COURSE: Prescribed Fire Planning and Implementation

TOPIC: Smoke Management (5b)

LESSON B: Quantifying and Achieving Smoke Management Objectives

I. Objectives:

A. Identify conflicting smoke management and prescribed fire objectives.

B. Define and discuss the three principle smoke management strategies available to land managers.

C. Discuss specific situations in which each smoke management strategy could be applied.

D. Describe the different techniques within each smoke management strategy that will enable the manager to better control smoke production.

E. List three locations on a prescribed burn that should be monitored for visual impacts.

F.* Plot a smoke trajectory and calculate emissions for a given prescribed burn unit.

* One of the tasks identified in the NWCG Prescribed Fire Task Book

II. Introduction

As prescribed fire managers you know to plan ahead in order to minimize the risk using your experiences in fire behavior, fuel, burning techniques and weather. **During this lesson, we will discuss ways to minimize smoke production and its impacts.** The first step in this process is to quantify the burn objectives. Once burn objectives are placed in measurable terms, strategies can be selected to mitigate smoke impacts, impacts can be monitored and objective decisions made to terminate a burn, when necessary.

III. Burn Plan Objectives

A. Writing Prescribed Fire Objectives--Good prescribed fire objectives do not always ensure good smoke management objectives. A separate set of smoke management objectives should be stated in the burn plan together with the production/duration prescription parameters to accomplish these objectives. Often times prescribed fire objectives conflict with smoke management objectives.

1. Example of prescribed burn objectives that appear to contradict with the guidance for good smoke management.

   Example: The burn is being done for silvicultural site preparation; extensive duff reduction is a goal. Smoke management guidelines say to minimize the smoldering phase.

   Example: The prescribed fire is an understory burn for hazard reduction, but the scorch on the residual trees must be strictly limited. Smoke management guidance is to burn with the highest intensity possible, in order to develop a strong convection column.

2. Examples of prescribed fire objectives that can be made compatible with guidance given for good smoke management.

   Example: To facilitate hazard fuel reduction, the down dead fuel needs to be removed. For good dispersal of smoke, a high intensity fire is desirable. Dry fuels enhance both.

B. Quantifying Smoke Management Objectives

The prescribed burn boss' responsibility with respect to quantifying the overall impacts of smoke production takes place in two distinct phases:

1. Pre-ignition–Written quantification of smoke management objectives takes place.

   During the pre-ignition phase:

   Ë Moisture assessments
   Ë Emission predictions
   Ë Smoke vectoring
   Ë Smoke modeling, e.g., SASEM (not covered in this class)
   Ë Develop mitigation measures

2. Post-ignition--Visual verification (quantification) of smoke management objectives must take place.

   During this phase, we monitor smoke. The Prescribed Fire Burn Boss relies primarily on the visual aspects of production as an indicator of overall impacts of the project (fuel moisture and weather prescription parameters cannot be manipulated once ignition occurs).

Generally speaking, it is this phase which presents the most difficult obstacles to a burn boss attempting to reduce the impacts of smoke production.

IV. Principles of Emission Production

Emission production depends upon:

A. Amount of fuel consumed

1). Fuel Characteristics: fuel loading, size, arrangement, fuel bed continuity

2). Fuel Moisture

High=Low fire intensity; low rate of spread; long duration burning; **greatest smoke production**

Low=high fire intensity, high rate of spread, short duration, **lowest smoke production**

B. Efficiency of combustion depends upon combustion phase

1) Flaming=fast constant rate, lower emission factor

2) Smoldering=slower rate, longer duration, higher emission factor.

V. Strategies

The first step in the process of quantifying visual smoke management objectives is to identify the strategies that will be used to meet these objectives.

A. Avoidance: Is a strategy of considering **meteorological conditions** when scheduling burn projects to avoid an incursion of smoke into smoke sensitive areas.

1. When resource considerations permit, schedule the burning outside the primary burning season to reduce competition for the air resource.

2. Burn when the wind is blowing away from smoke sensitive areas (e.g. brisk wind blowing 90 degrees from receptor site). Consider wind directions for:

   a) Convective lift phase of the burning period

   b) Non-convective phase (residual smoke)

   c) Burning into a strengthening wind pattern is preferred; light winds indicate stability and are generally unfavorable for smoke dispersion away from targets.

3. Avoid heavy use periods, e.g., weekends and holidays, especially around Class I areas and heavily populated areas.

4. Atmospheric scheduling: We can predict with some accuracy when favorable weather conditions exist in our area of concern and use this data to schedule burns.

B. Dilution: Controlling the rate of emissions or scheduling for dispersion to assure a **tolerable concentration** of smoke in designated areas.

1. Burn when weather systems are unstable, but not at extremes.

2. Vent smoke columns into fog layer or low clouds.

3. A poor time to burn is when a stable, high-pressure area is forming with an associated subsidence inversion.

   a) Avoid burning below the inversion layer.

   b) A temperature inversion can isolate smoke originating above the stable layer from areas below the inversion (mountains). At night, the stable layer may not eliminate entrapment of smoke by drainage winds.

4. Do not burn when air stagnation advisories are in effect or during pollution control episodes.

5. Start ignitions early in the morning.

   a) Improved mixing will usually occur as atmospheric heating occurs.

b) Avoid late afternoon and evening ignitions because of decreasing atmospheric stability.

c) Consider local winds, e.g., down slope, down canyon, night-time circulation.

6. Consider pre-burning of control lines (blacklining) to allow for hotter firing techniques.

Ë May still have residual smoke to contend with however.

7. Avoid days with low morning transport wind speed and mixing heights. These should be quantified. (See Section VI B for details and smoke forecast.)

a. Use test fire or helium balloons to measure transport winds at the burn site or smoke management forecasts.

C. Emission-reduction: Utilizing techniques to **minimize the smoke** output from a given burn.

1. Reduce the number of acres burned and/or pre-burn fuel loadings.

This may result in only delaying the release of emissions, either through a prescribed fire at a later date or a wildland fire. Consider individual burn versus annual targets.

2. Reduce Fuel Consumption:

Reduce the proportion of biomass that is actually burned and/or burn when fuel is less available.

a. Burn under higher fuel moisture conditions--less fuel is consumed and total emissions less (drawback - you may increase the smoldering phase of combustion and therefore smoke produced/unit burned). For example, when litter and duff moisture is high, 100-1,000 hour fuel moisture is high.

b. Isolate larger fuels, snags, and duff areas. Seek dry fuel conditions in the target fuel classes but not extremes.

3. Increase combustion efficiency

a. Use a backing fire--fuel consumption better and more consumed in flaming phase. Color of smoke is an indicator of fireline intensity and thus combustion. (Dark = less complete, light = more complete combustion).

b. If duff reduction is a burn objective, burn when duff moisture is low. Total fuel consumed may be higher but the combustion process is more complete. If the object is to expose mineral soil, burn when larger fuels and duff are dry enough to burn with a minimum of smoldering.

c) As necessary, provide for mop-up. Be prepared to mop-up stumps and snags, especially if large and decaying. Caution: May be contrary to prescribed burning objectives for hazard reduction.

d) When windrowing and piling debris, provide for best drying and avoid mixing with dirt.

e) Seek low relative humidity, but not extremes. It provides lower fuel moisture: at higher relative humidities, smoke particles combine with moisture to produce poor visibility (30-55% RH).

f) Use high intensity fires, e.g., aerial ignition and circular firing can create high intensity, short duration fires with good lofting and better fuel consumption in the flaming phase.

g) Schedule burn to be in "hot" fuel vs. "cold" fuel; utilize radiant heat from the sun to "preheat" fuel for more efficient combustion.

h) Use firing technique that produces the least emissions. (more discussion on this topic later)

VI. Ignition Techniques (Firing)

The following discusses the most common firing techniques used in prescribed fire programs and their relative smoke production, lofting, dispersal and duration.

A. General Principles:

1. Greatest smoke production occurs during the creeping and smoldering phases of combustion.

2. Headfires have a greater amount of creeping and smoldering than backing fires, because the flaming period is short.
3. Most larger sized fuels are consumed by creeping and/or smoldering types of burning.

4. Low intensity backing fires achieve minimal convective lift of smoke plumes.

B. Headfiring - These fires burn with the wind or upslope and therefore their intensity and spread rates are directly influenced by wind speed. Flaming phase predominates. They have highest intensity, flame lengths and rates of spread.

1. Advantages:
   - quick burning times (low cost)
   - greater convective lift
   - Greater lofting and therefore good smoke dispersal
   - Intensity can be modified using strip headfiring

2. Disadvantages:
   - greater difficulty of control
   - greater spotting potential
   - greater residual burning and lower rates of consumption of larger fuels (high spread rates)
   - Emission Rates higher

C. Backing Fire - These fires burn against the wind or move down slope. Intensity and rate of spread are less and wind has little influence on fire behavior.

1. Advantages:
   - easier to control
   - low spotting potential
   - produces minimum scorch as more heat is directed downward than up
   - fuel consumption in greater as slow movement allows for considerable preheating of fuels
   - Emission Rates Lower

2. Disadvantages:
   - slower burning, longer duration
   - needs strong winds to assist in smoke dispersal
   - smoke duration longer
   - needs continuous fuels

D. Flanking Fires - Fire set at right angle to the wind. Intermediate in intensity and slower rate of spread than head fire.

1. Advantages:
   - Fairly rapid burnout
   - Fairly good convection

2. Disadvantages:
   - Steady winds required
   - Close coordination required
   - Best in medium to light fuels

E. Concentric or Ring Firing - Generally a fire is ignited in the center of the unit and then the perimeter is ignited pulling the fire into the center. Strong indrafts are created.

1. Advantages:
   - Strong/high convective column - good lofting
   - Rapid burnout
   - Good consumption of larger fuels
   - Best smoke dispersal

2. Disadvantages:
   - potential for long range spotting
   - potential for violent convective column development
   - scorch/mortality higher
   - Difficult to terminate once started

F. Spot Firing - Similar to strip head firing except that a series of small spot fires are started and allowed to burn together to form a line.

1. Advantages:
   - Winds can be light and variable
   - Relatively quick ignition
   - Intensity can be adjusted with spot spacing

2. Disadvantages:
   - Proper timing and spacing of spot fires is key to success
   - Access - aerial ignition

G. Summary

VII. Guidelines/Methods for Quantifying Prescription Parameters

A. Guidelines

1. Start conservative--if smoke duration and amounts do not present violations of burn plan, liberalize prescription. (test fire)
2. Use measurable terms--numbers in feet, miles, etc.
3. Use the violation of parameters as a "red flag" or indication of when to assess a smoke situation as opposed to a hard/fast rule for termination of burn.

B. Methods - Suggested Prescriptions (include in burn plan)

1. Prescription for Good Ventilation:
   Maintain acceptable mixing heights/transport winds (violations will force termination considerations). Consult spot weather forecast and ask for smoke management forecast if available from National Weather Service.

2. Parameters which can be measured/estimated: (Quantitative) Mixing Height and Transport Wind Speed

   Suggested prescription:
   Mixing height--height to which relatively vigorous mixing of the atmosphere occurs. 500 meters or **1,640 feet above ground surface**.

   Transport wind--average rate of the horizontal movement of air throughout the mixing layer. Wind speed - **9 mph (4 m/sec)**.

3. Smoke Indices: Qualitative

   Descriptors or classes of ventilation and dispersion (e.g. excellent, good, poor) are found in some smoke management forecasts.

   a) **Ventilation Index**: Mixing height X Transport Winds - the atmospheric dispersion rate - representative of daytime conditions. At night the mixing height is approximately zero so this does not represent nighttime conditions very well.

   b) **Dispersion Index**: Integrates Mixing Height X Transport Wind X "Stability Class"into a single number. This is an extension of the Ventilation Index. The addition of the atmospheric stability variable (stability class) considers dispersion in stable conditions and is therefore more applicable to night time conditions when smoke concerns are often greatest.

Use of the Dispersion Index:

The higher the value of the dispersion index, the better the smoke dispersion. See Table 1, page 29, in the Guide for Rx Fire in Southern Forests. This table is preliminary and the break points have been "arbitrarily" determined but are nevertheless useful in a relative manner.

c) Additional Considerations

Relative Humidity

It is not recommended that you use these indices alone. They should be combined with relative humidity data (particularly nighttime) to make your decision.

A combination of a low index value and a high relative humidity generally means a high risk of visibility hazard

Diurnal Variations in Values:

- morning to noon 6 value climbs steadily
- early afternoon to before sunset 6 value reaches maximum
- around sunset 6 rapid drop in value and reaches a low around sunset
- sunset through night 6 maintains low value

Remember:

- Low mixing heights **L** low plume heights
- Low transport winds **L** poor plume dispersion
- Low dispersion index **L** smoke build-up

C. Areas to be Monitored

1. Burn Site

a. Specific minimum acceptable surface winds (20') (violation will force termination considerations). Suggested RX: Backing - minimum of 4 mph / Heading - 6 mph

b. Personnel: Require regular 2 hour personnel shifts (rotation) away from fire spread direction when working in fuel loadings greater than 10 tons/acre (slash models; chaparral).

2. Close Proximity

   a. <u>Highway visibility</u>. Specific *Minimum Acceptable Visibility (MAV*) for highways. A violation may force termination of your project. Consider whether traffic control is needed.

      Suggested prescription: Uses a safety factor similar to a fog braking factor.

      Safety factor = 1.75 X normal braking distance (dry, clear conditions) plus obscured visibility due to smoke and/or fog.

      Appropriate Mitigation:

      - Post smoke signs - mandatory when 2X (MAV) is present (Can county or state roads be posted?)

      - Reduce traffic speeds - MAV or less is present--speed limit is reduced to the level of the MAV that is present at that time

      - Close road to traffic or assign lead car--when 1/2 MAV is present

   b. Specific minimum acceptable visibility in close proximity to fire (such as neighbors). A violation could force termination of your project.

      Suggested prescription: Should be based upon legitimate complaints to Air Pollution Control (APC) or other (e.g. refuge, sheriff) office. Monitor complaints and set standards according to severity definitions.

D. Other Mitigation Considerations for a Burn Plan

1. Night Burning--base prescription violation on RH and/or surface windspeed. Low wind speeds will allow smoke to accumulate (below 4 mph). The combined effect of water and smoke on visibility

is far greater than smoke alone. Predicting smoke drift and visibility is difficult at night.

This effect (smoke creating fog) begins to occur at 70% relative humidity and is most likely to concentrate at critical stream crossings. Above 90%, fog potential of smoke becomes certain. So, a suggested prescription:

Relative Humidity

> 85% - consider termination of burn or intensive monitoring (all 3 areas)

70-84%- Marginal prescription conditions; consider monitors

< 70% - in prescription

2. Termination Considerations--Always consider alternatives to termination since suppression and mop-up may make conditions worse and may be contrary to burning objectives (hazard fuel reduction).

However, DOCUMENT decision process and chosen alternatives ON SITE.

If termination is considered, it should take place prior to 2 p.m. (Avoid increasing relative humidity).

VIII. Plotting Downwind Concerns / Trajoctories

A. Down wind Considerations and Prescriptions

1. Overview: Specific minimum acceptable "urban" visibility should be determined by population size based upon the fact that complaints increase as population increases and as the number of ill/elderly people increases (a violation will force termination of your project).

Suggested prescription: Violation to occur after 1/2 hour

Population		*Minimum Acceptable Visibility (MAV)
less than	15,000	at least 3 miles
15,000 -	50,000	at least 5 miles

Greater than 50,000 at least 7 miles

*Double minimum acceptable distances when population center is within minimum acceptable visibility (MAV) distance of Class I area.

Specific minimum acceptable visibilities are above and beyond critical/sensitive targets (e.g., airports, hospitals, schools, Class I areas, etc.).

Currently no dispersion model is available that is entirely appropriate. Instead the following steps are recommended: DESCRIBE qualitative impacts based on prevailing winds; INCLUDE local knowledge of where smoke normally goes; Describe who may be impacted under specific conditions. A method follows.

2. Steps to Plot a Smoke Trajectory

Step 1. Plotting Trajectory of Smoke

Ë Use maps showing improvements that are sensitive to smoke for: 10 miles downwind from the burn for backing fires, 20 miles for heading fires or large burns (1,000 acres or more) and 30 miles if fuel will be logging debris. Smoke sensitive areas that can be adversely affected by smoke are: airports, highways, communities, recreation areas, Class I areas, schools, hospitals, and factories. Locate burn on map and draw a line representing the centerline of the path of the smoke plume for the distance indicated (direction of wind). If burn will last three hours or more, draw another line showing predicted wind direction at completion of burn.

Ë To allow for horizontal dispersion of smoke, as well as shifts in wind direction, draw two other lines from the fire at an angle of 30 degrees from the centerline(s). If fire is represented as a spot, draw as in Figure A. If larger, draw as in Figure B.

Step 2. Identify Smoke Sensitive Areas

Identify and mark any smoke-sensitive areas within the 30 degree lines plotted above. These areas are potential targets for smoke from your burn.

Ë If NO potential targets are found - YOU MAY BURN AS PRESCRIBED.

Ë If any targets are found - continue this screening system.

Step 3. Identify Critical Targets

Identify and mark critical targets within the trajectory on your map. Critical targets are:

Ë Any potential targets (from Step 2) that are within 3/4 mile of your planned burn.

Ë Potential targets that already have an air pollution or visibility problem.

Ë Any potential targets where emission of sulfur dioxide (SO_2) will merge with the smoke plume. (Present research indicates that SO_2 in the presence of particulate matter is more of a health hazard than either pollutant individually). Likely sources are smelters, electric power plants and factories where coal is burned.

If there are any critical targets, continue the screening system.

Step 4. Determine Fuel Type

The effect of smoke on sensitive areas will vary by type and amount of the fuel consumed.

Ë If type is scattered LOGGING DEBRIS, and fuel loading is above 10 tons/acre and you have identified targets, DO NOT BURN under present prescription. Smoke production is much greater and will last for days unless total mop-up is feasible. This may be contrary to objective of hazard fuel reduction.

1. Prescribe a new wind direction to avoid all targets and return to the beginning of this system.

2. If you cannot avoid all targets-- you will need a better procedure than this system.

Ë NOTE: If your total fuel loading is less than 10 tons/acre smoke management should not be a significant problem over a long duration. Consider what targets exist within the area of concern and then importance. Consider WX and topography influences on smoke duration and travel.

Step 5. Minimize Risk

To meet your smoke management obligations when any smoke-sensitive area may be affected by your burn, you SHOULD meet all of the following criteria to minimize any possible adverse effects.

Ë Height of mixing layer (mixing height) is 500 meters (1,640 feet) or greater.
Ë No measurable rain within 48 hours (minimum) if 50% or more of fuel load is 10 hr. TL or greater.
Ë Background visibility is at least 5 miles within the plotted area.
Ë Fuel loading is less than 10 tons/acre.
Ë At identified targets, other sources of smoke are displaced to the side of your burn by at lease 1/2 the downwind distance.

IX. Calculating Emissions

1. Emission Factor Sources

    1. Emission factor reference tables (EPA, state or local APCD)

    2. Field measurements (past burning, monitoring equipment)\

    3. Computer programs (FOFEM, SASEM, NFPUFF)

HAVE TRAINEES COMPLETE A SMOKE TRAJECTORY MAP AND EMISSIONS CALCULATION. MAY WANT TO DEMONSTRATE SOME OF THE COMPUTER MODELS.

X. Review Elements of Smoke Management Section of Burn Plan

Location (legal), Duration of burn, type of fuels, emissions estimate, critical / smoke sensitive areas, dispersion and mixing heights, trajectory map

XI. Summarize

- Smoke Management Program Goals
  - Health and Safety
  - Good Public Image

- Ask Yourself the following questions:
  - What actions are required by policy/law?
  - What actions are prudent?
- FIT YOUR PROGRAM TO YOUR SITUATION AND CONCERNS