soil structure [12], infiltration [18], nutrient cycling [19], soil pH [20], and microbial populations [21]. Pile burning can also impact understory plants, seedbanks, and water holding properties [2 , 22 , 23]. Many studies suggest that pile burning occur when soils are moist to limit detrimental soil heating [11 , 13], despite the potential for biological damage that can result from burning piles when the soil is moist [24 â€" 26]. When slash piles are built using a bulldozer they are often a mixture of dense fuels, mineral soil, and surface organic horizons [13 , 27]. Once ignited, the piles often burn very hot for an extended period of time [27] and can produce long-term soil impacts. Pile size also plays a key role in soil impacts [14]. Season of burning and under-pile soil moisture and texture will alter the extent of impacts Table 1. In northwestern Montana, for example, spring burning of grappler-built slash piles on fine-textured soil resulted in increases in soil organic matter, carbon, and nitrogen. Fall burning of grappler-built piles when soil moisture was low resulted in loss of more than half of the organic matter, carbon, and nitrogen. There are methods to restore burn scars e. Mean slash pile size, soil moisture, and resulting changes in soil properties to a depth of 30 cm after slash piling burning in two seasons on two soil textures relative to the control, unburned soil at the Lubrecht Experimental Forest, Montana. Current Pile Construction Techniques Slash piles are currently used as the preferred method for residue disposal because they can be burned at various times of the year, offer a larger margin of safety, and are relatively effective at removing woody residues. Pile burning has been used for many years and is often the preferred method to reduce harvest-generated slash. Piles can be constructed in a variety of ways, by hand, bulldozer, excavator grappler , or log loaders. In Table 2 we describe several strengths and weaknesses of slash pile burning. Strengths and weaknesses of slash pile burning. Hand Piles Typically these piles are a loose stack of wood built by placing one piece of wood onto the pile at a time. No care is taken to elevate the pile from the ground, but typically the pile rests on a few supporting branches that elevate the pile. There is also little effort to densify the pile during construction; leaving many air voids. In some cases hand piles do not create detrimental soil impacts as a result of heating or the act of building the pile [8 , 29], but if soil moisture is low or the piles are extremely dry, they can impact the underlying soil. Hand-built piles constructed from smaller diameter thinning slash also surpassed lethal temperatures for 24 hours in the surface soil [8]. Charcoal production from hand-built piles can be considerable, yielding a 2-fold increase in soil C content compared to preburn levels, but short-term, concomitant declines in soil quality indices water infiltration, fungal and bacterial populations, and nitrate levels were also detected [30]. Bulldozer These piles are often very dense. Piles are pushed together and, when the pile is large, the bulldozer will ride onto the pile to further compact it. This action increases the density of the pile and may also lead to changes in soil under and near the pile as the dozer can compact, displace, or rut the soil. Depending on the use of a brush rake or the skill of the operator, the resulting pile may also contain displaced forest floor material or topsoil that becomes packed into the pile base. Occasionally, displaced topsoil buries wood in the pile resulting in reduced air reaching the charred wood and creating some charcoal, similar to mound-style kilns [31]. Grappler or Log Loader This equipment can also create a dense pile for burning. In addition, the equipment operator has more control over the placement of woody residues. Instead of residues pushed into a pile, they are lifted and placed on the pile. However, similar to the dozer, excavators or grapplers can drive onto the pile or force the pile into a more compact form by using its boom and grapple resulting in more fuel in contact with the soil. However, the size of the material added to the pile is critical to how the pile will burn and the heat pulse into the soil [27]. Both dozer and excavator piles are often built on compacted landings which can increase the depth and intensity of the soil heat pulse during burning, in turn increasing detrimental impacts. Making Biochar from Forest Residues There has been increased interest in using woody residues generated from thinning or bioenergy harvests to make biochar. However, transportation costs to move unmerchantable woody material to a pyrolysis unit can be expensive, as can the pyrolysis equipment itself [32

]. Therefore, creating biochar on-site can be less expensive and immediately applied back on a site as a soil amendment or to restore skid trails, log landings, or burned areas. It also alters cation exchange capacity and soil color and is the location of many ectomycorrhizal fungi [36]. Biochar can be used to restore soil function in areas where there is a loss of organic matter. One other potential use of forest residue-produced biochar is to augment lost soil organic matter in dryland farming [37 , 38]. This carbon is more stable and has a lower risk of releasing CO2 or other greenhouse gases into the atmosphere [41]. Amending sites with biochar during farming production or on forest sites after harvesting further protects biochar from degradation as it becomes part of the stable carbon pool [42]. In the next section, we outline methods that can be much less expensive than typical pyrolysis and deliver a high-carbon product that can be used to amend the soil. Burning Slash Piles and Creating Biochar We developed an alternative method for building slash piles to reduce the amount, extent, and duration of soil impacts from burning and create more charcoal for use in soil restoration in or near the piles. To maximize the creation of charcoal the burn pile was elevated above the soil surface on large logs, with smaller material piled perpendicularly on top Figure 1. Grapplers were then used to build a pile on the base logs. There are several advantages to elevated piles: Elevated machine pile being constructed. Finished burn pile a and biochar b. Production of biochar from this type of pile can be raked into the soil around the burn area for restoration of compacted soils or to provide additional organic matter near the pile. See Table 3 for information on carbon and nitrogen produced in slash piles. Carbon and nitrogen content of biochar created using pyrolysis and some low-technology methods. Other Methods to Create Biochar Kilns have been used for centuries to make charcoal. Often built as earth-covered pits or mounds, traditional kilns provided an inexpensive, efficient means for charcoal making [43]. Other kilns have been made of brick, metal, or concrete [33]. Kilns operate in batch mode in which feedstock is added and charcoal is removed. However, newer kilns can provide automatic feed see the rotary kiln description below. Metal Kiln Kilns made of metal were designed to be relatively portable [44]. They have two cylindrical sections and a conical cover with four steam release ports and the bottom section sits on four inlet ports. Air flow into and smoke out of kiln can be controlled through the ports so that both charcoal quantity and quality can be controlled. The kiln shown in Figure 3 can hold approximately 8 cubic meters 10 cubic yards. One batch takes approximately 2 days to complete which includes loading the kiln, lighting the fire, adding the chimneys, and closing off the inlet ports. Multiple kilns at one site can process the residues more efficiently. Because the kiln is constructed in section, it can be loaded onto a trailer for transport to the harvest site. Metal kilns can be used in remote areas accessible by a pickup truck and the feedstock needs little postharvest processing, such as chipping. In addition, unskilled personnel can be quickly trained to operate the kiln. Charcoal produced from this kiln has approximately the same dimensions as the wood that was put into it. However, the charcoal fragments easily and driving over it with a large truck shatters the charcoal to make it easier to spread. See Table 3 for an example carbon and nitrogen data from this type of biochar production. Rotary Kiln Rotary kilns were developed for large-scale forest harvest operations which generate large volumes of woody residue [45]. The tube is in constant motion which quickly exposes woody residues to extreme temperatures, allowing the feedstock wood chips to be rapidly heated. The extreme heating of small particles in a low oxygen environment quickly transforms the wood into three potentially high-value products biochar, biooil, and syngas. At times, biochar is the targeted output, but for other applications biooil may be the desired output. Rotating auger moving a chips and b biochar in the rotary kiln. The entire rotary kiln unit is housed in a shipping container or trailer making it relatively portable into a forest environment.

Chapter 4 : Piled Fuels Biomass and Emissions Calculator Help

Hardy, Colin C. Guidelines for estimating volume, biomass, and smoke production for piled slash. Gen. Tech. Rep. PNW-GTR Portland, OR: U.S.

The emissions factors used previously in Consume were found to be off by a factor of 0. Recommendations and Guidance The largest errors expected from using these guidelines will occur during the process of determining the gross pile volume s. The seven stylized pile shapes do not provide an exhaustive choice of geometric shapes for piled slash. These seven are presented because they reflect general shapes observed by the author [Hardy] and other experts, and also because their volumes can be calculated relatively easily from the formulae. Try to mentally "smooth" the lobes, ridges, and valleys into an average, smooth surface. If a significant amount of soil is either entrained within the pile or mounded beneath it, the volume of the soil must be estimated and subtracted from the gross pile volume. The packing ratios presented in these guidelines represent empirical field data from destructive sampling of 17 piles. Even though guidelines are provided to determine an appropriate packing ratio for specific piles, an agency or administrative unit may choose to specify packing ratios for applications under their jurisdiction. The values given for piles with different amounts of soil contamination are weighted means from eight in situ field tests of emissions from burning of piles of woody debris. Results from many other related tests were used to develop the relationship for predicting emission factors by using combustion efficiency. The values for PM 10 were not derived from actual field observations â€" only PM2. PM10 emission factors were estimated by using limited knowledge of the size distribution of particles. Hand Piled Fuels adapted from Wright et al. Unlike other fuel categories, consumption of piles is not directly dependent upon fuel particle size. Five steps are required to estimate emissions from a hand-constructed pile or piles of the same shape, size, and composition. Geometric volume of the pile Corrected volume of the pile Consumable oven-dry mass of wood Percentage of mass consumed Mass of emissions produced Volume, biomass, consumption, and emissions for multiple piles of the same shape, size and type are calculated as the amount for a single pile multiplied by the number of piles. Geometric Volume of the Pile The volume of a pile is dependent upon its shape. Piles are categorized into one of seven generalized shapes as shown in Figure 1. The equations for each shape are in Table 1. Adjusted Volume of the Pile Geometric volume is adjusted to reflect what Wright et al termed true volume Formula 5 or 6 , depending on the calculated geometric volume. If geometric volume is less than 1 m3 or Consumable Oven-Dry Mass of Wood The mass of hand-piled fuels is determined by using regression relationships reported in Wright et al. If the hand pile is composed of coniferous material: Percentage of Mass Consumed Hardy found that the amount of woody mass consumed when machine piles are burned ranges from 75 to 95 percent. It is assumed that consumption of hand piles is similar to consumption of machine piles. Several western states have smoke management-reporting programs that recommend values of 85 or 90 percent. Experience and expert knowledge must be used to determine the most appropriate value for percentage consumption. Mass of Emissions Produced As with machine piles, the mass of emissions produced when hand piles are burned is calculated by multiplying the mass of fuel consumed by an appropriate emission factor for the emission of interest. Emission factors differ with the combustion efficiency of the fire. Cleaner piles burn more efficiently than dirty piles and produce less of the products of incomplete combustion, of which particulate matter is a major emission species. By virtue of the manner in which they are constructed, hand piles contain very little, if any, soil contamination and are considered clean for the purposes of selecting the proper emission factor from Table 3. The rate of smoke emissions produced also varies with the combustion phase of a fire. Less smoke is produced per dry mass of fuel consumed during the more efficient flaming stage of combustion than during the less efficient smoldering and residual stages. Consequently, fuel consumption is analyzed by combustion stage to produce the best estimates for total emissions. The flaming, smoldering, and residual combustion emission factors used to calculate total emissions are listed in Tables 3 and 4. These emission factors are weighted according to the amount of fuel consumed in each combustion phase Formula 4. Multiply total emissions in pounds or kilograms by or , respectively to determine total emissions in tons or megagrams. Guidelines for estimating volume, biomass and smoke production for piled slash. Specific gravity and other properties of wood and bark for tree species found in North America. Wood handbookâ€”wood as an engineering material. Estimating volume, biomass, and potential emissions of hand-piled fuels. Wood density and specific gravity listed in alphabetical order by common name.