Southwest Area Fuel Moisture Monitoring Program:

Standard Methods and Procedures

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Special recognition is also in order for Jolie Pollet, Utah State BLM Fire Ecologist, whose Fuel Moisture Monitoring Guidebook served as the starting point for the Southwest Area program.

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Introduction

Wildland fire managers have recognized the strong influence that variations in live and dead fuel moisture content have on fire behavior. Fuel moistures help drive fire suppression staffing and funding decisions; guidelines for prescribed burning call for accurate values for the moisture content of fuels (USDI 2000). The National Fire Danger Rating System (NFDRS) uses or calculates as many as five fuel moisture contents. Depending on the fuel model involved, BEHAVE (fire behavior modeling program) requires up to three dead fuel moisture values and may call for a live fuel moisture value as well.

Although live and dead fuels are a major influence on fire behavior, they are only two of many factors affecting fire behavior. Consequently, live and dead fuel moisture should not be used alone to adequately evaluate potential fire hazard and fire behavior. Used in conjunction with the effects of other fire behavior influences, knowledge of the values and trends of fuel moistures can greatly improve the accuracy of fire hazard, fire behavior, and fire effects predictions for use in fire suppression, fire prevention, prescribed fire activities, and fire rehabilitation.

There is no calculation that will estimate fuel moisture content accurately. Direct sampling of fuels is the best alternative. Regardless of the purpose of fuel moisture sampling, a standard procedure for collecting, processing, calculating and reporting the moisture content is necessary. By following established procedures for collecting and measuring fuel moistures at a representative site, you can greatly reduce the possibility of errors in the process. Therefore, standardization of the collection procedure is necessary for accurate estimates.

The objectives of fuel moisture sampling and reporting are to:

- Assist in fire behavior predictions for wildfires and fire use
- Provide a basis for severity funding
- Determine whether a site is in prescription for prescribed burning
- Aid in determining post-fire resource effects
- Determine drought or drying trends
- Validate NFDRS calculated outputs

The expression of moisture content of wildland fuels is in relation to dry weight, not just the proportion of water in the fuel. The dry material provides the heat to evaporate water so that the fuel will burn. The definition of moisture content used here is the ratio of the weight of the water contained to the dry weight of the material, expressed as a percentage. The simple formula for moisture content is:

$$\frac{\text{wet weight} - \text{dry weight}}{\text{dry weight}} \times 100 = \text{percent of moisture in sample}$$

The purpose in this document is to provide a standard procedure for collecting and handling fuel samples from various complexes of fuels found in the Southwest Area.

Dead Fuel Moisture

Dead fuels consist of small to large diameter down and dead woody fuels (1-, 10-, 100-, and 1000-hr fuels), dead grasses and forbs and surface litter such as fallen leaves and needles. The categorization of duff and soil as dead fuels is also included in this guide, since they can influence mortality in prescribed fire and fire use applications.

Small diameter dead fuels typically carry the fire and determine the rate of spread and intensity, so their moisture content is extremely important. The Estimation of one-hour fuels can be accomplished more accurately and effectively using Appendix A, Fire Behavior Field Reference Guide, 1992 of the Fireline Handbook (NFES 0065) than collection, transportation and measuring of a sample. Ten-hour fuel moisture at most NFDRS stations is calculated by a series of complex equations that use observed weather elements as inputs and provide a relative measure of drying. Some stations make use of electronic fuel moisture sensors, but fewer and fewer NFDRS stations employ the actual weighing of 10-hour fuel sticks. Calculated and electronically sensed data may not be accurate enough to use as an indicator of 10-hour fuel moisture for prescribed fire or fire use implementation.

Many vital plant parts – rhizomes, roots, tubers – reside in duff; therefore, sampling the duff layer may be necessary.

Since some of the Southwest Area has very little or no duff, collecting and measuring soil samples may be the best way to evaluate the effects of fire below the surface. This may be necessary to protect the sprouting parts of some plant species that use the soil, instead of the duff layer.

Live Fuel Moisture

Live fuels consist of conifer needles, twigs and leaves of shrubs (evergreen and deciduous) and green (live) grasses and forbs.

The basis of live fuel moisture causes some confusion among fire practitioners (i.e., how can fuel have more than 100% moisture?). The expression of moisture content in wildland fuels is in relation to dry weight, not just the proportion of water in the fuel. The dry material provides the heat to evaporate water so that the fuel will burn. The chart below details live moisture content:

Moisture Content %	Stage of Vegetative Development
300	Fresh foliage, annuals developing early in the growing cycle.
200	Maturing foliage, still developing, with full turgor.
100	Mature foliage, new growth complete and comparable to older perennial foliage.
50	Entering dormancy, coloration starting, some leaves may have dropped from the stem. Also indicative of drought conditions.
>30	Completely cured.

The changes in live fuel moisture content directly relates to the physiological activity of the vegetation. The differences caused by soil moisture, soil temperature, relative humidity and air temperature are identifiable. During seasons of deficient precipitation, there is less seasonal growth, and moisture levels are lower in other living material than during seasons of normal or above normal precipitation. If this moisture deficiency persists through the summer, live fuel moisture can drop at an increasing rate.

Soil and air temperatures affect the time new growth starts and the level of moisture attained by the vegetation. In situations when soil moisture is not limiting, new growth will start earlier and often reach a higher level of moisture when the weather in late winter and spring is warm than when the weather is cold. Other factors that affect soil and air temperatures, such as slope, aspect, and elevation also affect the amount of new growth, the timing of growth, and the level of moisture in the living material.

The moisture patterns of different plant species vary seasonally. Moisture variations also occur between plants of the same species in the same locale, and often in material taken from different heights and aspects on the same plant. Site quality also affects live fuel moisture; shrubs on good sites tend to produce a greater amount of new growth, have higher moisture levels, and decrease in moisture more slowly during the summer than shrubs on poor sites.

Live plants may either suppress combustion or contribute to it, depending on their moisture content and flammability of chemical compounds contained in the plant. The NFDRS uses weather variables to estimate the moisture content of shrubs and herbaceous plants and then calculates the ignition component, spread component and energy release component from this information. However, previous experience has shown that control of the moisture content in live vegetation occurs by species physiology, available moisture and time of year. Therefore, these external variables may not give an accurate calculation.

Getting Started Sampling Fuel Moisture

For purposes of establishing trends in moisture content, the principles applied in sampling and monitoring fuel moisture are similar to those used in fire weather observations. We take fire weather observations at stations selected as being typical in weather characteristics of the geographical area of interest. Because of the geographical variability of local weather, observations at the station at any given time are not likely to correspond precisely to weather conditions at other points within the area. Therefore, a weather observation at the station is actually only a sample of the weather for the larger geographical area.

To begin observations of fuel moisture, select an area of a few acres that is representative of a more extensive geographical area. Collect samples of fuel from this small area for moisture determination. This fuel moisture sampling area serves the same function in fuel moisture monitoring as the weather station in the monitoring of fire weather. Like the fire weather sample, the fuel moisture sample will only approximate the fuel moisture conditions over the larger geographical area because of the spatial variations in factors influencing fuel moisture.

There are four major factors affecting the comparison of fire weather observations and indices. These include:

1. standardization of weather instruments,
2. the exposure of these instruments to variable weather conditions,
3. observation procedures, and
4. the specific time that observations are made.

Time and space comparability of fuel moisture observation are achieved by:

1. standardization of fuel sample collection,
2. moisture determination procedures, and by
3. specification of sampling conditions.

Site Selection for Establishing Seasonal Trends

When establishing a system to observe and monitor fuel moisture, select an area that represents a larger geographic area. Climatic variation is the primary parameter to consider in setting the boundaries of these areas.

It may be beneficial to select sites with interagency partners to capture variation in fuels, climate and geographic area. The goal here is to minimize duplicate efforts and the expenditure of time. Year-to-year comparison of fuel moisture levels and trends is an important function of all sampling areas. Therefore, sampling areas should be located on sites that are not likely to be disturbed over a period of years.

The site should represent the fuel model of concern; it should be relatively undisturbed, such as by heavy grazing or fuel manipulations, unless this highly represents the model. The sample collected should be the main carrier of fire or the one that represents most of the plant species in the area. If more than one plant species is of concern, it may be necessary to sample these as well for some time to determine if the moisture cycles of one represents the others. In addition, since the moisture cycles of deciduous vegetation is very different from evergreen vegetation, it may be necessary to collect samples of both to get an accurate representation of an area.

Ideally, the site should be located near a RAWS, or in an area with weather data collected by a nearby automatic or manual weather station. Location of the site near a weather station allows for study of the long-term correlation of fuel moisture cycles to weather. If monitoring / trending will occur during winter months a heated tipping bucket may be necessary for accurate measurement of collected precipitation.

The sampling site or plot should be about 5 acres in size, and relatively homogeneous in terms of species composition, canopy cover, aspect, and slope steepness. It should be easy to travel to and access, but not located near roads or water bodies.

Collect samples throughout the sampling area adhering to local protocol. For example, if a selected species is only located in a few spots on the site, it should be determined if individual samples will be collected in each location or if composite samples will be made.

Establish a photo-point by placing a permanent steel post at a location near the center of the plot. Take photos of the general setting of the site looking in the four cardinal directions from the photo-point. Adding a brightly colored, vertically placed meter stick will serve as a size reference for the vegetation. Photos looking downwards toward the fuels in four directions will also be useful for characterizing surface vegetation, litter and the amount of exposed soil.

Site Selection for Prescribed Fire

Fuel samples collected in conjunction with prescribed fire activity should represent the project area, spanning the range of conditions, elevations, positions, and situations at the prescribed fire site. If the fuels surrounding the prescribed fire area are notably different from those within it, it may be advisable to sample the surrounding fuels as well. Differences in anticipated fire behavior within and outside the intended fire area help to determine the needed contingency suppression resources in case the fire escapes.

Personnel for Fuel Sampling

Regardless of the reason for determining fuel moisture content, the sampling must follow standard techniques. Specific procedures for collecting live fuels must be determined for each species. Sloppy sampling and handling procedures can lead to poor results or serious mistakes. Only trained, skilled people should sample and handle the fuels and they must adhere to the procedures outlined in this guide. To achieve greater consistency in the results, the same person or small crew should do all the sampling in a given area.

Sampling Period and Frequency

If the purpose in sampling is to determine trends or for input to the NFDRS, begin sampling in the spring and continue until there is no potential for fire. Some areas in the Southwest Area will require sampling on a year round basis. This permits monitoring of fuel moisture from dormancy to peak moisture, through the decline of moisture during the summer, and into the often critically low moisture period in the fall. The standard time for NFDRS weather observations is at 1400 LDT (Local Daylight Time), usually the warmest part of the day. Collecting samples at this time is ideal; it is generally the time of day of highest temperatures and lowest relative humidity and will allow correlation of your information with other established outputs.

Since moisture content of live fuels, soil and 1000-hr dead fuel change slower, sampling periods of 10-15 days apart will normally be sufficient to indicate moisture trends; however, additional samples during prolonged heat waves or following precipitation may be desirable, particularly in the smaller size classes.

The seasonal period and frequency of sampling before prescribed burning is different for each situation. Sampling live fuels through fire season for a year or more prior to a prescribed fire can provide valuable information. This can be particularly important if the seasonal pattern and range of values of foliar moisture for key species are unknown. If you plan to conduct a fire during a particular part of a season, fuels will generally need sampling only before and during that period. If the prescription requires a specific set of weather and fuel moisture conditions, begin sampling several weeks before the targeted date of the prescribed fire. It may even be necessary to sample daily, as you get closer to prescription.

The Number of Samples to Collect

The sampling of fuels costs time and money, but so do errors in estimating how a fire will behave. It is the variability of the moisture content of a particular fuel across a burn unit at any given moment, along with the required precision, that combine to determine the number of samples needed; this number will vary, depending on the specifics of the operation, desired outcome and long-term effects sought.

See Appendix A for more detail and a worksheet to aid in determining the number of samples to collect. If you are unable to collect the number of samples that the worksheet recommends, a minimum of three should be collected.

Equipment Needed for Sampling

Refer to Appendix B for suggestions and estimated prices for equipment, and for a list of possible vendors to purchase equipment.

Containers

Containers for fuel moisture samples should have tight-fitting lids, be rustproof and labeled. Recommended containers are plastic bottles/jars that can tolerate high temperatures and have tight fitting lids that prevent moisture loss. Metal soil sample cans and zippered self-sealing bags made specifically for fuel moisture sampling are also available. However, do not to use metal cans made of steel since they may rust and the lids often do not seal properly; aluminum sample containers work well. In addition, plastic bags can be used to transport sample, but should not be used in the oven for drying. If using other drying devices, such as a Computrac moisture analyzer, glass containers such as mason jars will work as well. Containers should be marked with sequential numbers or some other identifying label. Mark containers and their corresponding lids by etching, stamping or with a permanent marker. Each lid and each container pair should be marked with the same label. If using the container in a conventional drying oven, weigh each clean, labeled, container plus lid to the nearest 0.1 gram and record this information in your files. Also, weighing these empty containers periodically will verify the weight has not changed. If using the Container strictly to transport samples, keep it clean and dry in its storage container.

If using metal cans, use ½-inch drafting tape to avoid spilling and escape of moisture. Masking, electrical, and shipping tape may leave a residue that is hard to remove and may affect tare weights. It is not necessary to seal plastic containers with screw-on tops and plastic zipper bags with tape.

Clippers

Good quality pruning shears with two curved sharp blades are most effective for clipping fuels. At least two pair should be available. Sharpening may be necessary during the field season.

Garden Trowel

Use a trowel with a heavy shank and a sharp blade for duff and soil sample collection.

Carrying Case

All field sampling equipment, supplies and necessary paperwork should fit into a carrying case. Insulated plastic coolers work well, or constructing a custom container may be done. The case should keep the samples cool and from losing moisture during transportation. Between sampling periods, keep all sampling equipment, supplies and extra forms in the carrying case.

Drying Oven

Electric ovens designed specifically for drying samples are available commercially. The best type is a forced-air convection oven (also known as a mechanical convection oven) with a fan to circulate the heated air. The oven must be able to maintain a regulated temperature. Place a thermometer designed for oven use in the oven to verify the actual temperature. The size and cost of ovens varies; use the oven that best suits the number of samples you expect to dry at any one time.

Moisture analyzers, such as a Computrac are also available. These devices predict values based on an algorithm, and can significantly reduce the amount of time required to obtain results.

It is preferable to avoid using a gravity convection oven because of their inability to regulate temperatures throughout the oven and the time required to heat the oven. However, since some units may have already purchased gravity convection ovens and they are useable, longer drying times must be factored in for numerous or very wet samples.

Scale

The weighing of samples requires a scale. A top-loading electronic scale capable of accurately measuring to the nearest 0.1 gram is adequate. These scales allow rapid weighing and are inexpensive; field usable, battery operated models are also available. Regarding scales, the most important factor is the use of the same scale whenever weighing a specific sample.

Accessing Information on Plant Phenology

The Fire Effects Information System (http://www.fs.fed.us/database/feis) is the most complete and accessible database for information on plant phenology. This database will supply valuable information on the various indicator species in the Southwest Area.

Collecting Fuel Samples

Material to be Sampled

The goal is to sample the moisture content of the materials that influence the way a fire will burn in those fuels. Selecting fuels to sample varies with the reason for sampling and the fuel type. To choose what fuels to sample, it may be necessary to seek guidance from others with experience, by doing research, from direct observation and other sources of documentation.

The sampling and processing of fuels may include one or more of the following:

1. Dead Fuels
    - Small diameter down and dead woody fuel, 0 – ¼ inch in diameter (1-hour fuels)
    - Branch wood down and dead woody fuel, ¼ - 3 inches in diameter (10, and 100-hour fuels)
    - Large dead and down woody fuel 3+ inches (1000-hr fuels)
    - Duff and soil
    - Dead grasses, forbs

- Surface litter, such as fallen leaves and needles.

2. Live fuels
    - Foliage, leaves and twigs
    - Green (live) grasses and forbs.

Sampling Methods

On arrival at the sampling site, place the sample case in the shade and prepare the field data sheet. Record the site name, date, time, and name of observer, weather observations and container label.

The sample collected should fill the container at least three-quarter full or about 20 grams. Once collected, place the samples in the carrying case for transportation.

Prior to weighing the samples, keep them cool and dry; refrigerate / freeze them if it is not possible to weigh within the first few hours after collection. Additionally, if the sample will be processed using a moisture analyzer (i.e. Computrac), storage for 24 to 36 hours will allow all of the material sampled to equalize, and will reduce the number of samples to run for an adequate measurement. Allow the sample to return to room temperature before processing. Discard Samples older than 72 hours and collect new samples.

Dead Fuels

Collecting the Sample

Do not collect dead fuels if water drops from rain or dew are present on material because the presence of free surface water will cause large errors in calculated moisture content. Shaking the sample to remove excess water or attempting to dry the sample in any way is ineffective. Return to the site later in the day or the next day to collect the samples.

A sample easily rendered to powder or dust when handled is generally unacceptable; however, some splitting caused by drying is acceptable. If the material is in such an advanced state of decay, it is more appropriate to treat it as a litter or duff fuel type. Collect wood in various stages of decay in proportion to its presence on the site, following the guidelines stated.

Fuel Sampling Guidelines

1- and 10-Hour Fuels

Take samples of 0- to ¼-inch and ¼ to 1-inch-diameter down and dead woody fuels from several twigs and branches resting on the ground. Depending on the reason for sampling (i.e. prescribed fire vs. wildland fire), it may be necessary to collect samples from shaded or unshaded areas, or a combination of both. Regardless, do not collect the entire sample from one location or from a single branch. Collect twigs of as many sizes as possible within the size class. All samples must be collected from dead wood that is detached from its growth point. Do not collect parts buried in the litter, duff, or soil. Do not collect dead branches attached to the base of live trees or shrubs.

Cut several 1- to 1½-inch-long sections from each 0- to ¼-inch diameter down, dead twig or branch and collect in the sampling container.

Collect only one piece of sample from each ¼- to 1-inch down, dead branch and put in the sampling container. These samples should not be from the terminal end of the fuel; take the sample from at least one inch from the end. Remove all lichen or other debris and very loose pieces of bark from the samples prior to placing in the sample container.

100- and 1000-Hour Fuels

Take samples of 1 to 3-inch, 3+-inch diameter down and dead woody fuels from one or more branches resting on or are just above the ground. All samples must be collected from dead wood that is detached from its growth point. Do not collect parts buried in the litter, duff, or soil. Do not collect dead branches attached to the base of live trees or shrubs. Do not sample from branches or logs that have recently fallen.

For 100-hour fuels, select a sound branch (1- to 3-inches in size) and slice out one or more wafers less than ½-inch thick, starting at least six inches from the end of the branch.

For 1000-hour fuels, select a sound log 3- to 8-inches in diameter and slice out one or more wafers less than ½-inch thick, starting at least six inches from the end of the branch. Use a hand saw for cutting wafers; oils from chainsaws may affect the dead fuel moisture results. Each wafer is one sample. Remove all lichen or other debris and very loose pieces of bark from the samples. Another way to collect samples is to use a brace and large wood bit. To do this, bore at least two cross section holes completely through the material at 45-degree angles. Just as taking wafers, the holes should be at least six inches from the end or any other holes previously drilled.

Other methods that will work for measuring 100- and 1000-hour fuels are to:

- use a moisture probe that can be inserted into branches and logs
- chopping up a wafer obtained from a branch or log and putting it into a sampling container to be dried and weighed or,
- place an oven-dry piece of branch or log wood of a known dry weight on a site to measure increases in fuel moisture (similar idea to the 10-hour fuel sticks).

If consistently followed, these methods may all be acceptable. Be sure to note the sampling method used in the remarks section on the data collection forms.

Duff and Soil

Moisture content of duff and soil has important influences on the depth of burning below the ground surface. Careful, selective and concise sampling is required if duff and soil moisture measurements are to be accurate and consumption of these fuels predicted well. When collecting duff and soil samples, measure the depth of the collected sample; do not estimate. The base of the litter layer is a reference point for the duff depth and the base of the duff layer (if there is a duff layer) is a reference point for the soil depth. To accurately measure moisture conditions, it may be necessary to collect several duff or soil samples at a site and at different depths. As before, select sampling spots that are representative of the area (i.e. shaded /unshaded). Additionally, collect these samples at the same time each time samples are collected.

To differentiate between the litter, duff and soil layer, use these rules of thumb:

- Material in the litter layer is generally not compacted, but could be organized enough for slight compaction to begin
- Material in the duff layer will be decomposed so that the original plant species is not readily recognizable
- The duff layer often contains a very dense network of very fine hair-like strands, called fungal hyphae, and
- Soil particles are generally easy to feel when rubbed between your fingers, and will fill the indentations in your fingertips.

Remove all live plant stems, roots, or other parts of living plants, and animal droppings from the samples. Be careful to avoid including mineral soil in the duff sample (and vice versa), also avoid stones in the sample. Place the sample in a sampling container with a lid.

Dead Grasses and Forbs

Collect the sample from 15 to 20 plants. Collecting this sample requires clipping dead blades or vegetation from all portions of the grass/forb, including, tops, and sides. Collect vegetation that is brown or tan, but not gray looking. Collect an entire specimen and clip it into short pieces as you place it into the sample container.

Litter

Gather litter (whole, undecomposed leaves or needles) from both sunny and shady spots within an area. Collect only uncompacted dry litter. Place litter into the sampling container.

Live Fuels

Collecting the Sample

Do not collect live fuels if water drops from rain or dew are present on leaves or stems because the presence of free surface water will cause large errors in calculated moisture content. Shaking the sample to remove excess water or attempting to dry the sample in any way is ineffective. Return to the site later in the day or the next day to collect the samples.

Place only the twigs and foliage into the sample container. Remove any flowers, seedpods, nuts, berries and similar material. Also, remove any dead material.

Plant material often stiffens as it dries, and it may spring from the containers while in the drying oven. This makes the lid difficult to replace and some of the sample may fall out. For this reason, pack material loosely in the container. Never compress samples to get extra material in the container; however, collect an adequate amount to fill the container about ¾ full, or approximately 20 grams. Cut the stems of each shrub or herbaceous plant into small pieces and let them drop into the container. Cutting the plants into smaller pieces also allows a greater amount of material to fit into the container.

As you move about the site and collect material, replace the lid on the container to cover materials already collected. When the container is full, immediately replace the lid tightly;

record any comments or observations about the phenology of the plant in the remarks section on your field data sheet at this time.

Sampling Guidelines for Tree, Shrub and Grass/Forb Fuels

Juniper Trees

Using clippers, clip the foliage (needles) into the sampling container. In the container, clip a mixture of new and older growth and take material from all sides of trees. Foliage from more than one tree can be in the same sample container. Take samples from several trees at different heights and different aspects. Only collect foliage, not stem material from trees. Do not include dead or diseased foliage, cones, or berries in any stage of development.

Conifers

Using clippers, clip only the needles formed in previous years, but not foliage from twigs so old that they are thickened or woody. In the container, clip a mixture of new and older growth and take material from all sides of trees. Foliage from more than one tree can be in the same sample container. Take samples at different heights and different aspects. Only collect foliage, not stem material from trees. Do not include dead or diseased foliage or cones in any stage of development.

Shrub

Using clippers, clip the foliage and pliable small stem material into the sampling container. In the container, clip a mixture of new and older growth and take material from all sides of shrubs. Foliage from more than one shrub can be in the same sample container. Take samples from several shrubs at different heights and different aspects. Eliminate all dead twigs or twigs with diseased or insect-infested foliage. Do not include flower buds, flowers, seedpods, or berries in any stage of development.

Grass/forb

For grasses, collect only the leaves; do not collect seed heads. Do not collect stems, seed heads or succulent white or pale-green leaf bases. For tall grasses, clip the leaves from all vertical portions of the plants cutting the blades near their point of attachment to the stem. For smaller grasses, clip blades of different lengths; include only the leafy material and not the base of the leaves.

For forbs, collect the entire plant of small, single-stemmed forbs by clipping the stem at ground level. If a species has multiple stems, cut one stem with leaves from each plant. Remove and discard all flowers and fruits in any stage of development from all herbaceous plants.

Clip these materials into pieces, as you fill the container.

Drying the Samples

Conventional oven

Preheat the drying oven to a minimum of 60°C (140°F). Transfer the information from the field data sheet to the calculation sheet. Adjust the scale to zero. Place a closed container on the center of the scale platform. Read the scale and record it as the "wet" weight on the calculation sheet. Check to see that the identification and contents of the container match those recorded on the field and calculation sheets. Repeat this procedure with all samples. Also, verify the scale is set to zero between each sample, since minor vibrations and movement of the scale while weighing can cause errors.

Remove the lid as you put the sample in the drying oven. If any sample material falls out when placing it in the oven, throw this material away and weigh the sample again. Space the samples evenly in the oven so that air circulates freely around every container. If drying only a few samples, center them on the middle rack of the oven. Record the date and time that the samples were put in the oven.

For 100-hour, or 1000-hour samples in wafer form, remove the wafer from its container and weigh it. Place the wafer directly on the rack in the oven and dry; weigh as you would for samples in containers.

Dry the sample for at least 24 hours at a minimum of 60°C (140°F). Large samples of very wet fuels or fuels with a waxy surface, such as manzanita, should dry 48 hours. Do not put additional samples into the oven while drying a set of samples, as the original samples will absorb moisture from the new samples and require additional drying time. Dry very wet samples, especially 1000-hour fuels, for 24 hours and then weigh; then dry for an additional 12 hours. If the weight does not change, the sample is dry. If the weight changes, continue to dry until the sample does not lose additional water weight.

At the end of the required drying time, take the samples from the oven and quickly replace the matching lid tightly. This prevents the absorption of moisture from the air. Do not leave the oven door open. Open the oven door only long enough to remove a few samples, as moisture from the room may enter the oven and be absorbed by the dried samples inside, causing errors. If any sample material falls from a container during the drying process, throw the sample away unless you know which container it fell from and you can replace all of it in the right container.

Check the container number and its contents before you record the dry weight on the laboratory sheet. Check the scale for a zero weight setting before weighing the next sample.

After weighing each dried sample, save until the fuel moisture content is calculated. If an obvious error appears in the calculation, reweigh the sample again to verify. After making fuel moisture calculations, discard the sample and clean the container for reuse. Wiping with a clean rag is sometimes enough to clean the containers, but they may need to be washed and scrubbed to remove plant residue. Containers should be free of residue and completely dry.

Once they are reconditioned, replace the lids and store the containers in the carrying case for future use.

Moisture Analyzer

Moisture analyzers, such as a Computrac, use computer technology to reduce test times. They work by placing a sample on aluminum sample pan sitting atop an electronic force balance inside a test chamber. As the sample heats and loses weight due to moisture evaporation, the balance records that weight loss and transmits the data to a microprocessor. The microprocessor interprets the information and compares the samples weight loss to a standard drying curve. The microprocessor makes the calculation of the final value from the curve, giving you results in minutes.

The Computrac has the dry weight formula loaded into its firmware specifically for forestry and can test the material in one of three ways:

- Utilizing a program with pre-established parameters (most efficient)
- Utilizing a "rate" mode, which completes the test when a pre-specified rate of weight change remains constant for 8 seconds, or
- Utilizing an "auto predict" mode, which completes the test when the moisture loss curve and algorithm match up.

Whichever method is used, allow the unit to equalize to the idle temperature for the material to be tested. Once equalized, open the lid and place a clean pan on the pan support. Close the lid and press [start]. The unit will tare the empty pan, and then prompt you to load the sample. Open the lid; without jarring the sample pan, load the sample, spreading evenly throughout the pan. Close the lid on the analyzer to begin the test. Quickly replace the lid on the container holding your sample, so to not transfer any additional moisture. Allow the analyzer to process the sample, usually six to ten minutes. Once the test has completed, note the value from the analyzer on the log sheet, open the lid, then gently remove the pan and sample and discard. Allow the unit to cool back down to idle temperature before testing the next sample. Repeat this procedure three to five times per sample for averaging or until the entire sample is gone. When running the additional samples, load the same quantity each time into the analyzer to ensure near identical tests.

Calculating Moisture Content

The formula for calculating moisture content is:

$$\frac{\text{weight of water in sample}}{\text{dry weight of sample}} \times 100 = \text{percent of moisture in sample}$$

An easier formula would be:

$$\frac{\text{wet weight} - \text{dry weight}}{\text{dry weight} - \text{tare weight}} \times 100 = \text{percent of moisture in sample}$$

The use of the excel spreadsheets can greatly increase the speed and accuracy of the calculations.

Common Sources of Error

Field Errors

Some of the most common sources of error while collecting samples are:

- Placing the samples in a container with a different number than is listed on the field data sheet
- An incorrect lid on a container
- Incorrectly recording the container number on the data sheet
- Drops of rain or other free water contaminating the sample
- Small rocks, animal droppings, and other material are included in the duff, soil, or litter samples
- An inadequate amount of material is collected. Remember to fill the container at least ¾-full
- Failure to collect material from several spots, aspects, and plants on a site
- Heating a sample prematurely with excessive exposure to the sun or leaving in a vehicle. This is detectable by condensation on the inside of the containers lid
- Plastic bags not labeled, have holes, or not sealed properly.

Laboratory Errors

Some of the most common sources of error in the laboratory are:

- Failure to check the container numbers against the sample contents as recorded on the calculation sheet
- Some material falls out of the container while drying
- Failure to set the scale to zero before weighing
- The scale is misread
- Errors are made during the entry of values into the calculator or while doing the calculations (this is possibly the greatest single source of error – double-check!)
- When using a moisture analyzer, leaving a sample container open with untested sample inside and,
- Metal cans that have rusted; clean or discard if this occurs.

Data Reporting and Display

Southwest Area Fuel Moisture Monitoring Program Web Page

All reporting and display of sampled fuel moisture data will be done through the Southwest Area Wildland Fire Operations Web Site (http://www.fs.fed.us/r3/fire), under the Predictive Services – Fuels section. This web page will also have information and resources pertaining to the program, including a copy of this document, maps depicting the sampling locations and electronic versions of the various forms. The online form used for entering sampled data will be protected with a global password, which will be distributed to participating units. As a backup to the online reporting method, data should be faxed to SWCC using the main fax number found in the Southwest Area Mobilization Guide.

Fuel Moisture Monitoring Site Description Form

In order to participate in the Southwest Area Fuel Moisture Monitoring Program, units are required to submit a completed Fuel Moisture Site Description Form (Appendix A – 1) for each sampling location. Site description forms need to be submitted to Southwest Area Predictive Services by February 15th of each year to allow adequate time to prepare the various maps and web resources that will facilitate display of the information throughout the fire season.

Reporting Requirements

Sampling should be done at the beginning and middle of each month from at least March 1st through November 1st, and submitted to Southwest Area Predictive Services by the first and third Thursday of each month. A schedule of the specific reporting due dates will be posted on the Southwest Area Fuel Moisture Monitoring Program web page for reference. Units may elect to sample and submit data more frequently, or for a greater portion of the year, and all data received by the reporting due dates will be utilized and displayed.

Calibration of NFDRS Fuel Moisture Values

As part of the fuel moisture monitoring program, it is expected that fuel moisture data obtained will be entered into WIMS to calibrate the NFDRS fuel moisture values for the appropriate RAWS/NFDRS stations. This should be done as soon as possible after samples have been taken, using the "ENFDR" Fastpath in WIMS. Consult the WIMS User's Guide or Appendix C of this guide, or contact the WIMS Help Desk or Southwest Area Predictive Services for further assistance.

Data Reports and Displays

Sampling data will be posted to the Southwest Area Fuel Moisture Monitoring Program web site within 1-4 days of the reporting due dates, from March through early November. From December through February, data may be posted periodically depending on how many reports are received and whether or not there is a perceived need. Reasonable efforts will be made to accommodate special requests from the field for the posting of data. Reports and displays will include:

- A clickable map of the Southwest Area showing all the sampling locations and providing access to the site description and most recent data graphs.
- A comprehensive report including both tabular and graphical depictions of all the data, broken down both by sampling location and sampled species.

References

Measuring moisture content in living chaparral. Gen. Tech. Rep. PSW-36. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1979. 27 p.

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Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (2002, October). Available: http://www.fs.fed.us/database/feis/.

Measuring fuel moisture content in Alaska: Standard Methods and Procedures. Gen. Tech. Rep. PNW-171. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 34 p.

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APPENDIX A – FORMS

The following forms are described below and are available on the Southwest Area Fuels Monitoring Program web page:

1. Fuel Moisture Site Description Form
2. Worksheet for Determining Number of Samples
3. Fuel Moisture Content Worksheet

1. Fuel Moisture Site Description Form

1. Date ____________________________ 2. Observer ___________________

3. Unit _____________________________ 4. Site Name or # ______________

5. Latitude _________________________ 6. Longitude __________________

7. UTM Coordinates __________________

8. Major Vegetation: (include an * next to those species that will be routinely sampled)

Tree species 1_________________________ percent cover_____________
Tree species 2_________________________ percent cover_____________
Tree species 3_________________________ percent cover_____________
All other trees_________________________ percent cover_____________

Shrub species 1_________________________ percent cover_____________
Shrub species 2_________________________ percent cover_____________
Shrub species 3_________________________ percent cover_____________
All other shrubs_________________________ percent cover_____________

Grass/forb species 1____________________ percent cover_____________
Grass/forb species 2____________________ percent cover_____________
Grass/forb species 3____________________ percent cover_____________
All other grasses/forbs__________________ percent cover_____________

9. Predominant aspect _____________ 10. Predominant % slope __________

11. Elevation (feet) __________________ 12. NFDRS fuel model ____________

13. Associated NFDRS or RAWS weather station number(s)__________________________

14. Vegetation condition description of layer chosen for moisture sampling:

Average height (ft) _____________ Percent dead _____________

Continuity of layer ______________

15. Photo numbers and descriptions____

16. Historical Data: Year that data began to be collected at site____________________

17. Historical Data: Do you have records of previously collected data YES / NO

If yes, please send records electronically to cmaxwell@fs.fed.us or mail to Chuck Maxwell c/o SWCC, 333 Broadway SE, Albuquerque, NM 87102.

Instructions - Fuel Moisture Site Description Form

Instructions: Complete this site description form. Take digital photos of the area on the same day the site is described.

1. Enter the date of this observation.

2. Enter the observer's name so there is a contact for questions.

3. Enter organizational unit by name (ex. Taos Field Office)

4. Site Name descriptive of location (ex. Dry Park) or site number.

5 - 7. Enter latitude and longitude (NAD 83) or UTM coordinates and zone as displayed by GPS or determined from a map.

8. Enter the names of the predominant species on the site and the approximate percent canopy cover of each for the following: trees, shrubs, and herbaceous. Include an asterisk (*) next to those species that are intended to be sampled routinely. Leave blank if type isn't present. If there are more than three species of a type on site, enter the percent coverage of all the remaining species of that type and list the other species (in no particular order). Also enter the percent cover of bare soil at this time of year, that is soil that is not covered by either live or dead plant material.

9. Enter the general aspect of the site as N, NW, W, SW, S, SE, E, NE.

10. Enter the average or most common percent slope on the site.

11. Enter the site's elevation in feet.

12. Enter the NFDRS fuel model that best represents the vegetation on the site.

13. Enter the NFDRS or RAWS weather station number(s) associated with the site (if one is associated).

14. Describe the general condition of the vegetation layer that is being sampled for moisture content: average height in feet, an estimate of the average percent dead material in the plants, the continuity of the plant layer (continuous, patchy, isolated individuals).

15. Note the photo numbers/names and a brief reference to the scene pictured.
In the Remarks Section include any other information about the condition of this vegetation that has not been covered (i.e., grazing disturbance, insect: disease, activity, etc).

16-17. Enter the year that data began to be collected at the site and indicate whether or not there are historical records available.

2. Worksheet for Determining Number of Samples

The following worksheets can be used to help determine the adequate number of samples to take. The first worksheet can be used to calculate the sample size, and the second worksheet is an *example* of how to use the worksheet to calculate sample size. The CD contains an excel version of this worksheet.

Worksheet to Calculate Sample Size

A. How many pre-fire samples have been collected?
n = ____________

B. How close must your value of fuel moisture content be for your intended project?
± _________percent

C. Using your pre-fire samples, list one set of collected moisture content samples below:

	x	x^2		x	x^2
1	________	________	11	________	________
2	________	________	12	________	________
3	________	________	13	________	________
4	________	________	14	________	________
5	________	________	15	________	________
6	________	________	16	________	________
7	________	________	17	________	________
8	________	________	18	________	________
9	________	________	19	________	________
10	________	________	20	________	________

D. Add all the values of x: Σx = ____________

E. Multiply each value by itself (x^2) and add all the values:
Σx^2 = ____________

F. Multiply the value in **D** by itself and divide by the value in **A**: $(\Sigma x)^2/n$ = ____________

G. Subtract the value in **F** from the value in **E**: $\Sigma x^2 - (\Sigma x)^2/n$ = ____________

H. Subtract 1 from the value in **A**: $(n - 1)$ = df = ____________

I. Divide the value in **G** by the value in **H**: $(\Sigma x^2 - (\Sigma x)^2/n) / (n - 1) = s^2$ = ____________

J. What is your acceptable moisture content error?
± ____________ percent

K. How sure (percent) do you want to be that you will be within your range of acceptable error? P = ____________ percent

L. Take the value in **K**, subtract it from 100, and divide the result by 100: $(100 - P) / 100$ = probability = ____________

M. Go to a t table and down the left-hand column under "df" to the value in **H,** and across to the right to the column under the probability value in **L.**

List the value at the intersection: t = ____________

N. Multiply the value in **J** by itself: E^2 = ____________

O. Multiply the value in **M** by itself: t^2 = ____________

P. Multiply the value in **I** by the value in **O** and divide by the value in **N**: $(t^2 s^2) / E^2 = m$ = ____________

Q. Round to the next highest integer: __________

This is the number of samples you must collect to be sure you will achieve your acceptable precision in estimating the moisture content of the selected fuel.

Worksheet to Calculate Sample Size-Example

A. How many pre-fire samples have been collected? n = 12

B. How close must your value of fuel moisture content be for your intended project? 1 percent

C. Using your pre-fire samples, list one set of collected moisture content samples below:

	x	x^2		x	x^2
1	7	49	11	7	49
2	9	81	12	6	36
3	8	64	13		
4	7	49	14		
5	6	36	15		
6	8	64	16		
7	9	81	17		
8	10	100	18		
9	9	81	19		
10	8	64	20		

D. Add all the values of x: Σx = 94

E. Multiply each value by itself (x^2) and add all the values:
Σx^2 = 754

F. Multiply the value in D by itself and divide by the value in A:
$(\Sigma x)^2/n$ = 94 x 94/12 = 736.3

G. Subtract the value in F from the value in E:
$\Sigma x^2 - (\Sigma x)^2/n$ = 17.7

H. Subtract 1 from the value in A: $(n - 1) = df$ = 11

I. Divide the value in G by the value in H:
$(\Sigma x^2 - (\Sigma x)^2/n) / (n - 1) = s^2$ = 17.7/11 = 1.6

J. What is your acceptable moisture content error? ± 1 percent

K. How sure (percent) do you want to be that you will be within your range of acceptable error? P = 90 percent

L. Take the value in **K**, subtract it from 100, and divide the result by 100: (100 – P) / 100 = probability = (100 - 90)/100 = 0.10

M. Go to a t table and down the left-hand column under "df" to the value in **H,** and across to the right to the column under the probability value in **L**. List the value at the intersection: t = 1.796

N. Multiply the value in **J** by itself: E^2 = 1

O. Multiply the value in **M** by itself: t^2 = 3.23

P. Multiply the value in **I** by the value in **O** and divide by the value in **N**: $(t^2s^2) / E^2 = m =$ 5.2

Q. Round to the next highest integer: 6

This is the number of samples you must collect to be sure you will achieve your acceptable precision in estimating the moisture content of the selected fuel.

3. Fuel Moisture Content Worksheet

Agency	State	Unit	Site Name/Number

Collection Record			Moisture Determination Record		
Observer	Date	Time	Observer	Date in oven	Time put in oven

Container Number	Species (Live) Size Class (Dead)	A	B	C	D	E	F
		Gross Weight		Tare Weight	Water Weight	Dry Weight	Percent Moisture
		Wet	Dry				

Sample Material Collected		Calculation Summary
		A - B = D B - C = E (D / E) * 100 = F
Live Fuels [ ]	Dead Fuels [ ]	
		Average of Samples =

Weather (Optional)

Dry Bulb _______   RH _______%   Wet Bulb _______   Cloud Cover _______

Please submit final fuel moisture data via the Fuels section of the SWCC web site at www.fs.fed.us/r3/fire/ Backup Method - FAX: 505-842-3801	Remarks:

Instructions for moisture content sampling data sheet

The form has room to enter 15 samples. You will need at least one copy of each form for live and dead fuel samples, but you may use more forms for differing vegetation types or when you take more than 15 samples.

1. Enter header information on each sample collection form:
   Agency
   State
   Field Office
   Site name or number

2. Enter **Collection Record** header information:
   Observer (your) name
   Date
   Time

3. Take a few moments to fill out the **Remarks** section with any phenological observations or other comments. Note anything unusual or of special interest about the site. Also note if you're collecting anything other than a *mix* of old and new growth for live fuel samples.

4. Mark the appropriate boxes for the type of sample material collected (live or dead fuels). For live fuels, mark whether you're collecting leaf and stem material or leaf material only.

5. Enter the **Container Number** as you select each from your pack or box.

6. If collecting only 1 species for live fuel moisture, note the species in the first row under **Species** heading. If you are collecting more than one, note species in each row. For dead fuels, note the size class (e.g., 1-hr, 10-hr, 100- hr, 1000hr, grass/forb, duff, soil, or litter).

APPENDIX B - Equipment Vendors, Suggested Equipment and Estimated Costs

Equipment Vendors

This is not a comprehensive nor inclusive list of all possible vendors for equipment. The BLM does not endorse any of these companies. This vendor list is only a sample of all the possible providers of equipment. You are encouraged to go beyond this list to find the best equipment at the best prices.

http://www.benmeadows.com (containers, clippers, scales, etc.)
http://www.forestry-suppliers.com (containers, clippers, scales, etc.)
http://www.daigger.com (new ovens)
http://www.bluem.com (new ovens)
http://www.seedburo.com (new ovens)
http://used-line.com (used ovens)
http://www.triadsci.com (used ovens)
http://www.bhiequipment.com/labware.htm (used ovens)
http://www.azic.com (Computrac moisture analyzers)

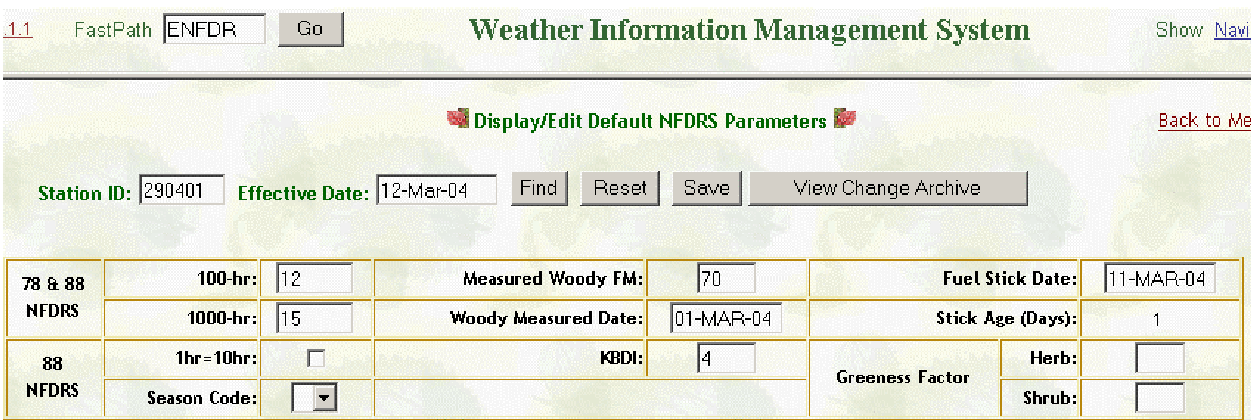
Suggested Equipment and Estimated Costs

- 8 oz. size, polypropylene jar with lid, heat-resistant, $3/ea
- Small pruning shears, $30/ea
- Insulated ice chest large enough to hold all samples, $40
- 2 to 4 cubic foot mechanical convection oven, $1,000 to $3,000
- Computrac Moisture Analyzer, $6,000 to $8,000
- 200-gram capacity scale with 0.1 gram resolution, $150

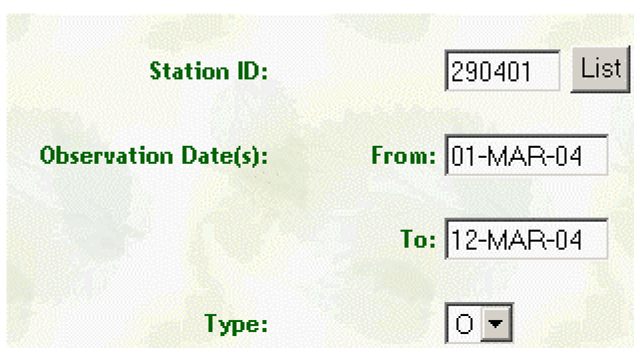
APPENDIX C – NFDRS Calibration

Sampled live fuel moisture data should be entered into WIMS as soon as possible after samples have been taken, as the entered values will only affect NFDRS outputs for 30 days. Below are instructions for entering live fuel moisture into WIMS and recalculating NFDRS outputs back to the sampling date.

1. Access WIMS at http://famweb.nwcg.gov and login.
2. Type "ENFDR" in the FastPath at the upper left.
3. Enter the appropriate Station ID and hit Find.
4. Enter the sampling date and live woody fuel moisture value under Woody Measured Date and Measured FM. The screen should look something like this:



5. Click Save and the fuel moisture values are now entered.
6. Next, type "ENRR" in the FastPath.
7. Enter the appropriate Station ID and starting and ending dates of the recalculation period. **Be sure that the earlier date is the same day you entered on the previous form as your Woody Measured Date and the last day is the current day.** The form should look similar to this:



8. Hit Find and then Recalc.
9. After the system recalculates the NFDRS outputs for the period in question, hit Close.

APPENDIX D – Guidelines for Fire Behavior and Tactics Based on Live Fuel Moisture Values

Nevada BLM (www.nv.blm.gov/fuels/) developed the following guidelines for fire behavior and tactics based on moisture values. The break points were developed from years of past fire and fuels observations. Although the break points were created for the BLM in Nevada, they may be able to be applied to fuels and fire behavior in some parts of the Southwest Area. Use these break points as guidelines and refine locally when appropriate. These break points correspond to *live fuel moisture* values.

Live Fuel Moisture

181% and Higher

Fires will exhibit VERY LOW FIRE BEHAVIOR with difficulty burning. Residual fine fuels from the previous year may carry the fire. Foliage will remain on the stems following the burn. Fires can generally be attacked at the head or flanks by persons using hand tools. Handline should hold fire without any problems. Fires will normally go out as soon as the wind dies down.

151% to 180%

Fires will exhibit LOW FIRE BEHAVIOR with fire beginning to be carried in the live fuels. Both foliage and stem material up to ¼-inch in diameter will be consumed by the fire. Burns will be generally patchy with many unburned islands. Engines may be necessary to catch fires at the head and handline will be more difficult to construct, but should hold at the head and the flanks.

126% to 150%

Fires will exhibit MODERATE FIRE BEHAVIOR with a fast continuous rate of spread that will consume stem material up to 2-inches in diameter. These fires may be attacked at the head with engines but may require support of dozers and retardant aircraft. Handline will become ineffective at the fire head, but should still hold at the flanks. Under high winds and low humidity, indirect line should be considered

101% to 125%

Fires will exhibit HIGH FIRE BEHAVIOR leaving no material unburned. Frontal attack with fire engines and dozers will be nearly impossible on large fires, but may still be possible on smaller, developing fires. Aircraft will be necessary on all these fires. Flanking attack by engines and indirect attack ahead of the fire must be used. Spotting should be anticipated. Fires will begin to burn through the night, calming down several hours before sunrise.

75% to 100%

Fires will exhibit EXTREME FIRE BEHAVIOR. Extreme rates of spread and moderate to long range spotting will occur. Engines and dozers may be best used to back up firing operations, and to protect structures. Indirect attack must be used to control these fires. Fires will burn actively through the night. Air turbulence caused by the fire will cause problems for air operations.

74% and Below

Fires will exhibit ADVANCED FIRE BEHAVIOR with high potential to control their environment. Large acreage will be consumed in a very short time period. Backfiring from indirect line, roads, etc. must be considered. Aircraft will need to be cautious of hazardous turbulence around the fire