AN APPROACH TO ESTIMATING THE EFFECTS OF WALDSTERBEN ON SEDIMENT PRODUCTION

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Overall catchment response to Waldsterben or other forest disturbances is controlled by the effects of forest vegetation on rate, amount, and spatial patterns of runoff and sediment production. This paper reviews an approach to estimating the effects of Waldsterben or other disturbances of vegetation on sediment production from hillslopes and channels. The companion paper by Pearce presents the actual estimates of changes in total sediment delivered to the Gangbach stream based on field studies in the Gangbach catchment. These studies were conducted during a workshop on effects of waldsterben on sediment and debris flow production. The reason for undertaking this analysis is that the rate and timing of sediment production from hillslopes can strongly influence the magnitude of property damage, the productivity of soils on hillslopes, and the generation of debris flows and excessive bedload that can damage downstream areas.

Since the Gangbach catchment examined in this workshop is a single study site and one with limited extent of forest cover due to climatic, soil, and land use factors, we feel that it is worthwhile discussing our analytical approach in general terms. This general approach could be developed further and applied elsewhere. Prediction of changes in hydrology and sedimentation in the Gangbach and most other basins its size is greatly limited by:

1. the diversity of geomorphic processes and geologic, geomorphic, hydrologic, and vegetative conditions.
2. the lack of a well-studied, analogous forest disturbance to guide predictions
3. a lack of quantitative description of present rates of sediment production processes in the catchment.

With these limitations in mind, our contribution in laying out a general scheme for analysis may be of greater value for assessing the effects of Waldsterben on other catchment areas than the actual estimates for the Gangbach catchment. The Gangbach estimates were based on only a few days of field observations with little opportunity to assess how typical the Gangbach area is of regions under threat from Waldsterben.

THE APPROACH

Dunne (1984) summarizes approaches to prediction of erosion in forest lands under the headings: geological reconstructions, mapping of sediment sources, extrapolation from field measurements, extrapolation from representative basins, deterministic mathematical models, stochastic mathematical models, and sediment budgets. In Dunne's discussion of sediment budgets and throughout this paper, sediment refers to both colluvium and alluvium, that is, particulate matter on hillslopes or in channels. The approach that we used to predict the sediment-production consequences of Waldsterben has no widely accepted name, but falls in the realm of Dunne's (1984) sediment budget approach. We use a conceptual form of distributed process-response modeling, combined with sediment budget analysis similar to that used by Pearce (1976), Dietrich et al., (1982); Swanson et al., (1982), and others. The two main components of the analysis are (1) to define the background sediment-routing system (the spatial pattern of sediment storage, linkages between storages, and rates of transfer) and (2) to estimate the effects of forest disturbance on those storages, linkages, and transfer rates. This approach has been used to evaluate effects of major storms (Nolan and Hill, 1987), vegetation destruction resulting from local sources of air pollution (Pearce, 1976), land use practices (Reid, 1981; Reid and Dunne, 1984), and major earthquakes (Pearce and Watson, 1986) on sediment budgets and sediment delivery over both short and medium durations (up to 50+ years).

This discussion of the approach is idealized. In the analysis of the Gangbach catchment, for example, limitations of time, geography, and background data on process rates permitted only a single run through steps 1-6 shown in Table 1 which summarizes the approach. It would be preferable to iterate through the steps several times, incorporating additional key data and checking internal consistency to improve the successive versions of the sediment budget. Furthermore, this approach can be applied to channels as well as hillslopes, but in the Gangbach workshop we used it only to study hillslopes.

The following discussion of the approach traces the steps outlined in Table 1. Steps 1-5 define the baseline sediment routing system; Steps 6-8 consider the effects of vegetation disturbance.

1. Identify the significant processes of sediment transfer and their location within the catchment. The mapping efforts by Sandri (1987) provide exceptionally detailed information on locations and process types for the Gangbach catchment.

2. Identify storage sites and their location within the catchment. Important sediment storage sites include colluvium of variable thickness, depending on slope movement history, and various channel storage sites, such as fans and log accumulations. Maps by Sandri (1987) also contain some of this type of information, although not all relevant mapping units are expressed in terms of sediment storage, and most information is qualitative rather than quantitative.

3. Define qualitatively the relations among transfer processes and storage sites. This can be done by composing a flow chart (Reid, 1982) showing soil/sediment flux among storage sites. This exercise helps identify processes operating in parallel or in series. This is particularly important for avoiding double counting flux rates for processes working in series, i.e., adding the rates of sediment movement by processes in series accounts for the same sediment twice, thereby overestimating sediment delivery to a point (Dietrich et al., 1982). The downslope, in-series arrangement of geomorphic and hydrologic processes in the Gangbach is best exemplified by the Rickiwald slope summarized in Table 1 of Pearce (this volume).

Since different groups of processes may dominate on different slope or channel segments, the relations among processes may have to be considered separately for various parts of a catchment. This step of the procedure for the Gangbach is described in the companion paper by Pearce and mapped in his Figure 1, summarized from Sandri (1987).

4. Quantify or estimate rates of transfer processes and volumes of sediment in storage. This can be done using appropriate literature values, modeling based on empirical or physical relationships, direct field measurements, or best estimates of upper and lower bounds of transfer rates. Different approaches are used in estimating sediment yield by episodic and by continuous or frequent processes. The rates of sediment production by the continuous processes of surface erosion and soil creep, for example, are probably adequately represented by average annual rates under alternative scenarios of vegetation condition. This could be evaluated with field data or by use of a model such as the Universal Soil Loss Equation where appropriate. More episodic processes, such as landslides, may be evaluated by a variety of techniques, including stability analysis (for single slide-prone sites) and estimates based on the frequency of sliding using inventories of past sliding (for areas containing multiple potential slide sites). Several of these approaches have been incorporated in analysis of the Gangbach catchment summarized by Pearce (this volume).

5. Compare measurements or estimates of present soil/sediment production from hillslopes with estimates of total catchment yield to see if there is reasonable agreement. This analysis can consider both long-term average rates and effects of a major event. If there is a major discrepency between estimates of sediment production from slopes and yield from the basin, it should be reconciled by reevaluating steps 1-4.

6. Estimate effects of Waldsterben or other causes of vegetation disturbance on individual processes and parts of the catchment by considering changes in soil water balance, surface and subsurface hydrology, root strength, structure of the litter layer, and other relevant factors. Examples of this analysis are summarized in the companion paper by Pearce. This analysis should include both trends in average rates and effects of a major event.

7. Considering effects of vegetation disturbance, examine quantitatively, if possible, the relations among processes and storage sites to determine if changes in the rates of some processes or in storage at some sites may affect other parts of the sediment routing system. For example, depletion in the volume of sediment stored at a particular site in the landscape will change its role as a source of sediment and sediment transfer from that storage may cease. Accumulation of sediment at some sites may buttress the toe of unstable slopes, thereby reducing the rate of sediment production from colluvium, or may overload quasi-stable slopes, thereby increasing the rate of downslope movement. In practice this is likely to be a qualitative exercise in which positive and negative feedback mechanisms are stated and their relative importance estimated.

8. Summarize results of this analysis in a description of the sediment routing system using (a) a flow diagram to qualitatively describe relationships among transfer processes and storage sites and (b) a sediment budget to show rates of sediment production for various parts of a basin for designated conditions of forcing factors (e.g., storms) and intrinsic site stability (e.g., vegetation and management conditions).

ITERATION

Completion of these steps can be extremely time consuming if they are approached with the objective of obtaining very precise estimates of values in the sediment budget. To achieve the maximum benefit of this approach and greatest project efficiency, it is best to approach the project iteratively, beginning with a quick, complete, low precision analysis based on available information.

Results of this preliminary analysis reveal the weaknesses in our understanding of a sediment routing system and the data base available for characterizing it. Important weak points can then be addressed with further field study or other work and the steps of the analysis can be retraced to provide a better estimate of sediment production. In this sense the approach is an iterative one which stops when the precision needed to meet project objectives is reached.

HISTORICAL PERSPECTIVE

It is important also to place results of the analysis of present and future sediment routing in historical context. This pertains to both the history of erosion triggering events (e.g., major floods) and of changes in the inherent stability of the landscape resulting from alterations of vegetation either naturally (e.g., wildfire) or by humans (e.g., conversion of vegetation type or changes in grazing practices). The "memory" of the sediment routing system for such events may be profound, long-lasting, and complex. The effects of the "memory" may be opposite in different parts of a catchment depending on what occurred there in previous events.

The Gangbach catchment presents an interesting challenge for interpreting the historical context of past and future erosion. The photographs of the catchment taken in 1911 and 1981 document important changes in catchment conditions. A major storm in 1910 struck the catchment in a condition much more vulnerable to erosion than at present. In 1910 the forest cover was less extensive and grazing pressure in pasture lands appears to have been significantly greater, based on observation of dense networks of animal grazing trails in some parts of the landscape. As a result of afforestation beginning in 1932, areas of forest are now more extensive and crown cover is more complete.

The 1911 photographs may show the effects of one of the maximum erosion events of the past few millenia, since a major (100 yr return period) storm occurred during a period of minimum vegetation cover. Consequently, the sediment production represented in the 1911 photographs might be an upper bound for that expected, for a similar storm, under Waldsterben conditions. Improved pasture management since 1911 and the extensive, existing network of erosion control structures and drainage works on gullies and unstable hillslopes may result in less severe erosion even in the worst case scenario of Waldsterben. Furthermore, erosion earlier this century may have depleted some sediment storage sites of colluvium, making them less significant producers of sediment in a future period of Waldsterben. Stability of the Gangbach may be strongly influenced by changes in the condition of pasture lands resulting from air pollution, altered farm management, and other factors.

VALUES OF THE APPROACH

The product of this type of analysis is a set of increasingly refined estimates of sediment production for different processes and areas within a catchment. By identifying the major processes and areas of sediment production, these results target key items for further study to refine sediment production estimates. These results can also be used as a basis for planning the most cost effective methods and location of erosion control practices within the catchment (e.g., cost per unit volume of sediment retained). Furthermore, the objective of compiling a sediment budget for these or other purposes would help guide future intensive, management-oriented studies of catchments, such as Sandri's (1987) work on the Gangbach.

This approach differs from the type of detailed field studies exemplified by Sandri (1987) for the Gangbach in several important respects. The analysis of the sediment routing system provides a description of how the entire system works based on presently available information. This forms a basis for predicting future behavior of the system. Detailed mapping of hydrologic, vegetative, and landform features within a chatchment is useful background information in undertaking such a systems analysis, but greater emphasis on process rates at the expense of some detailed mapping would be beneficial. The detailed maps do not give a description of sediment movement through a basin. Analysis of the sediment routing system does this in the forms of a flow diagram and sediment budgets for alternative conditions.

FURTHER WORK IN PREDICTING EFFECTS OF WALDSTERBEN

Predicting the consequences of a phenomenon of probable major importance that is still in its early stages would ideally combine (1) intensive, interdisciplinary, process-oriented field studies, (2) long-term field monitoring programs, (3) computer simulation modeling, and (4) evaluation of other sites where similar deforestation events have occurred in the past. The analysis should be iterative, allowing improvements as the changes within the system develop and as research and modeling produce new data and perspectives.

Concerning items (1) and (2) above, several field studies deserve attention:

A. Conduct trial exercises through steps 1-5 for areas where process data are available to assess which elements are most important and least understood.

B. Install specific process studies to measure transfer rates of important processes that are poorly known.

C. Map regolith type and thickness variations in several "typical" catchments with different ecologic and/or geomorphic histories. Emphasize categorization of regolith into different storage sites based on volume, residence time, types of recharge, and discharge processes.

D. Using long term monitoring and process studies, determine the relationships among decline and death of overstory trees, vigor of other vegetation, litter layer and root conditions, surface and subsurface hydrology, and soil movement.

E. Conduct experimental killing of standing forest by herbicide, then monitor effects, including those factors listed in D.

We know of no computer simulation models for soil erosion in steep, forest land that are directly applicable to the Gangbach and similar situations in the Alps. However, the potential magnitude of Waldsterben and the applicability of such a model to other forest disturbances may justify investment in its development. We envision a model developed through the steps outlined in this paper, using general treatments of sediment transfer processes distributed across the site-specific geologic, edaphic, and topographic conditions of the real catchments to be studied. If erosion processes are appropriately linked to vegetation conditions, it should be possible to make predictions of effects of vegetation change on erosion. Some limited, data-intensive models of this type have been developed for forest land by Ward et al. (1981) and Simons et al. (1982).

Evaluation of other sites where deforestation has occurred in the past may provide some insight to the consequences of the worst case Waldsterben situation. The closest analogs may be areas downwind of localized pollution sources, such as Sudbury (Canada) and Ashio (Japan). Natural dieback in forests (Mueller-Dombois, 1987) may set up other useful opportunities for study. Erosion research in these areas, however, has been limited and major differences in parent materials, topography, climate, and other factors constrain transfer of results from one area to another.

Some useful lessons might also be learned from sites where other types of system change have been evaluated. A large-scale, interdisciplinary research project in Colorado, for example, considered how increased precipitation in response to cloud seeding would affect hydrology and soil and sediment movement in high mountain catchments (Caine, 1976). This project included field and modeling studies designed in an overall systems perspective, a useful frame of reference for tackling the complex problem of evaluating Waldsterben.

SUMMARY

The effects of forest decline and death on hydrology and soil and sediment movement are common problems with many causes: Waldsterben, overgrazing by domesticated and wild animals, forest conversion, fire, volcanic eruptions, and others. Consequently, it is worthwhile to develop general approaches to study and prediction of these effects. The case of Waldsterben presents special opportunities and challenges because the outcome is uncertain and the areal extent, duration, and impacts are potentially great. We present here an approach to evaluating effects of Waldsterben on soil and sediment movement involvin analysis of the sediment routing system, field studies, and modeling.

Table 1. Steps in analysis of effects of Waldsterben on sediment production.

1. Identify transfer processes and their location within the catchment.

2. Identify storage sites and their location within the catchment.

3. Define qualitatively the relations among processes and storage sites.

4. Quantify/estimate the rates of transfer processes and volumes of sediment in storage for the present conditions.

5. Compare measurements/estimates of present sediment production from hillslopes with estimates of total catchment yield.

6. Estimate effects of Waldsterben or other causes of vegetation disturbance on individual processes.

7. Examine quantitatively the relations among processes and storage sites to determine if changes in the rate of some processes or in storage at some sites may affect other parts of the sediment routing system.

8. Compile results in the form of flow diagrams and sediment budgets for baseline and post-disturbance sediment routing systems.

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