INDICATOR 25:

AREA AND PERCENT OF FORESTLAND EXPERIENCING AN ACCUMULATION OF PERSISTENT TOXIC SUBSTANCES

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A. RATIONALE

Forest ecosystems may be adversely affected by toxic substances carried by air and water from industrial and urban sources or from chemicals used in forest management. As defined by the Technical Advisory Committee to the Montreal Process, this indicator aims to assess the degree to which pollutants and environmentally damaging chemicals from activities conducted outside of the forest (e.g., air pollution), forest management activities, specific events, or the legacy of past human activities may be affecting ecosystem function and the future health and productivity of the forest ecosystem. Although the accumulation of persistent toxic substances in the soil is typically viewed as problematic, soils can also play a beneficial role in detoxifying pollutants and limiting releases to aquatic environments through processes such as the microbial decomposition of pesticides and the immobilization of metals (Sparks, 1995).

Several intergovernmental bodies have identified specific persistent toxic substances of particular concern (e.g., aldrin, chlordane, DDT, dieldrin, dioxins, eldrin, furans, hexabromobiphenyl, hexachlorobenzene, mirex, PAHs, PCBs, pentachlorophenol, and

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toxaphene). However, at present, there are no national level monitoring programs to address this indicator. The accumulation of persistent toxic substances in the soil depends upon a large number of site-specific factors, including proximity to the source, the composition and chemistry of the soil (e.g., pH, organic matter content, clay content), drainage, and local climate. For this reason, pollutant accumulation can only be measured at the local level and cannot be inferred from deposition or soil properties alone.

It is not within the scope of this data report to discuss the potential impacts of specific types of toxic deposition on forest health. Rather, the objective is limited strictly to: (1) identifying nationally-consistent sources of data that can be used to quantify this indicator, either now or in the future, and (2) providing an initial analysis of those data sources that are currently available.

B. DATA USED TO QUANTIFY THE INDICATOR

The adsorption of chemicals to soil particles is complex and depends upon a large number of chemical, physical and environmental factors including: the chemical properties of the contaminant, soil texture, clay mineralogy, soil temperature, soil moisture content, leaching rate, soil solution chemistry, pH, and organic matter content. For this reason, accumulation of toxic substances in the soil can only be monitored at the local scale through direct measurement. Although pollution monitoring programs exist at the national, state, and regional levels, these programs focus predominantly on assessing air and water pollution and do not specifically address accumulation in soils. Similarly, localized soil contamination data available from the EPA's Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or

Superfund) program cannot be extrapolated to the regional or national level. At present, there are no national level data to directly address this indicator.

This report will combine several approaches to assess the potential sensitivity of forest soils to certain types of pollutants. First, an index of soil adsorption capacity will be modeled based on soil organic matter content (SOM), soil texture, and local hydrologic conditions (e.g., slope and drainage class) reported in soil survey data from the Natural Resource Conservation Service (NRCS) STATSGO database. Application of these limitation ratings in this context is experimental and results should be interpreted accordingly. Next, data on pesticide and herbicide application in National Forest System lands will be combined with chemical information on pesticide persistence to assess the potential for the accumulation of pesticide residues in forest soils from current management practices. Finally, estimations of the spatial distribution of potential sources of toxic pollutants will be identified relative to sensitive forest soils using EPA Toxic Release Inventory (TRI) data. For all of these analyses, it is important to emphasize that these estimates provide only a rough index of potential accumulation rates and care needs to be taken in inferring the relationship between application and accumulation.

B.1 Soil Adsorption Ratings

The USDA NRCS is responsible for collecting, storing, maintaining, and distributing soil survey information for privately owned lands in the United States. The NRCS has established three soil geographic databases that are produced at different intensities and scales of mapping. Each database has a common link to an attribute data file for each map component. The State Soil Geographic database (STATSGO) is a 1:250,000 map that was designed primarily for regional and multistate interpretations (USDA NRCS, 1994). Details of the STATSGO database structure and the aggregation method employed in this analysis may be found in Appendix A. Documentation and metadata for STATSGO may be found at: http://www.ftw.nrcs.usda.gov/stat_data.html.

Soil survey interpretation ratings have been developed by the NRCS to evaluate the potential of soils to transmit pesticides through the soil profile and contaminate surface and ground-water supplies. In this model, the capacity of the soils to retain pesticides or positively charged metal ions on the surface of soil particles is interpreted as a function of infiltration rate and soil permeability as represented by the Soil Leaching Loss Rating (SLLR) where (National Soil Survey Handbook; Goss, 1988):

$$SLLR = (\text{Surface Layer Depth}) * (\text{Organic Matter Content})$$

To evaluate the potential for pesticide sorption in woodland soils, an SLLR was determined for each woodland soil component in STATSGO. The SLLR was then combined with data on infiltration rate (slope and soil hydrologic group) to develop a limitation rating. The decision matrix in Table 25.1 was used to categorize soil components as having a “slight,” “moderate,” or “severe” leaching potential. These ratings were converted to a numerical scale and a spatially weighted average determined for each map unit (Appendix A.) The leaching loss rating used in this report, the modified soil leaching loss rating (MSLLR), represents a modified version of the NRCS limitation rating and as such, this analysis does not take into account local hydrologic variables such as ponding, flooding, restrictive bedrock layers, and seasonal precipitation patterns. The MSLLR is based on the potential for soils to retain pesticides within the boundary of the rooting zone and is not directed toward any particular pesticide or family of pesticides. For the purposes of this analysis, materials that are not leached into the water table are assumed to accumulate in the surface soils (i.e. soils with a low MSLLR are assumed to have a higher tendency to accumulate pesticides in the soil).

B.2 Surface Runoff Ratings

In addition to the pesticide leaching within the soil profile, water soluble contaminants may also be transported from the soil surface by surface runoff, either as dissolved constituents or adsorbed to sediments that are suspended in runoff. Based on the soil survey, the tendency of soils to lose pesticides though overland flow is represented by the Surface Loss Rating (SLR) (National Soil Survey Handbook, 2001; Goss, 1988). The SLR is a function of hydrologic group and the soil erodibility factor (K factor) and was determined using the following criteria:

For all soils in Hydrologic Group A, the SLR is < 0.

For soils in Hydrologic Group B with a K factor ≤ 0.17, the SLR is 0 to < 1.0.

For soils in Hydrologic Group B with a K factor >0.17, for all soils in Hydrologic Group C, and for soils in Hydrologic Group D with a K factor ≤ 0.20, the SLR is 1.0 to 2.8. and

For soils in Hydrologic Group D with a K factor >0.20, the SLR is >2.8.

SLR values for U.S. forestlands were derived for each soil component in STATSGO. The SLR was then combined with information on runoff potential (slope angle and soil hydrologic group) and soil erodibility (a function of soil particle size distribution, SOM, structure, and permeability) to develop a modified limitation rating (MSLR) following the decision matrix in Table 25.2. These ratings were converted to a numerical scale and a spatially weighted average determined for each map unit (Figure 25.2; Appendix A.) As with the MSLLR, the limitation rating is based on the potential for soils to retain pesticides within the boundaries of the field where they are applied and is not directed toward any particular pesticide or family of pesticides.

Because of their relatively high SOM content in surface horizons, the majority of forest soils exhibit some tendency to retain pesticides and other pollutants as indicated by “moderate” to “low” MSLLR ratings (Figure 25.1). However, given the coarse scale of the STATSGO mapping units and the modifications made to the NRCS limitation ratings method, the MSLR and surface loss limitation ratings were combined into a single index to highlight those soils that have the highest potential for accumulating toxic substances based on low infiltration and low runoff rates (Fig. 25.3). Based on these two indices of adsorption potential, woodland soils primarily located in the southeastern Coastal Plain, the Mississippi River Valley, and the upper Midwest were characterized as having a strong tendency to adsorb pesticides as a result of low leaching rates and low losses to runoff (Figure 25.3). Due to the relatively small distribution of soils characterized by low runoff, the spatial distribution of soils with both slight leaching and runoff ratings closely mirrors the distribution of soils with low SLR values (Figure 25.2 and 25.3).

B.3. Herbicide and Pesticide Application on National Forest Lands

The persistence of herbicides in soils depends upon the chemical properties of the agent, the chemical and physical properties of the soil, and the local climate. Soils high in clay and organic matter provide sites for adhesion on soil particle surfaces (adsorption). The degree of adsorption for a given chemical compound is typically measured by a *sorption factor* (K_{oc}) which describes the tendency of a pesticide to bind to soil particles (Sparks, 1995). Adsorption processes limit pesticide movement within the soil and may also increase persistence because the pesticide is physically and chemically protected from degradation. The K_{oc} values are derived from laboratory data in which a higher K_{oc} indicates a greater sorption potential. The persistence of a pesticide in soil may also be characterized in terms of a soil half-life, which represents the theoretical length of time that it would take for a pesticide to degrade to half of its original concentration. Pesticides with a half-life of more than 100 days are categorized as persistent. However, because persistence is sensitive to variations in site, soil, and climate, a typical soil half-life value is only an approximation and may vary greatly in nature.

On a national basis, the use of herbicide in forestry is small compared to agricultural use, which accounts for 83% of the herbicides and plant growth regulators applied in the U.S. each year (Fig. 25.3). The remaining 17% consists of the combined application from home, industrial, commercial, and government uses, including forestry (EPA, 1999). Depending on tree species and region, treated forestlands typically receive fewer than three applications of herbicide over a 15 to 125 year rotation period (Nyland, 1996; SAF 2001). The USFS Forest Health Protection program compiles information about pesticide and herbicide use on National Forest System lands. In 1999 and 2000, more than 624,500 acres of National Forest Lands were treated with pesticides or herbicides (Table 25.4). In 1999, just under 200,000 lbs of pesticides were applied, as compared to 157,110 lbs in 2000. Of the dominant pesticides applied in these two years, the majority could be classified as moderately persistent, with a soil half-life of between 30 and 100 days (Table 25.5). Although these applications may represent a source of concern for surface and ground waters or for forest biota at the local scale, the treated area represents approximately 0.003% of the total acreage of NFS lands, making it unlikely that these management practices represent a major source of accumulated persistent toxic materials in soils on NFS lands at a national scale.

B.4. Potential Sources of Pollutants

The EPA's Toxic Release Inventory (TRI) collects information about chemical releases and waste management reported by major industrial facilities in the United States. As part of the Emergency Planning and Community Right-to-Know Act of 1986, industrial facilities in certain sectors of the economy are required to report on their waste management practices and other release of approximately 650 toxic chemicals to the environment. Data included in this report are derived from the EPA's Environmental Scorecard from 1999 and includes data from over 22,000 manufacturing and federal facilities.

In 1999, 7273 x 10^6 lbs of toxic materials were released to the environment (Table 25.6). The majority of these releases (65% or 4747 x 10^6 lbs) represented releases to land. Although land releases can have a significant impact on both soil and ground water, the effects on soil tend to be highly localized. Of greater significance for this indicator is the 2010 x 10^6 lbs of toxic material released to the atmosphere. Atmospheric releases can travel far from their source and deposit toxic materials over large areas of the landscape. More than 90% of all atmospheric releases in 1999 occurred in the eastern U.S, with 42.1% occurring in the northern RPA region and 48.5% occurring in the southern RPA region.

C. INTERPRETATION

Given the spatial distribution of the existing data, it is not currently possible to quantify the extent of U.S. forestlands experiencing an accumulation of persistent toxic substances. However, data from the NRCS STATSGO database can provide some general insights into the susceptibility of different regions of the landscape to accumulation of toxic substances. In general, forest soils tend to have relatively high concentration of organic materials at the soil surface. Because organic matter has a high sorption capacity for a wide range of pollutants (e.g., pesticides, herbicides, heavy metals), most forest soils will have some tendency to accumulate toxic substances in the forest floor and upper mineral soil horizons. Soils of the eastern coastal plain, Mississippi River Valley, and upper Midwest exhibit both a low leaching potential and a low runoff potential, suggesting that they may be at greater risk for pesticide absorption than soils in other regions. At the same time, TRI data indicates that both the southern and northern regions have higher levels of toxic releases to the atmosphere than other regions of the United States. However, these data are only indicative of potential conditions, and detailed research and monitoring is needed to determine actual accumulation of persistent toxic substance in the soil.

The accumulation of persistent toxic substance in the soil depends upon a large number of site-specific factors, including proximity to the source, the composition and chemistry of the soil (e.g., pH, organic matter content, clay content), drainage, and local climate. As such, measurements of accumulation can only be made at the local level and great care must be taken in inferring the relationship between deposition and accumulation.

The accumulation of persistent toxic substances in the soil is typically viewed as problematic by land managers because of the potential negative effects that these accumulated toxins may have on forest vegetation and animals. However, it is important to recognize that soils can also play a beneficial role in detoxifying pollutants through processes such as the microbial decomposition of pesticides and the immobilization of metals (Sparks, 1995). In some cases, accumulation of toxic materials in high organic matter forest soils may prevent large leaching and runoff losses to aquatic environments which may be more sensitive than soils. For the purposes of forest health, soils may be viewed both as a resource that can be damaged by pollution and as a resource that can mitigate pollution in other parts of the ecosystem.

D. LIMITATIONS TO DATA

As described earlier, the adsorption of chemicals to soil particles is complex and depends upon a large number of chemical, physical and environmental factors. For this reason, accumulation of toxic substances in the soil can only be monitored at the local scale. At present, there is no national system for monitoring the accumulation of toxic materials in the soil.

Information on local hydrology, SOM content, soil texture, and the thickness of surficial soil layers can be combined into a rough index of potential sensitivity to pollutant accumulation. This index may be useful in understanding coarse-scale patterns related to the physical properties of soils and their position on the landscape. However, these maps are only indicative of potentials and do not reflect the actual status of the soil with regards to accumulation of persistent toxic substances or proximity to possible sources. Both the scale of the STATSGO soil data (1:250,000) and the use of weighted averages to define limitation ratings within an entire mapping unit preclude the use of this data at anything other than a national or regional scale. More detailed estimates should be based on the county-level State Survey Geographic Database (SSURGO) at mapping scales ranging from 1:12,000 to 1:63,360.

As defined by the NRCS, the pesticide loss limitation ratings are based primarily on physical properties of the soil and not the chemical and mineralogical properties of the soil mineral fraction that may enhance or limit the accumulation of toxic substances. The approach used in this report represents a simplification of the limitation ratings as described in the National Soil Survey Handbook (2001). As such, it provides a less precise index of adsorption than could be obtained from a regional soil survey and further refinements are needed to address differences in pollutant accumulation potential resulting from local hydrologic features such as restrictive bedrock layers, ponding, flooding, or strongly seasonal moisture regimes. Application of these limitation ratings for pollutant retention is experimental, and results should be only considered as illustrative of general trends. Given the coarse scale of the STATSGO mapping units and the modification to the NRCS limitation ratings method, it is most appropriate to use the two limitation ratings (MSLLR and MSLR) in concert with one another to highlight those soils that have the greatest sensitivity for accumulating toxic substances as a result of multiple hydrologic factors. In addition, soil survey data may be more heavily weighted towards agricultural soils and may under-represent forest floor horizons in undisturbed forested stands. In future versions of this report, detailed geochemical modeling approaches such as the GLEAMS model (Knisel *et al*, 1993) should be used to develop more quantitative analyses of soil sensitivity.

An additional limitation with the soil survey limitation ratings as applied in this report is the use of woodland soil types as a base layer to represent U.S. Forest Lands. For the purposes of soil survey, woodland ecological sites are separated from rangeland ecological sites based on the historic climax plant community that occupied the site before the arrival of European settlers. An Ecological Site Type of "woodland" is assigned where the historic vegetation was dominated by a 25% overstory canopy of trees, as determined by crown perimeter-vertical projection. A tree is defined as a woody-stemmed plant that can grow to 4 meters in height at maturity (National Soil Survey Handbook, NRCS, 2001). Woodland soils are then assigned to a woodland group that is comprised of soils that are suited to the same types of trees, similar production potential, and similar hazards and limitations for management. Because these definitions differ from those used in the USFS Forest Inventory and Analysis program, the acreage of soils assigned to the "woodland" category will necessarily differ from estimates of forested area in other sections of this report.

Data from the TRI may be useful in understanding the general distribution of potential atmospheric sources of core toxic materials. Although the TRI is the most comprehensive source of data on toxic chemical releases in the U.S., the data have a number of limitations that preclude use in explicit spatial analyses. For example, although spatial information on release locations is provided, the coordinates for these locations are self-reported by individual businesses and are not provided in a standard format. In many cases, locations were rounded to the nearest whole degree of latitude or longitude. For this reason, it is not currently possible to use these point data in a GIS analysis to derive the quantity of emissions within forested regions.

E. IF CURRENT DATA ARE NOT ADEQUATE TO MEASURE THE INDICATOR, WHAT OPTIONS ARE AVAILABLE FOR REMEDY?

There are currently no data from national scale monitoring efforts related to the accumulation of toxic substances in forested soils of the U.S. Data are available only at the research or plot scale and the distribution of sampling locations is insufficient to make any statements about national patterns of contamination. Due to the availability of data sources, this report focused on the accumulation of pesticides in soils. However, deposition of heavy metals also represents a potential forest health risk that needs to be addressed under this indicator. In recognition of this deficit, the FIA soil indicator program has initiated analysis of an additional suite of chemicals from mineral soil samples collected on detection monitoring plots (including manganese, iron, nickel, copper, zinc, cadmium, lead, aluminum, and sulfur). These data will provide critical baseline information on the current status of forest soils and establish a mechanism for monitoring future changes in soil quality in response to atmospheric deposition.

Alternatives to national scale monitoring efforts may include reports on sample sites or research studies chosen to represent variations in forest soil types. Sites should include controls that consider natural variations in geology, landform, and hydrology as well as sites with known proximity to pollution sources of various intensities. In addition, modeling procedures developed for quantifying pesticide loss from agricultural soils (e.g., GLEAMS) can be modified to allow for a more rigorous analysis of soil pesticide accumulation potential.

F. LITERATURE CITED

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FIGURE CAPTIONS

Figure 25.1 Modified Soil Leaching Loss Ratings (MSLLR) for woodland soils derived from the NRCS STATSGO database. Values shown represent those soil mapping units with a "moderate" or "low" rating for the potential loss of pesticides due to leaching. For the purposes of this analysis, materials that are not leached into the water table are assumed to accumulate in the surface soils (i.e. soils with a low MSLLR are assumed to have a higher tendency to accumulate pesticides in the soil).

Figure 25.2 Modified Soil Leaching Loss Ratings (MSLR) for woodland soils derived from the NRCS STATSGO database. Values shown represent those soil mapping units with a "moderate" or "low" rating for the potential loss of pesticides due to runoff. For the purposes of this analysis, materials that are not leached into the water table are assumed to accumulate in the surface soils (i.e. soils with a low MSLR are assumed to have a higher tendency to accumulate pesticides in the soil).

Figure 25.3 Combined map showing map units where MSLLR and MSLR are both categorized with a "moderate" or "low" rating for pesticide loss due to leaching and runoff. For the purposes of this analysis, materials that are not leached into the water table are assumed to have a higher tendency to accumulate in the surface soils.

Figure 25.4 Mean volume of pesticide active ingredient by type and sector (1996 and 1997). Data source: EPA Office of Pesticide Programs.

Appendix A. STATSGO Database Structure and Aggregation Procedure

In county-level soil maps, each map unit usually represents a single soil component (e.g., there is a 1:1 relationship between the soil mapping unit and the associated attribute data). In contrast, each map unit on a STATSGO map can contain up to 21 different soil components. Although attribute data is provided for each soil component, there is no visual distinction as to the location of these components within the mapping unit. For example, a mapping unit map may contain a 10% inclusion of a wetland soil type; however, there is no way to determine which 10% of the mapping unit this wetland type represents. In addition, each component consists of multiple layers representing different soil horizons. Development of interpretive maps requires aggregating data from the lowest level in the schema (layer) up to the component level and then aggregating component level data up to the map unit level.

In this report, interpretive maps were developed by limiting analyses to the upper soil layer of each map component. Mean SOM content was multiplied by the thickness of the upper layer to determine an SLLR value. Data were then sorted by hydrologic group and mean slope and MSLLR ratings assigned following the decision matrix in Table 25.1. Ratings were converted into a numerical scale ("slight" = 1; "moderate" = 2; "severe" = 3). A weighted average of component data was then determined for each map unit by multiplying the mean value for a given soil component by the percent of the mapping unit represented by that component and then summing across all components. For example, weighted averages of MSLLR were derived as follows:

$$\text{Weighted MSLLR} = \text{Map component MSLLR} * \text{Component percent}$$

$$\text{Map Unit Weighted MSLLR} = \sum \text{Weighted MSLLR}$$

The numerical scale was used within a GIS coverage to categorize map units into one of three MSLLR rating categories.