Cumulative Effects of Land Management on Soil and Water Resources: An Overview

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ABSTRACT
The concept of cumulative effects encompasses a broader spectrum of resources and land uses than has typically been evaluated in research. As management pressures in large drainage basins intensify, pristine areas may be subjected to multiple human activities. These activities are distributed through time and space, and their effects can occur at the location of a particular land use or away from the location. Even though individual land uses may not significantly degrade environmental components such as soil productivity, water quality, or aquatic habitat, the combined effects of several activities may be unacceptable. Theoretically, cumulative effects of land management may also provide benefits to portions of ecosystems, such as increased stream productivity generated by nutrient inputs. Cumulative effects of land management must also be evaluated within the context of natural processes and events, such as large storms, wildfire, geochemical weathering, and vegetation succession. This overview provides examples of cumulative effects of land management and introduces the papers in this issue that were presented at a special symposium held during the American Society of Agronomy meetings in 1989.

EXAMPLES OF LAND USE ACTIVITIES in predominantly forested and rangeland areas that can generate cumulative effects include timber harvesting, grazing, mining, recreation, site preparation, road construction, vegetation conversion, and pesticide/herbicide application. Other anthropogenic factors that can affect these ecosystems include long-term climate change and acid rain caused by atmospheric pollution. These land uses and related effects have immediate and future impacts on soil and water resources, as well as carryover effects from past years. These effects can occur on-site, such as with reduced site productivity related to repeated soil compaction from logging equipment (Gent et al., 1984; Geist et al., 1989), or great distances away from the source as in the case of channel changes downstream related to upland disturbances and associated erosion (Lyons and Beschta, 1983; Hooke and Redmond, 1989).

Primarily agricultural and range watersheds can also experience cumulative effects from such practices as long term fertilization, pesticide and herbicide application, residue management, waste recycling, tillage practices, and water development projects. For example, long-term fertilizer and manure applications may result in groundwater nitrate levels exceeding the maximum concentration limit of 10 mg nitrate-N L⁻¹ (Keeney, 1986; Smith et al., 1990) and soil test P values 10- to 20-fold greater than optimum levels (Olsen and Barber, 1977). These excessive accumulations of essential plant nutrients in different parts of the soil profile may be further modified by tillage practices (Follett et al., 1987; Sharpley and Smith, 1983). Encroaching urbanization in both agricultural and forested wa-
tersheds can generate increased peak flows and stream channel incision (Hollis, 1975; Booth, 1990). The interactions of forestry and agricultural management practices need to be evaluated in larger basins, especially in terms of downstream water quality concerns.

**OVERVIEW OF RESEARCH**

Past work on cumulative effects of land management practices is sparse and largely focuses on legal issues and compliance protocols and models (Cobbourn, 1989; Klock, 1985). Much of the research presented in this issue documents changes in basic physical, chemical, and biological components of ecosystems. These components are the building blocks of managed ecosystems and are generally the first components of the system in which environmental change is manifested (Sidle, 1990). Studies or management policies that focus too high on the food chain (e.g., birds, mammals, fish) to detect cumulative effects of land management activities can result in catastrophic consequences to the basic components of the ecosystem.

Cumulative effects of agricultural and forestry practices on soil and water resources involve an inherent link between human systems and the natural environment. Oberle and Keeney (1991) present a method, based on systems theory, that is used to identify and evaluate components and goals of agricultural systems and to understand complex interactions among system components. Long-term impacts of agricultural and range management practices on soil and water quality were evaluated by Berg et al. (1991). They found that cumulative effects of annual wheat (Triticum aestivum L.) cropping on terraced soils in the Southern Plains contributed to saline seeps. Schepers et al. (1991) demonstrated that excessive fertilizer recommendations for corn (Zea mays L.) in Nebraska as the result of over optimistic yield goals adversely affected groundwater quality. Nitrate-nitrogen levels in groundwater were positively correlated with residual soil N prior to the growing season, reflecting the effects of past fertilizer and water management practices. Cureton et al. (1991) examined the effects of 2 yr of landfill leachate recirculation on grass and tree vigor and infiltration. Cumulative declines in some physiological processes in the two tree species tested [hybrid poplar (Populus spp. NM6) and weeping willow (Salix babylonica L.)] were noted during the 2 yr. At a more general level, Jensen et al. (1991) applied ecological classification and analysis to assess the cumulative effects of forest and range management practices in the northern region of the western USA.

Runoff and erosion are ecosystem responses that are subject to cumulative effects from land management and natural processes. Garbrecht (1991) found that both runoff magnitude and variability usually decrease in the downstream direction. The spatial distribution of peak runoff in the upland subwatersheds played an important role in the downstream synchronization of runoff and in the determination of the magnitude and variability of the accumulated peak runoff. Cumulative effects of intensive forest management practices can influence landslide occurrence and surface erosion as well as resulting sediment transport. Long-term effects of timber harvesting and road construction strategies on sediment production from mass wasting and the resultant effect on stream bed elevation were simulated at a fifth-order watershed scale using Monte Carlo techniques (Ziemer et al., 1991). The frequency of treatment-induced bed elevation was consistently greater in the second 100 yr after logging than in the first 100 yr. Sidle (1991) developed a conceptual model to evaluate on-site changes in root cohesion in response to vegetation management on steep hillslopes. Progressively shorter clearcut and partial cut rotations and shorter intervals between initial and final shelterwood cuttings cause temporal declines in root strength that in turn increase the probability of slope failure. Megahan et al. (1991) developed a model to predict the probability of occurrence of sediment yields from granitic roadfills in the Idaho Batholith for various levels of ground cover density. The model uses Monte Carlo simulation based on 22 yr of rainfall erosivity data for the area. Ryan and Grant (1991) developed an analytical tool, based on a channel morphology index, to evaluate long-term channel changes in response to forest management activities.

**RESEARCH NEEDS**

Results presented at this Symposium and in the recent literature indicate that a variety of research approaches are needed to address concerns on the cumulative effects of land management on soil and water resources. Research on cumulative effects represents a major departure from research on individual land management effects in that it aims to evaluate the interaction of events or treatments separated in time and space. Long-term watershed studies provide data bases for the evaluation of cumulative effects, especially when they can be complemented with detailed mechanistic investigations related to such processes as nutrient cycling, erosion, and subsurface flow. Retrospective studies using sequential aerial photographs and interpretive maps can detect long-term site changes that occur as the result of changing land uses and intensities (Sebastiani et al., 1989). Temporal rates of erosion and sedimentation can be reconstructed by evaluating stratigraphic sequences of physical and chemical (including radioactive fallout products) tracers (Gilbert and Church, 1983; Ritchie and McHenry, 1990). Models simulating ecosystem processes (including water quality and erosion) and an analysis of ecosystem response variables (such as channel morphology, riparian vegetation, and water chemistry) are viable approaches to studying cumulative watershed effects. Powerful computer simulation methods and geographic information systems are important technologies available to facilitate the extension of existing and proposed research on the cumulative effects of land management practices. Detailed retrospective and modeling studies, together with research on physical, chemical, and fundamental bio-
logical processes, are needed to address the temporal and spatial issues intrinsic in cumulative effects analyses.

REFERENCES


