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Models for evaluating water quality and BMP effectiveness at the watershed scale

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Abstract The Environment Protection Agency (EPA) and other water resource agencies have identified the need to develop watershed-scale assessments to evaluate progress in meeting the goals of the Clean Water Act. The forestry community has been a leader in developing these watershed evaluation techniques. While watershed-scale monitoring, adaptive management assessments, and modelling combinations are all used effectively in the US, this paper emphasizes realistic modelling. Models can be used to test different alternatives and are not confounded by the weather or watershed variability associated with even well paired adjacent watersheds. Examples of watershed-scale models frequently used in forestry for assessing water quality response are DHSVM, BOISED, and BASINS2.0.

EVOLUTION OF FOREST WATERSHED PROTECTION IN THE UNITED STATES

The Federal (US) Clean Water Act (CWA) and development of state nonpoint source control (NPS) programmes for silviculture necessitated evaluation of control practices. While early assessments focused on site-specific impacts and local response, more comprehensive assessments are now being required to assess the effectiveness of controls at a watershed scale and cumulatively with other activities. This paper provides a guide to approaches useful for evaluating the effectiveness of forest practices at the watershed scale and emphasizes modelling approaches. Observations concerning impacts to streams from forest management activities go back to the birth of forestry in the United States (Schenck, 1955). The origins of the National Forest system are tied directly to watershed concerns. Steen (1991), writing about the early legislation that established the National Forests, concluded that: "the primary driving force behind forest reserve legislation at that early time was the protection and enhancement of water supplies, including flood protection." Passage of the 1972 Federal Water Pollution Control Act (commonly known as the Clean Water Act) greatly accelerated the development of state water-quality protection programmes for forestry and the need to assess the effectiveness of control practices, known as best management control practices (BMPs).

Operationally, BMPs are useful for forest nonpoint sources because they are often designed to prevent adverse impacts before they occur, and they provide a measure of certainty about the operator's responsibility to protect water quality. Also, it is generally easier to assess BMP implementation than it is to measure water-quality standard compliance in dynamic forest stream systems.

Initial assessments of BMP effectiveness involved research plots, field evaluations, small paired watershed studies, and application of agricultural models like the USLE to forest conditions. All these provide valuable information, but they are also limited. Most were designed to provide only a local assessment of impacts, often to a single operation at a specific site. The assumption was that if impacts could be minimized at the site, they would be diluted downstream. However, concerns about cumulative effects caused forest managers to explore alternative assessment approaches. Cumulative effects for forestry is defined as "changes to the environment caused by the interaction of natural ecosystem processes with the effects of two or more forest practices". Federal agencies began analysing for cumulative watershed effects from forestry under the National Environmental Policy Act of 1969 (NEPA) and requirements of the Clean Water Act (CWA, Coats & Miller, 1981). In some national forests, management limits were set, based on the percent of watershed harvested or roaded, to avoid cumulative effects. With maturation of CWA assessments, watershed specialists began to recognize both the dynamic nature of watersheds and streams and the potential for and need to address operational fall-down of BMPs (Callaham & DeVries, 1987).

Coincident with the rise in interest in CWA assessments, watershed management was receiving increasing attention by the early 1990s. This attention was highlighted by growth of watershed-related organization like the Watershed Management Council and the American Institute of Hydrology. Legal requirements to develop total maximum daily surface water load limits (TMDLs) and the growth of Geographic Information Systems (GIS) technology and landscape ecology methods capable of addressing spatially complex watershed problems further stimulated watershed-scale assessments.

ALTERNATIVES FOR EVALUATING BMP EFFECTIVENESS

As a result of this new federal activity, forest nonpoint source (NPS) control programmes are increasingly being asked to assess the effectiveness of BMPs at a watershed scale for multiple activities over long time periods to demonstrate that watershed, water quality, and landscape ecology goals can be met. Basin-wide cumulative response to BMPs remains one of several "potential" issues for the forestry community in its efforts to validate the effectiveness of BMPs. But larger scales for both spatial and temporal assessments create problems for those attempting to validate BMPs. While this is a difficult task, there are three general approaches: adaptive management approaches, large watershed monitoring, and models.

The industry can show that overall water quality has improved for the nation since the 1972 Federal Water Pollution Control Act Amendments were enacted and that silvicultural BMPs have the capability to protect water quality. But can we document that overall water quality is benefiting from forest NPS control programmes?

ADAPTIVE MANAGEMENT APPROACHES

Adaptive management approaches are designed to utilize ongoing management as a test from which to learn. Probably the two most useful examples of adaptive management monitoring at the watershed scale are source searches and watershed analysis. Source search or synoptic survey assessments involve a snapshot of water quality throughout a basin at one time. This can be a powerful tool although there are potential problems associated with this type of infrequent monitoring view (i.e. potential differences in hydrologic conditions in the watershed or unrepresentative conditions for estimating pollutant loads).

Watershed Analysis (WA) is a structured approach to develop a forest practice plan for a Watershed Administrative Unit based on a biological and physical inventory (Washington Forest Practices Board, 1993). Information about watershed hazards from forest management and public resources at risk is used to develop watershed-specific prescriptions. Watershed Analysis provides useful stand-alone watershed-scale information by developing hypotheses that connect upslope hazards with downstream risks through key watershed processes. It has stimulated development of basin-scale assessment tools and has allowed sharing of experiences between watershed assessments.

LARGE WATERSHED MONITORING

Small basin studies usually measure the integrated response to management and may provide some on-slope or upstream monitoring to support the assessments about impacts. Large watershed studies are usually designed to measure tributary and multiple reach response to assess the conservative/nonconservative nature of pollutant/flow transport. This can allow an interpretation of the relative hazards in the watershed (erosive soils), risks (i.e. deposition zones), and connections. An example is the Mica Creek watershed study in Idaho (McGreer *et al.*, 1995). For Mica Creek, watersheds are nested to allow assessment of impacts as they are routed downstream (Fig. 1).

Aerial reconnaissance methods and remote sensing of large watershed-scale monitoring approaches are useful where site-specific information is not helpful or where technology provides advantages for basin-wide assessments. For example, landslides are traditionally measured at the watershed or even regional level using aerial photos or aerial reconnaissance methods. Recent work by the Oregon Department of Forestry is providing some information about the detection bias associated with aerial photo and aerial reconnaissance methods compared with on-the-ground measurements (Robison, 1996). NCASI is working with Oregon State University to develop a low cost, rapid response video method for recording landslides (Rosenfeld *et al.*, 1996). Thermal remote sensing has also been used to track stream temperatures quickly throughout a basin. The application of large-scale remote sensing information to water quantity and quality assessments could present a major advance in watershed assessment.

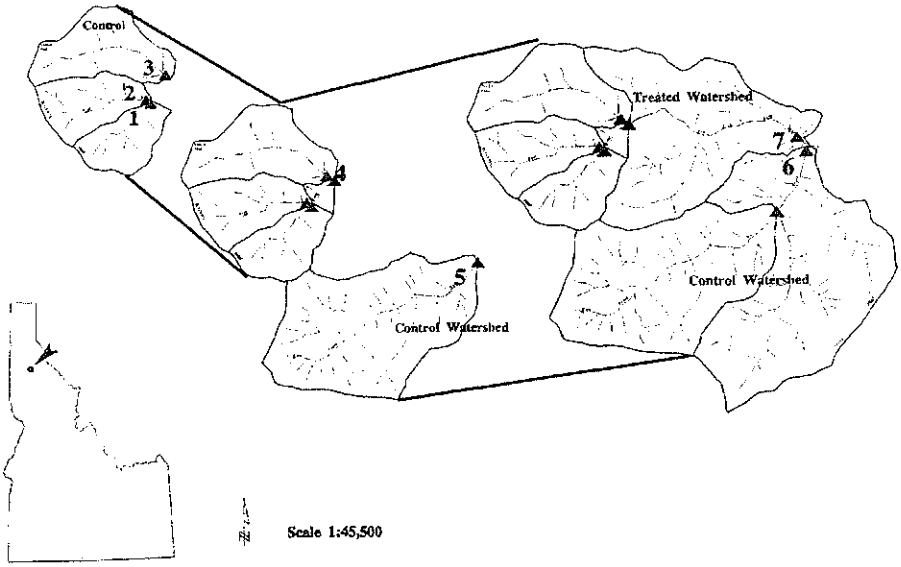

Fig. 1 Locations and design of Mica Creek watershed study in Northern Idaho, showing controls at different scales.

MODELS

One of the approaches that is most appealing to foresters is the development of credible models that can simulate response to forest management practices at both the site and watershed scale. Unfortunately, much work has gone into developing various watershed models, while little work has gone into validating these models, calibrating them to different watershed conditions, and making them user friendly.

NCASI has been working with the University of Washington and Battelle Northwest Laboratories to validate the Distributed Hydrologic–Soil–Vegetation Model (DHSVM) against watershed data collected by companies for different conditions. DHSVM accounts explicitly for the effect of topography and the spatial distribution of land surface processes at the scale (30–90 m) of currently available Digital Elevation Models (Wigmosta, 1996). Features include: grid-based digital elevation model; automated model setup using the GIS ARCINFO; explicit representation of road networks; spatially-distributed vegetation and soils properties; absorbed shortwave radiation, precipitation, and downslope water movement; a two-layer soil rooting zone model; a two-canopy evapotranspiration model; simplified topographically-driven surface and subsurface flow routing; GIS post-processing of model outputs; and channel flow routing.

Testing of DHSVM is occurring on gauged forested watersheds, including the Little Naches in eastern Washington, the Deschutes in western Washington, Mica Creek in northern Idaho, and Carnation Creek on Vancouver Island. Figure 2 compares the DHSVM simulated water discharge for the Little Neches River with corresponding observed values. Although discrepancies are noted, the comparison is considered reasonable. Factors responsible for these differences include: location of the raingauge, spatial homogeneity of affected watershed, and infiltration/runoff parameters.

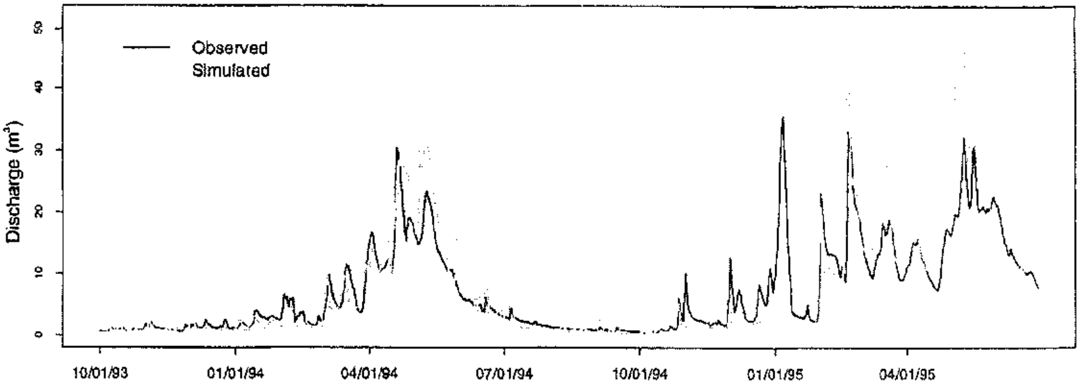

Fig. 2 A comparison between observed discharge for The Little Naches River in Central Washington and simulated discharge using DHSVM (from Storck *et al.*, 1998).

Megahan *et al.* (1992) used the well-calibrated empirical model BOISED, a version of the Forest Service R1-R4 sediment yield prediction model (WATSED), to provide a retrospective assessment of sediment yield for a tributary of the South Fork of the Salmon River. WATSED is based on locally derived empirical streamflow and sediment yield data, and uses stand properties and landscape units defined in terms of landform, lithology, and soil characteristics. On-site surface and mass erosion estimates are adjusted for slope delivery based on topographic conditions, and downstream sediment delivery is adjusted on the basis of a watershed sediment delivery ratio. The model is sensitive to alternative forest cutting and soil disturbance activities, including silvicultural practices, alternative road construction practices, and wildfire. Megahan *et al.* (1992) estimated that abusive jammer logging and associated road construction boosted sediment yields (mass/total watershed area/year) from about 450 Mg of sediment to over 1300 Mg. With present day BMPs, the authors estimate sediment increases could have been reduced by 45 to 95% (Fig. 3). These scenarios portray: (a) a reconstruction based on the historical record of management practices, (b) improved road design, (c) maximum mitigation, and (d) helicopter logging. In all cases, except helicopter logging, the same mix of silvicultural methods (clearcutting and selection cutting) and logging systems (jammer and tractor logging) was used, and the same lengths and locations of logging roads were assumed. Effects of a 1989 wildfire were also modelled for each of the four scenarios. The sediment yield from the undisturbed watershed was estimated at 450 Mg and provides a benchmark for evaluating the sedimentation caused by the alternative land-use activities for the period 1950–1995.

An emerging tool for modelling is BASINS2.0 (Whittemore & Ice, 1998). BASINS2.0 is a comprehensive EPA software package recently released by the Office of Water. It is designed to enable water-quality analysts and watershed managers to perform studies using GIS, watershed land use and water-quality monitoring data, and state-of-the-art environmental assessment tools. BASINS2.0 provides information for any of the 2150 watershed in the contiguous 48 US states. It incorporates well-known models such as HSPF, TOXIROUTE, and QUAL2E. BASINS2.0 has much promise, but its coarse spatial scale and treatment of land-use activities do not support

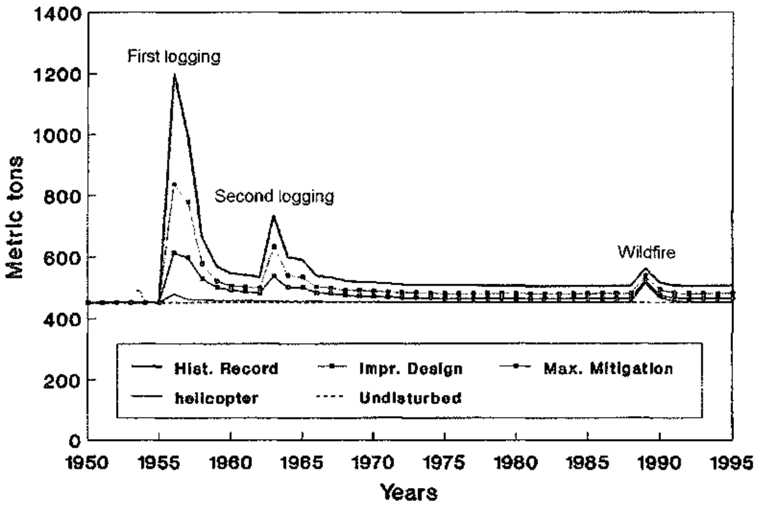

Fig. 3 WATSED model demonstrates how BMPs have reduced sediment yield from historic loads in Dollar Creek, Idaho, USA (Megahan *et al.*, 1992).

assessments of alternative forest management activities at this time and more work is needed to build a field-scale parallel of the crude EPA watershed assessment tool. It is certain that modelling frameworks such as BASINS2.0 will play a major role in US water quality assessments in the coming decades as watershed-scale efforts become commonplace. Integration of modelling with GIS means that spatial variability concerns can be addressed with the modelling tools. BASINS2.0 is but one prominent option.

INTEGRATION OF MONITORING AND MODELLING

Clearly, modelling and monitoring are related. All models require calibration and validation studies to ensure that they are performing acceptably. In the future, we may begin to develop hybrid monitoring and modelling systems that incorporate real-time remote sensing data to parameterize models and provide for rapid calibration to existing conditions. These models can then be used to test alternative management scenarios. More importantly, however, models need to be developed that can be used to solve field-scale issues and provide rapid guidance to land-use managers in evaluating alternative management practices. Also, regulatory pressures in the US to develop basin assessment tools will continue and the inherent variability of forested ecosystems will add to these challenges.

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