

CUMULATIVE IMPACT ESTIMATION FOR LANDSCAPE SCALE FOREST PLANNING**Finn Krogstad & Peter Schiess¹****INTRODUCTION**

Currently, forest management and environmental protection (even under adaptive management) are commonly planned at the scale of a single operation. A harvest is scheduled, a road is built, and regulations are applied without detailed consideration of how it will impact neighboring operations, and the cumulative present and future environmental impacts they produce. These approaches may obtain a locally optimal solution, but combining many locally optimal solutions across a landscape generally produces a solution that is not optimal for the system overall. For example, a collection of locally optimal harvest units may leave patches between them that are poorly accessed by any of the locally optimal harvest units. As another example, prohibiting yarding across a stream will prevent a one time disruption to the riparian buffer, but may require additional road segments (and impacts that they entail) to access the far side of the stream.

Finding economically and environmentally optimal solutions for a landscape requires planning the forest management at the landscape scale. Any number of such plans are possible, with differing environmental objectives, road networks, and silvicultural options. For example, one might want to reduce road density by shifting to larger harvest units and longer yarding distances. Some sort of tool is needed to compare the economic and environmental impact of alternate plans and options.

The economic impacts of management activity can be accumulated through net present value of each action. Road construction, maintenance and decommissioning as well as silvicultural operations (planting, thinning, harvest, site preparation, etc.) all have costs and/or yields whose net present value can be estimated. The sum net present value of all activities in a plan can then be estimated and accumulated, and compared with the net present value of alternate plans to identify the economically superior option.

A similar metric is needed to identify the environmental costs of alternate management plans by accumulating environmental costs of each action, at each point in the landscape, over the period of the plan. Such an environmental equivalent of net present value might be called 'cumulative impact'. The basic hydrological component models of such a framework already exist in one form or another. Basic attempts have

¹ University of Washington, College of Forest Resources, Seattle Washington 98195, USA, (206/543-1583), (206/685-3091), fkrogsta@u.washington.edu, schiess@u.washington.edu.

been made at estimating production, delivery, and input of various hydrologic inputs (peakflow, sediment, wood, etc). The combination of these impacts into a single value of cumulative impact presents some problems however.

HYDROLOGIC MODELING

Geographic Information Systems (GIS) can provide a basis for environmental analysis if the issues of concern can be coded as spatial algorithms in terms of readily available data sets. These data sets include soils, streams, topography, stands, precipitation, roads, future management activities, etc. Representing the earth's surface as a grid of cells provides a flexible and general approach to modeling. Data from polygon related features (stands, soil units, etc) can be converted to grids so all available information about every given point on the landscape is available for analysis.

A grid based approach is particularly amenable to hydrological analysis, since a grid of topography gives the flow direction to the lowest neighboring cell, which in turn gives a number of useful hydrologic properties. A cell's contributing area is just the cells that eventually flow into it. Streams can be identified as cells within a minimum contributing area or a minimum slope-area product. The flow path distance down to these streams or up to the ridgeline is found by following these flow directions. We can also integrate the values in these cells, such as the sediment eroded from each contributing cell, or the time to flow through each cell along a flow path.

Our approach generally follows that of the Washington State Watershed Analysis procedure (WFPB, 1997) and separately considers each watershed input (wood, sediment, peakflows, etc). The production of each input is estimated at each point in the landscape, delivery or delivery fraction is determined, the delivered inputs are accumulated at each downstream point, the geomorphic/hydrologic sensitivity of this point is determined, and the resource vulnerability is assessed.

As an example, local landsliding hazard has been modeled as a function of local topographic slope and contributing area (Montgomery & Dietrich, 1994). Local estimates of soil thickness, density, cohesion, and friction angle can be drawn from soil inventory coverages, and local root reinforcement and vegetation weights can be estimated from fields in the stand inventory coverage. Converting landslide hazard into landslide probability will give an expected landslide frequency, which combined with soil depth and expected slide area will give expected sediment production from each cell in the landscape.

Stand data provides information about the size and number of trees adjacent to each stream reach, the in-stream stability of which can be estimated from stream power, which in turn is a function of contributing area and local slope. Stream shading can be evaluated both from stand height and canopy density and stream width as estimated from contributing area.

Some models have been developed for larger areas such as harvest areas or basins. These models can be applied at each grid cell. For example, snowmelt can be estimated by averaging basin elevation, canopy, precipitation, and temperature (WFPB, 1997), but the basin in

question can be each individual grid cell. Similarly, sediment erosion from forest management activities (Cline et al, 1981) can be calculated according to the management activities of each cell.

Whether (and how much of) these runoff products is delivered to the stream network can be estimated from the path it would take on its way to the stream. Standard GIS commands exist that identify the path that water takes on the way to the stream. These can incorporate significant features along this path such as slope or soil type that might impact the nature of the flow, such as the travel time for subsurface stormflow or the conditions under which landslides turn into debris flow (Benda and Cundy, 1990).

For each downstream cell, we can accumulate the delivered input from each cell in its watershed. Multiplying the production of each input (wood, sediment, water) in each cell by the derived occurrence (0 or 1) or delivery fraction (0% or 100%) gives the delivered input, which can be integrated over the contributing area to get the accumulated delivery to each reach. The sensitivity of a given reach to each input will be a function of its gradient, confinement, and contributing area (e.g. a steep confined channel may be insensitive to fine sediment inputs) which are derived from topography. The existence of fish in a given reach might also be estimated from topography (Lunetta, et al, 1997).

CUMULATIVE IMPACTS

Having constructed grids of accumulated inputs delivered to each sensitive fish-bearing reach, we face the problem of how to integrate these inputs into a total cumulative impact. If we are interested in a single species, we could write a formula under which fish population is a function of fine sediment, coarse sediment, peakflow, wood, and shade. Such a model could be constructed from theoretical models, and from empirical fitting of fish population surveys. Subsequent comparison of model predictions and observed values would allow model evaluation and improvement.

A first approach to accumulating these impacts would be to assume that all identified inputs have an inverse impact on populations, and that their impact is multiplicative. A more realistic model of cumulative impacts would be to recognize the factors limiting population at each stage of their life.

We need not limit our cumulative impact assessment to riparian impacts. Harvest impacts on species requiring stand interior habitat can be evaluated by assigning an 'interior' value to each cell as a function of distance to the stand edge. Management impacts on terrestrial migration can be evaluated by assigning a 'migration cost' to each grid cell, then using existing path cost functions to identify the resulting cost minimizing path. Cultural and scenic impacts can also be estimated using existing functions.

The problem with combining these different inputs to produce a single cumulative impact value is that unlike the multiple impacts on fish, is that it is difficult to imagine a single value (such as fish population) that incorporates all these impacts. How do you compare one plan that favors owls, to another that favors salmon? Weighting impacts on various species and stakeholders would need to be a political decision.

DISCUSSION

It should be obvious to even the casual reader that such a framework lies significantly beyond the accuracy of current models and data sets. There are several reasons however why we might want to shift to this form of evaluation. First, the fastest way to improve our current models is to use them to make predictions and compare them with observed outcomes. Second, even flawed predictions will provide forest managers with insight into the processes by which their activities produce environmental impacts. Finally, crude predictions from flawed models using uncertain data are still better than writing broad regulations for a hypothetical activity on hypothetical trees at some hypothetical future date on a hypothetical piece of ground above a hypothetical stream with hypothetical fish in it.

CITATIONS

- Benda, L.E.; and T.W. Cundy, 1990. Predicting deposition of debris flows in mountain channels. *Canadian Geotechnical Journal*. 27(4):409-417.
- Cline, R., G. Cole, W. Megahan, R. Patten, J. Potyondy, 1981. Guide for Predicting Sediment Yields from Forested Watersheds. USDA Forest Service, Northern Region & Intermountain Region. 48 pp.
- Lunetta, R.S., B.L. Cosentino, D.R. Montgomery, E.M. Beamer, T.J. Beechie, 1997. GIS-based evaluation of salmon habitat in the Pacific Northwest. *Photogrammetric Engineering & Remote Sensing*, 63(10):1219-1229.
- Montgomery, D.R., and W.E. Dietrich, 1994. A physically based model for the topographic control on shallow landsliding. *Water Resources Research*, 30(4):1153-1171.
- Washington (State) Forest Practices Board, 1997. Board manual: standard methodology for conducting watershed analysis under chapter 222-22 WAC, version 4.0, Washington Forest Practices Board, Olympia, Washington.