Forest Service Air Program
Management Strategy: Using critical load and target load information for resource management.

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Introduction

Air pollution emitted from a variety of sources is deposited from the air into ecosystems. These pollutants may cause significant harmful ecosystem effects when exceeding a threshold, known as a critical load (CL). When a CL is exceeded, negative ecosystem effects are likely to occur, immediately or over time. Similarly, when deposition is reduced and exceedances eliminated, recovery occurs at different timescales. In some cases, improvements are unlikely even when deposition is eliminated; mitigation and restoration together might be necessary to enable ecosystem improvements. The Clean Air Act and the Forest Service 2012 Planning Rule require an understanding of the potential negative ecosystem effects of air pollution, as well as an understanding of how to preserve and protect ecosystem health in the face of these threats.

Air quality assessments are used to inform managers in national forests and grasslands about critical load exceedances within their boundaries, and to help them set target loads (TLs) when appropriate. This information can be used to communicate the risk of air pollution effects on various resources to Forest Service personnel, to the public, and to the air regulators who issue permits to air pollution sources. This document outlines some of the management options available to reduce critical load exceedances and mitigate the effect of air pollution on national forests and grasslands.

When discussing management alternatives with line officers seeking to minimize the ecosystem effects associated with air pollution, it is helpful to highlight the relationship between critical load exceedances and subsequent impacts to ecosystem services. Ecosystem services are defined as the benefits people obtain from ecosystems. Sullivan (2012) integrates the principles of ecosystem services with the use of critical loads for public land management and natural resource policy decision-making. Specifically, Sullivan suggests that a CL exceedance indicates an increased likelihood that there will be a loss of one or more ecosystem services. Examples of ecosystem services that can be affected by critical load exceedances are available in Fenn et al. (2011), summarized in Table 1 and separated into potential acidification and nitrogen saturation impacts. Ecosystem services potentially affected by critical load exceedances in terrestrial ecosystems include decreased soil fertility leading to potential reductions in timber available for harvest. Similarly, aquatic ecosystems may exhibit decreased water quality causing reduced fish populations used for sustenance and recreation. The reductions in timber harvest and fishery populations are secondary effects (resulting from primary effects including loss of soil base cations, degraded water quality, etc.) but serve to highlight the potential costs associated with failing to address critical load exceedances. Sullivan concludes that, based on the estimated loss of ecosystem services, management and/or policy decisions might be made to change emissions regulations (by air regulators), and/or implement remediation or restoration actions (by resource managers).

A series of management options are presented that can be implemented to eliminate or reduce critical load exceedances or mitigate the effect of air pollution on national forests. Management options are presented by pollution effect: acidification or nitrogen saturation.

Management Options for Exceedance of CLs of Acidity

1. Reduce sulfur (S) and nitrogen (N) emissions at the source.

Aquatic and terrestrial resources are at risk of damage when critical loads of acidity are exceeded. In some cases, decreasing acidic deposition can reduce the rate of base cation leaching from soils enough to allow ecosystem recovery and improvement, through the weathering of the parent bedrock in forest ecosystems. In other situations, additional strategies will be needed to mitigate the effects of acidic deposition and achieve restoration goals. In both cases, the first step toward recovery is to reduce sulfur and nitrogen containing emissions at the pollution source to decrease deposition. The Forest Service only has direct control of emissions produced from activities conducted or permitted by the forests, and these emissions generally contribute a small amount to overall deposition. For all other sources of pollution, the forest must work with state, tribal, or federal air quality partners with the authority and responsibility to regulate emissions of pollution into the atmosphere.

Since the mid-1980s, the Forest Service has reviewed and commented on proposed new or modified major point sources of air pollution to air regulators. This is an important approach, but the Forest Service role in the regulatory process only extends to sources that may negatively impact federally designated Class 1 wilderness areas, which is a limited number of sources. Participating in the development of state, tribal, or federal air implementation plans can be an effective tool for the increased protection of resources affected by air pollution. Forests can also support state and tribal partners who implement stricter health and mobile source standards, because the resulting emission reductions are likely to have positive effects on natural resources. Finally, the forests can be advocates for secondary air quality standards designed specifically to protect the environment. In all of these cases, CLs and TLs help the forests communicate the negative effects of air pollution on ecosystems, highlighting current and predicted resource conditions and identifying concerns.

Working with regulators to identify total maximum daily loads (TMDLs) for surface waters impaired by acid deposition is another path towards emissions reductions. The TMDL process is used by states and tribes for discharge permitting and to help identify and correct point-source water pollution problems. Forests have often helped develop the TMDLs for streams within their proclamation boundary. In collaboration with both water and air regulators, TMDLs can be set for streams degraded by air pollution. If a forest decides to work with regulatory partners to develop TMDLs, the information gathered to develop CLs and calculate CL exceedances can be used to support this process.

2. Mitigate acidification effects through resource management.

There are areas where damage is so severe that emissions reductions alone will not be sufficient for ecosystem recovery within a desired timeframe (e.g., acidified streams on forests in the Alleghany Plateau and Southern Appalachians). Depending on the severity of acidification, desired condition of the resource, and timeframe to reach desired conditions, a variety of management options could be considered.

Techniques to mitigate acidification effects to streams.

- Surface water liming can help restore acidified streams, lakes, and ponds. There are several examples of liming surface waters for direct mitigation of acidification effects on aquatic biota (fish and macroinvertebrates). West Virginia has been liming streams on the Monongahela National Forest for many years to support trout stocking. The George Washington National Forest in Virginia has added limestone sand to headwater streams and successfully restored and maintained macroinvertebrate and fish populations (Hudy et al. 2000; St. Mary's Wilderness Liming Project; St. Mary's report). In both cases the forests recognized that recovery from acidification and restoration of naturally functioning aquatic systems also required deposition reductions.
    - There are different methods of liming, but all are temporary and must be repeated at intervals in order to maintain water chemistry that allows fish stocking or natural reproduction to take place.
    - Permanent or semi-permanent liming stations require power to automate the process. Liming material can be trucked to the edge of a stream where rainfall washes the material into the stream channel. Helicopter delivery of liming material to the headwaters is another option in some areas.
    - Successful restoration may require the inclusion of additional micronutrients, as well as the treatment of stream networks rather than single isolated streams (McClurg et al. 2007).
    - Adverse effects from liming can occur, including increased sedimentation in the stream bed and the formation of toxicity zones resulting from the mixing of lime and acidic water.
    - By masking the effects of acid deposition, stream liming can foster the public perception that acidification is no longer a problem. Communication with the public is therefore important to ensure continued awareness of the risks associated with acidification.

Techniques to mitigate acidification effects to soils. Because of the link between soil chemistry and surface water chemistry within a watershed, exceedance of either CL can indicate potential problems with soil nutrient status. In areas where surface waters are showing signs of acidification, nutrient status has already been affected. Eventually this may be reflected in reduced plant growth (including trees) as base cations are depleted from the soil. Areas where both aquatic and terrestrial CLs of acidity are exceeded are at the highest risk of soil nutrient deficiencies. There are several management practices that should be considered in these areas. Forests should avoid activities that would lead to further removal of base cations from the site and consider opportunities that promote recycling or augmentation of base cations in the soil. As the strategies become more restrictive to timber harvesting, obtain on-site stream water and soil chemistry to verify the CL exceedance calculations. Different combinations of the following management strategies should be considered:

- Minimize soil disturbance, specifically the mixing and removal of soil surface horizons, where the majority of nutrients are stored. This will help minimize loss of base cations (and carbon) that are commonly exported from the soil along with anions following timber harvest.
- As much as possible, leave organic material after any harvesting method to maximize the potential for resupplying nutrients to the soil. Rather than clearing or removing downed trees, standing dead trees, and debris for firewood, leave this material on the ground to decompose.
- Allow only the bole of the tree to be removed from the site during harvesting. Leave the tops and limbs onsite to decompose and recycle base cations (and carbon) into the soil.
- Follow soil best management practices (BMPs) when logging, and use systems with the smallest footprint on the site (e.g., helicopter logging, cable yarding, use of lightest weight logging equipment, one single entry with a long chain). Incorporate specific BMPs into timber sale contracts.
- Do not allow removal of below ground biomass.
- Restrict short-rotation whole-tree harvesting.
- When harvesting, investigate practices that limit the need for repeated entries into impacted areas.
- Restrict utilization of small diameter woody material based on Site Index.
- Restrict commercial timber harvest in these areas
- Initiate soil amelioration treatments (e.g., liming) after harvesting to mitigate the impacts of logging operations and to replace previously leached base cations (Mizel 2005, Sharpe et al. 2006, Cho et al. 2010). *Soil amelioration could also take place independent of harvesting operations, but may be more difficult to fund.* Several different materials have been tested in experimental settings with success. Replacement of the base cations is likely to have long-term (10 or more years) benefits in improving soil, vegetation, and aquatic health.
- Prepare for more extensive environmental analyses of potential impacts to soil resources and forest health before harvesting in these areas.

3. Conduct additional monitoring in areas where risk is high (CLs are exceeded) but data on current condition is insufficient to support some of the actions discussed above.

In Virginia and West Virginia additional surface water and soil chemistry information is collected prior to implementing mitigation actions. If the forest does not have current site-specific information to support the CL exceedances, conduct additional monitoring prior to implementing mitigation measures. The locations, timing, and types of measurements collected will depend on the specific issues for the forest. Involve the appropriate specialists when developing the monitoring plan (e.g., hydrologist, aquatic ecologist, fisheries biologist, soil scientist, geologist, silviculturist, botanist, air specialist). Additional information on monitoring is available in the Monitoring Strategy.

Below are two examples depicting the implementation of management actions in an attempt to mitigate or reverse the impacts of acid deposition, based on knowledge of CL exceedances:

- The George Washington and Monongahela National Forests lime water to mitigate stream acidification, while limiting timber harvesting and the removal of other organic material in areas considered highly sensitive to acidification.
- The Monongahela National Forest collects and analyzes additional soils data for the environmental assessment process in areas identified as sensitive to acidification (Connolly et al. 2007).
- The Green Mountain National Forest participates in a collaborative long term acid deposition soil monitoring network in Vermont. Trend analysis on long term data can be incorporated into land management decisions.

Management Options for Exceedance of Empirical CLs for Nutrient N

This section focuses on the progressive negative changes in vegetation community structure and composition resulting from excess nitrogen (e.g., native forbs and other plant species being replaced by invasive grasses and other species that are more productive under elevated N deposition). These shifts in community composition and species richness can lead to losses in biodiversity, impact some threatened and endangered species, and affect fire dynamics (e.g., exotic annual grass invasion increases fine fuels and fire risk). Management options for mitigating exceedance of nutrient N CLs are based on reducing N emissions (and N deposition) and reducing the nitrogen available for plant use through biomass removal, prescribed fire, or control of invasive grasses. Ultimately, N deposition decreases will be needed for long-term ecosystem protection and sustainability, and this is the only strategy that will protect the most sensitive communities, such as lichens and native forbs.

1. Reduce nitrogen emissions at the source.

The most effective way to reduce the effects of nitrogen excess is to improve air quality, by decreasing emissions at the source. The Forest Service only has direct control of emissions produced from activities conducted or permitted by the forests, and these emissions generally contribute a small amount to overall N-deposition. For all other sources of pollution, the forest must work with state, tribal and federal air quality partners who have the authority and responsibility to regulate emissions of pollution into the atmosphere.

Since the mid-1980s, the Forest Service has reviewed and commented on proposed new or modified major point sources of air pollution to air regulators. This is an important approach, but the Forest Service role in the regulatory process only extends to sources that may negatively impact federally designated Class 1 wilderness areas, which is a limited number of sources. Participating in the development of state, tribal, or federal air implementation plans can be an effective tool for the increased protection of resources affected by air pollution. Forests can also support state and tribal partners who implement stricter health and mobile source standards, because the resulting emission reductions are likely to have positive effects on natural resources. Finally, the forests can be advocates for secondary air quality standards designed specifically to protect the environment. In all of these cases, CLs and TLs help the forests communicate the negative effects of air pollution on ecosystems, highlighting current and predicted resource conditions and identifying concerns.

2. Mitigate nitrogen effects through resource management.

The most extensive discussion of resource management options for nitrogen impacted ecosystems in the US is the Fenn et al. (2010) paper focused on California. Options for mitigating the effects of excess N vary widely among vegetation types due to the differing resource impacts caused by N deposition. All mitigation options require effective concomitant nitrogen reductions. Different combinations of the following management strategies should be considered, however many of these strategies may be counter-productive in areas where acidification is also a concern:

- Prescribed fire:
    - Prescribed fire applied at regular intervals will reduce N pools in the aboveground ecosystem through volatilization. Fire has a limited capacity to reduce N pools in the mineral soil. The benefits of prescribed fire for N reduction are variable by vegetation type and should be weighed carefully prior to applying this management option.
    - There is also an increase in N uptake through the vigorous regrowth of vegetation following burning.
    - For areas where invasive exotic grasses have replaced native species, spring burning prior to seeds dropping can significantly reduce the seedbank of exotics. This provides a window of opportunity for re-seeding by residual native plants, or for planting native species if necessary. Because some invasives increase in abundance after burning, this approach should be used selectively and targeted to specific species.
    - Prescribed fire can have a liming effect on soils, increasing soil pH as well as the Ca/Al ratio (Boerner et al. 2004).
- Mechanical stand thinning:
    - Used in forested situations, this option can lead to increased N uptake by the vigorous regrowth of vegetation that occurs in openings and increased growth by residual trees. Similar to prescribed burning, this technique has a limited capacity to liberate N stored in the mineral soil.
- Mechanical control of invasive grasses through grazing, mowing, or manual weeding in areas where fire and herbicides cannot be used.
    - Selective herbivory on N rich grasses is an essential process maintaining local diversity in grasslands affected by N deposition. For example, moderate grazing by cattle in the South San Francisco Bay was effective because the animals selectively fed on the invasive annual grasses, reduced biomass accumulation, and mechanically broke down litter leaving an environment conducive to the growth and propagation of native short annual forbs. Because invasives vary in lifecycle timing and palatability (e.g., cheatgrass is more palatable to livestock before it sets seed), this approach should be targeted to specific species and timed accordingly.
    - Mowing is an effective tool for treatment areas too small for grazing. If possible, time the mowing so that it occurs when native plants have set seed but the exotic seeds have not fully ripened. Consider the impact of this technique on wildlife management concerns, like those for neo tropical birds and other species.

    - Manual weeding is a labor-intensive technique best reserved for situations where other methods are not feasible, or for high value recreation areas like campgrounds or administrative sites. This method is recommended in desert areas where the establishment of shrub seedlings is desired.
- Herbicides:
    - Grass-specific herbicides can be effective in controlling annual grasses, but some exotic forbs in California have been shown to increase more than native plants after herbicide application. Some herbicides are acidifying and should not be used in areas with acidification concerns.
- Mulch (applying wood chips to the soil in harvested areas):
    - This technique provides some level of N immobilization and reduces nitrate leaching from the soil in northern hardwood forests with elevated N deposition (Homyak et al. 2008). The technique has been used in coastal sage scrub but the impacts were short-lived. Mulching is impractical for large-scale restoration projects.

Summary

The best option for reducing resource impacts associated with excess air pollution is to reduce the pollution, whether you are dealing with acidification or excess nutrient nitrogen impacts. Ultimately, air regulators hold the authority to require the emission reductions needed to restore ecosystems affected by air pollution. These management actions can be applied by resource managers to help alleviate some of the negative impacts until air quality can be improved and atmospheric deposition reduced.

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