CRITERIA 4, INDICATOR 18

AREA AND PERCENT OF FORESTLAND WITH SIGNIFICANT SOIL EROSION

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A. RATIONALE

Soil erosion is a natural geologic process in the building up and wearing down of the land surface. However, for resource managers concerned with optimizing production on a specific parcel of land, erosion can represent a threat to soil, water, and related forest and plant resources. By removing stored nutrients and organic matter from the soil surface, accelerated erosion diminishes the capacity of the soil to support vegetation. In general, erosion rates in undisturbed forest ecosystems tend to be much lower than on tilled agricultural lands due to thick surface organic layers and tree roots that hold the soil in place and limit downslope movement. However, accelerated losses of surface soils can result from the removal of vegetative cover and the breakdown in root system integrity following site disturbance, harvest, or preparation. High rates of localized soil erosion can also occur in response to road construction on steep hillsides or as a result of tree harvests on sites with fragile or erodible soils.

The purpose of this indicator is to measure the extent of soil erosion in forest areas that is of sufficient magnitude to lower soil productivity or cause significant sediment delivery to adjacent streams. In the context of this indicator, soil erosion is defined as the accelerated movement of

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soil materials resulting from forest harvesting, road construction, or other human impacts. Long-term rates of geologic erosion or soil loss due to mass wasting events (e.g., landslides, slumps, slope failures, mining) are not considered in this report, although these may be a significant source of sediment following harvesting and should be considered in future reporting efforts.

Assessment of soil erosion at the national scale is complex and interpretations of the ecological significance of soil losses need to be made within the context of specific soil-vegetation associations. Concerns about accelerated erosion tend to be at the local scale and are often centered around specific management practices. Localized factors such as topography, rainfall intensity, soil type, and harvest method can play a large role in mediating both the extent and severity of soil erosion, complicating the modeling of these disturbance effects over large spatial scales. In addition, intensive research studies into the effects of forest soil erosion on sediment transport and downstream water quality are often focused at the stand or watershed level and are not distributed in a representative way across vegetation and soil types.

It is not within the scope of this data report to discuss the potential impacts of disturbance on rates of soil erosion or the relationship between erosion rates and forest health and productivity for specific ecosystems. Rather, the objective is limited strictly to: (1) identifying nationally-consistent sources of data that can be used to help quantify this indicator, either now or in the future, and (2) providing an initial analysis of soil erosion based on data collected as part of the Forest Inventory and Analysis (FIA) and Forest Health Monitoring (FHM) programs.

B. DATA USED TO QUANTIFY THE INDICATOR

In general, erosion rates are difficult and expensive to measure in the field and can only be accomplished at a research scale. As a result, potential soil erosion rates are typically modeled from empirical and functional relationships driven by factors related to soil properties, climate, and landscape position. These models do not represent actual soil erosion losses and only provide estimates of potential erosion under specified climatic conditions. Without repeated field-based measurements, there is currently no way to determine actual erosion losses.

This report combines two different approaches for estimating potential water erosion rates from forested lands. First, the sensitivity of woodland soil units to erosive forces will be assessed using woodland erosion limitation ratings derived from the NRCS STATSGO (State Soil Geographic) soils database. These results will then be compared to modeled estimates of water erosion based on data from the Forest Inventory and Analysis (FIA)/Forest Health Monitoring (FHM) detection monitoring plots as determined by the Water Erosion Prediction Project (WEPP).

B.1 Woodland Erosion Risk (NRCS STATSGO)

The USDA Natural Resources Conservation Service (NRCS) is responsible for collecting, storing, maintaining, and distributing soil survey information for privately owned lands in the United States (USDA NRCS, 1994). 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.

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 percent 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). 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. The woodland erosion limitation rating represents the probability that erosion damage may occur in a well-managed woodland as a result of site preparation and the aftermath of cutting operations, fires, and overgrazing. A risk category of *slight* indicates that the expected soil loss is small; *moderate* indicates that some measures are needed to control erosion during logging and road construction; and *severe* signifies that intensive management or special equipment and methods are needed to prevent excessive loss of soil (USDA National Soil Survey Handbook).

Estimates of erosion potential for U.S. forestlands were derived by assigning a numerical rating code to the erosion limitation ratings for individual soil components. Spatially weighted averages of erosion limitation ratings were then determined for each map unit and the weighted data from each state compiled into a single national map (Figure 18.1). Details of the STATSGO database structure and the aggregation method employed in this analysis may be found in Appendix A.

Empirical models of soil erosion such as the Universal Soil Loss Equation (USLE) base the potential for erosion on five factors: rainfall intensity, soil erodibility, vegetative cover, slope and slope length, and management practices (e.g., Renard et al., 1997). The general distribution of woodland soils with severe erosion limitation ratings in Fig 18.1 is consistent with the co-occurrence of areas with regionally high relief with areas of moderate to high intensity rainfall. Soil map units rated with severe erosion limitation ratings were clustered the southern Appalachian region (West Virginia, Virginia, Kentucky, North Carolina), the Northern Rocky Mountains (Idaho and Montana), and the Coastal Mountain ranges of Washington, Oregon, and California. The lower limitation ratings found in some high relief areas of the interior west may also be attributed, in part, to the aggregation scheme used for producing this map (Appendix A); because limitation ratings are assigned only for woodland soil components but aggregated over the entire map unit, map units that contain a large portion of "non-woodland" (e.g., rangeland) soils will tend to have a lower severity rating.

B.2 Modeled Estimates of Potential Erosion Rates (FIA/FHM data)

Parameters for modeling soil erosion were developed and initially measured by the FHM program in the 1990's. In 1999, they were transferred to FIA and now are a subset of the FIA sample grid, with one forest health plot for every 16 standard plots (Stolte et al., 2002). When fully implemented, soil variables will be collected on approximately 7,800 plots measured over a 5-year cycle. Variables used to assess soil erosion are based primarily on assessments of exposed bare soil, plant cover, forest floor thickness, soil texture, and slope. These field data are then combined with ancillary data on climate and landscape position to parameterize soil erosion model inputs. Documentation of the FIA/FHM sampling design and field methods may be found at http://fia.fs.fed.us/library.htm.

Percent Bare Soil

The majority of the factors used to model erosion rates (e.g., climate, soil texture, slope) are relatively static. The primary management factor controlling erosion losses from forested systems is the amount of bare soil exposed at the ground surface following disturbance (e.g., Amacher et al., in review). FHM data from 1999-2000 indicate that, although trace amounts of exposed mineral soil appear to be a common occurrence in all regions of the country sampled, the number of plots reporting levels of bare soil large enough to increase erosion estimates is relatively small. The majority of plots (65 percent) reported bare soil on less than 5 percent of the plot area (Figs. 18.2). Only 2 percent of plots measured in these years recorded areas of bare soil that covered more than half of the plot area. At the ecosection level, the highest mean values for bare soil were located in parts of the interior west (Fig. 18.3). In the eastern United States, plots in the southern Appalachian region that were identified with more severe erosion limitation ratings (Fig. 18.1) reported mean levels of bare soil on 5-10 percent of the plot area at the ecosection level.

Water Erosion Prediction Project

The Water Erosion Prediction Project (WEPP) is a process-oriented, continuous simulation, erosion prediction model developed by an interagency team of researchers from the US

Departments of Agriculture (Forest Service, Agricultural Research Service, and Natural Resources Conservation Service) and Interior (Bureau of Land Management and Geological Survey). In contrast to other established soil models such as the Universal Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RUSLE), which model erosion losses based on long-term mean average climatic conditions, WEPP allows for the calculation of predicted erosion rates following precipitation events and disturbances of differing intensity. The model is applicable to small watersheds and mimics the natural processes that are important in soil erosion. Processes addressed in the model structure include: infiltration and runoff; soil detachment, transport, and deposition; and plant growth, senescence, and residue decomposition.

Researchers at the USFS Forestry Sciences Laboratory in Moscow, Idaho have developed an interface to the WEPP model that specifically addresses erosion prediction on forestlands. This interface provides results in a summary form as well as probability tables that estimate the likelihood of a given level of erosion occurring following a particular disturbance. The on-line technical documentation for Disturbed WEPP (Elliot et al., 2000; http://forest.moscowfsl.wsu.edu/cgi-bin/fswepp/wd/weppdist.pl), provides additional information about the disturbed forest interface and the WEPP model.

Potential erosion rates on FHM plots measured in 1999 were modeled using the WEPP model. Mean slope angle, slope length, and percent cover from each plot were combined with climate statistics from the nearest climate station. For this initial analysis, models were run under the assumption that the forest was undisturbed, based on the relatively low proportion of exposed bare soil reported on plots (Fig. 18.2). Sensitivity analyses were then used to determine the sensitivity of model estimates to this assumption. Details of the application of the WEPP model to FIA/FHM plots and results from sensitivity analyses of model parameters to these assumptions may be found in Amacher et al. (in review).

Initial modeling with WEPP suggests that erosion rates from undisturbed forest lands are generally low under average climatic conditions. Nearly 90 percent of the plots modeled (599 out of 677) had potential erosion rates less than or equal to 0.05 tons acre^{-1} under average precipitation events (Figure 18.4). Only 1.2 percent of plots had a predicted erosion rate of greater than 1 ton acre^{-1}. Under a more severe precipitation event (100-yr storm), the amount of modeled soil erosion increased, with 19.6 percent of plots having a modeled erosion rate greater than 0.5 tons acre^{-1} (median 0.04 tons acre^{-1}). Although the potential for erosion is greater under more extreme climate events, these mean erosion losses are still lower than the estimated 3.1 tons acre^{-1} annual loss estimated for U.S. croplands (NRI, 1997). Under average storm events, highest potential erosion rates were associated with plots on steep slopes located within the Coast Range and the foothills of the Sierra Nevada mountains in California [Fig. 18.5(a)]. Under a 100-yr storm scenario, erosion rates of between 1.0 and 5.0 tons acre^{-1} were modeled for plots in the mountainous regions of the western coast, portions of the interior west, and the southern Appalachian mountains [Fig. 18.5 (b)].

As a starting point for this type of analysis, initial modeling runs assumed that forestlands were in an undisturbed state, although the actual amount of ground cover measured in the field was used to parameterize the model. To test the potential limitations of this assumption, mean erosion values for each state were determined by using the mean slope, mean percent cover, and climate data from the weather station that most closely approximated the mean conditions for the state. The WEPP model was then run assuming three different disturbance scenarios: skid trails, low severity burns, and high severity burns (Fig. 18.6). Using this approach, the mean erosion loss predicted across all states in mature forests was 0.02 ± 0.10 tons $acre^{-1}$. Mean erosion rates increased under disturbance scenarios in the following order: low severity fires (0.30 ± 0.43 tons $acre^{-1}$), skid trails (1.94 ± 3.56 tons $acre^{-1}$), and high severity fires (9.47 ± 11.18 tons $acre^{-1}$).

C. INTERPRETATION

Erosion is a natural process in the building up and wearing down of the land surface in which soil material from upland areas is removed, transported, and redeposited downslope through the combined effects of rainfall, snowmelt, wind, and gravity. For resource managers concerned with optimizing production on a specific parcel of land, erosion represents a threat to soil, water, and related forest and plant resources. Removal of topsoil from upland areas results in the loss of soil organic matter, plant nutrients, and anchorage for roots. However, it is important to recognize that these same geomorphic processes may result in increased deposition of soil in lowland areas, providing anchorage and nutrients for new vegetation and fostering greater productivity. For example, the establishment of some pioneer species, such as alder, benefits from soil disturbance and removal. Negative effects of erosion can only be quantified within the context of the plant species of interest, the soil, topography, and landscape where species are located, the timing and intensity of rain events, and the products or values of interest to resource managers.

For the purpose of this indicator, it is desirable to limit our area of concern to those instances in which human-induced disturbances accelerate erosion processes to levels beyond those of natural systems. Although the background rates of erosion can be difficult to define since erosion is not typically monitored in undisturbed forested settings, initial modeling efforts with WEPP indicate that erosion rates tend to be low in undisturbed forests (Fig. 18.4). For this reason, any measurable erosion loss from a disturbed site is likely to be greater than the long-term average. Given the spatial distribution of the existing data, it is not currently possible to quantify the extent of U.S. forestlands experiencing erosion. However, data from the NRCS STATSGO database and the FIA/FHM soil indicator program can provide some general insights into the susceptibility of different regions of the landscape to erosion processes. In general, areas of erodible soil, high relief, and intense rainfall co-occur in the southern Appalachian mountains of West Virginia, Kentucky, North Carolina, and Virginia and in areas of high relief in the northern Rocky Mountains and the Cascade Range. Management practices on sensitive soils should reflect the increased potential for erosion.

At this stage of development, application of erosion models to FIA/FHM plots is experimental and results should be interpreted accordingly. However, initial modeling from the WEPP model indicates that erosion losses from undisturbed forest lands under long-term mean climatic conditions are low. Perturbations to the system, either through extreme weather events, through management practices that expose bare soil at the surface, or as a result of natural disturbances such as fire can result in large soil losses from forested areas located on slopes. Sensitivity analyses based on the WEPP model demonstrate that predicted rates of erosion may increase by two to three orders of magnitude following a major disturbance such as a severe fire or the presence of skid trails (Fig 18.6). Although modeled erosion rates increase sharply following disturbance, process level studies have demonstrated that soil erosion potential decreases rapidly once plant community recovery begins, even during high return period precipitation years. For example, Robichaud and Brown (1999) reported that soil erosion rates decreased from 40 Mg/ha the first year after a fire to 2.3 Mg/ha the second year, and to 1 Mg/ha the third year. Additional modeling and data are needed to address the potentially large effects of logging roads on sediment delivery.

D. LIMITATIONS TO DATA

Due to inherent differences in soil types, landscape positions, and climatic conditions, national-level data on soil erosion is challenging to summarize in a statistically meaningful way. When fully implemented, the FIA/FHM soil erosion measurements will represent the only nationally consistent, repeated measurement of factors needed to estimate soil erosion on forested soils. However, because erosion estimates are made on the basis of modeled results, analysis of this indicator is necessarily limited by the model assumptions. It is also important to recognize that aggregate estimates of soil erosion have little meaning in and of themselves because of natural variability in soil erosion. The term "significant," as presented in the indicator, needs to be defined with respect to variation between different landscapes and soils. To address this source of variability, agricultural erosion monitoring programs typically measure soil erosion losses relative to the tolerable loss (T factor) for that soil type. Where possible, similar reporting practices should be adopted for forested systems. Finally, even in regions where erosion rates can be reliably estimated, the links between soil erosion and forest productivity are not always well understood. Extensive field-based studies are costly and timeconsuming to replicate, and research plots are not evenly distributed across different soil types and vegetation complexes.

The models used in this analysis consider only erosive losses due to the action of water. However, in some regions of the country, wind erosion may also be a significant forest health concern. Additional research is needed to adapt wind erosion models for use with this indicator. In addition, these models do not consider soil loss resulting from geologic processes such as mass wasting (e.g., landslides, slumps, mining). In mountainous regions, mass-wasting events can be a major source of sediment delivery to streams and these losses should be considered in future analyses.

Erosion risk maps based on limitation ratings are 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 potential and do not reflect the actual status of the soil with regards to management practice or disturbance. 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) database at mapping scales ranging from 1:12,000 to 1:63,360.

An additional limitation with the soil survey limitation ratings as applied in this report is that the aggregation scheme averages the limitation ratings across both woodland and non-woodland components. Because erosion limitation ratings are not assigned to non-woodland soils, calculating a weighted average across the entire mapping unit will have the effect of reducing the overall limitation rating for the map unit. As a result, a map unit that has been identified with a "slight" limitation rating may reflect a high proportion of woodland soils at low risk for erosion or a high fraction of non-woodland soils that were not rated. This approach provides a conservative estimate of only those map units that have the highest proportion of area with severe limitation ratings. Details of assumptions made in this aggregation scheme are provided in Appendix A. Because of the coarse scale and the assumptions used in producing this product, Fig. 18.1 should only be used to illustrate general trends across large areas and not for use in specific management applications.

Soil data collected on FHM and FIA plots are intended to be interpreted as one part of a multi-tiered approach for detecting changes in soil properties across the landscape. FHM has five major activities: Detection Monitoring, Evaluation Monitoring, Intensive Site Monitoring, Research on Monitoring Techniques, and Analysis and Reporting (Tkacz, 2002). Detection Monitoring consists of nationally standardized aerial and ground surveys designed to collect baseline information on the current condition of forest ecosystems and to detect changes from those baselines over time. Data presented in this report were collected as part of this effort. Evaluation Monitoring studies examine the extent, severity, and probable causes of changes in forest health identified through the Detection Monitoring surveys. Intensive Site Monitoring projects are conducted to enhance understanding of cause and effect relationships and assess specific issues at multiple spatial scales. Research on Monitoring Techniques focuses on developing and refining indicator measurements to improve the efficiency and reliability of data collection and analysis at all levels of the program (Rogers et al, 2001). Finally, Analysis and

Reporting activities are designed to synthesize information from various data sources both within and external to the USDA Forest Service to produce reports on status and change at national, regional, and state levels. As such, soil data reported in this analysis should be viewed as an initial assessment to detect changes in the presence of reported compaction. More detailed research collected under other portions of the FHM program is still needed to determine the ecological significance of erosion estimates.

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

Most of the parameters required to initialize existing erosion models are relatively static and are available (at varying scales) from existing datasets (e.g., soil texture, slope length, climate data). The primary dynamic factor regulating erosion loss in forests is disturbance and the exposure of bare mineral soil. For this reason, future field data collection efforts should focus on providing more detailed information about the spatial distribution of site disturbance factors and land practices, such as the orientation, location, and scale of roads, the thickness of forest floor cover, and the time since last disturbance. In addition, more detailed information is needed to adequately describe slope shape (convex or concave) and slope position. In future reports, this data may be available from digital elevation models or other sources.

As with other soil indicators, additional research into quantifying the impacts of changes in soil chemical variables on forest health and productivity is needed. A mechanism for conducting this research already exists as part of the FHM Evaluation Monitoring and Intensive Site Monitoring programs. To the extent possible, additional process-level research should be used in combination with FIA plot data to improve the scaling and interpretation of data from FIA/FHM plots. Additional alternatives to national scale monitoring efforts may include reports on sample sites or research studies chosen to represent the variation in forests and their uses. Sites should include controls that consider natural variations in geology, landform, and hydrology as well as sites with known types, intensity, and frequency of uses. Finally, one of the difficulties in interpreting this indicator is that little information is available to quantify historical erosion rates in forests. As the FIA/FHM detection monitoring plots become fully implemented across the U.S., these data will form the baseline for future trend analyses. One potential source of information for addressing this indicator in future reports may come from compliance reporting and monitoring for Best Management Practices. However, at present, these data are not collected in all states and, for those states that do monitor compliance, both the design of the monitoring programs and reporting schemes vary. A series of reports documenting the status of reporting programs for individual states and regions of the U.S. has been produced by the National Council for Air and Stream Improvement and are listed in the references for this report (NCASI, 1994; NCASI, 1996a; NCASI, 1996b).

F. LITERATURE CITED

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APPENDIX A. STATSGO DATABASE STRUCTURE AND AGGREGATION PROCEDURE

The USDA National Resource Conservation Service leads the National Cooperative Soil Survey and is responsible for collecting, storing, maintaining, and distributing soil survey information for privately owned lands in the United States (USDA NRCS, 1994). The NRCS has established three soil geographic soil databases representing different sampling intensities and scales. The State Soil Geographic database (STATSGO) was designed primarily for resource planning and management at the regional, multistate, river basin, and multicounty levels. With the exception of Alaska, STATSGO provides national coverage of U.S. soils at a scale of 1:250,000; Alaskan soils are mapped at a scale of 1:2,000,000. Metadata for STATSGO data and compilation procedures can be obtained from the National Resource Conservation Service at http://www.ftw.nrcs.usda.gov/stat_data.html.

In county-level soil maps, each map unit usually represents a single soil component. In contrast, each map unit on a STATSGO map can contain up to 21 different 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.

Erosion limitation ratings within the STATSGO database are assigned as text (e.g., "severe," "moderate", "slight"). Interpretive maps were developed from these data by assigning a numerical value to these three rating scales ("severe" = 3; "moderate" = 2; "slight" = 1). 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 as follows:

(1) Weighted Component Rating = Component limitation rating * Fraction of map unit in component

(2) Map Unit Weighted Rating = ∑ Weighted Component Ratings

The weighted limitation rating for the map unit was then used to classify the map unit into one of three limitation ratings.

Map units may contain both woodland and non-woodland components. However, limitation ratings are assigned only to woodland components. When weighted averages are taken over a map unit that contains both woodland and non-woodland components, the numerical limitation rating is reduced in proportion to the size of the non-woodland component. As a result, the limitation ratings in Figure 18.1 reflect both the limitation ratings as well as the fraction of the plot that is defined as a woodland soil. Map units that have been identified with a "slight" limitation rating may represent either a high proportion of woodland soils at low risk for erosion or a high fraction of non-woodland soils that were not rated. This mapped product should only be used to illustrate general trends across large areas and not for use in specific management applications.

FIGURE CAPTIONS

Figure 18.1 Erosion limitation ratings derived from the NRCS STATSGO database. Erosion limitation ratings for each soil component were converted to a numerical scale and a weighted average determined for each map unit (see Appendix A). The final rating for each map unit reflects both the limitation ratings assigned for woodland components within a map unit as well as the fraction of the map unit that contains woodland soils.

Figure 18.2 Frequency distribution of mean bare soil cover reported on FHM plots (1999-2000).

Figure 18.3 Mean bare soil cover on FHM plots (1999-2000). Symbols represent the mean value of four cover measurements made on each plot. The size of the symbol indicates the percent of the plot with exposed mineral soil. Mean plot values were then aggregated by Bailey's ecosection. Differences in shading are not intended to represent statistical significance.

Figure 18.4 Frequency distribution of WEPP-modeled erosion rates for FHM plots (1999) under an average precipitation event (2-yr return interval) and following a 100-yr storm event. As an initial step in this analysis, model runs assume an undisturbed forest.

Figure 18.5 Modeled erosion for FHM plots (1999) using the WEPP model. (a) summarizes potential erosion rates under an average precipitation event (2-yr return interval); (b) indicates erosion potentials following a 100-yr storm event. Note the difference in scales between the two modeling scenarios.

Figure 18.6 Sensitivity analysis of mean erosion rates on FHM plots from the WEPP model under three disturbance scenarios. Input parameters were based on the mean percent cover and mean percent slope recorded on all FIA/FHM plots within a state during 1998 and 1999. Mean climate was modeled using the climate station with an average annual precipitation level closest to the average annual precipitation for the state. Values shown assume a 2-year precipitation return period. Due to space constraints, not all states modeled are shown in this figure.