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Assessing the Cost of Best Management Practices in Arkansas

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Abstract

A geographic information system (GIS) is a set of powerful, computer-based, analytical algorithms for solving spatial data problems. Recently, due to increases in memory size, computing speed, and programming advances, personal computers have been used in spatial analysis problems. This study reports the benefits of using a PC-based GIS system to solve a common, but complicated problem in forest management: assignment of harvesting areas with harvesting exclusion zones. Two stands each from the USDA Crossett Experimental Forest, the University of Arkansas Forest, and the Ouachita National Forest (total six) were analyzed to determine the changes due to following best management practices (BMPs) and by excluding sensitive areas from harvesting activity with stream-side management zones (SMZs). A onetime loss land, averaging seven percent of the forest land, was taken out of production due to the implementation of SMZs. Benefit cost ratios of harvestable timber value to harvesting cost decreased with the imposition of SMZs, but the judicious use of portable bridging to span SMZs at critical locations mitigated losses significantly.

Introduction

Geographic information systems (GIS) provide a powerful set of computer based analytical algorithms that may be used in solving spatial data problems. In addition to their conventional mapping capabilities, GIS programs can solve difficult spatial allocation problems that do not lend themselves to traditional intuitive solutions (Weih and Hutchins, 1993). These include problems that are too complex mathematically to be attacked by plane or solid geometry or operations research methods. More recently, GIS programs have become available for PC-based DOS and Windows operating environments. This paper reports the use of one such program, IDRISI (Clark Labs, 1995), in a land classification problem and an operating cost problem associated with the implementation of best management practices (BMPs).

Problem Statement.--BMPs have been instituted for a variety of reasons including stream and watershed protection. Decreased stream turbidity due to reduced skidding perturbations, decreased insolation with associated rises in stream temperatures, and protection of faunal habitat are all direct benefits from SMZ setasides (Foreman, 1995). However, there are two management costs associated with SMZs. First is the one-time loss in productive area for growing trees because of land taken out of, or partially out of, the normal productive land base. The second problem is the increased operational cost of harvesting because equipment must go around SMZs, thereby extending skidding distances. It is commonly believed that restrictions on machine operational mobility result in sub-optimization of the harvesting plan and significantly greater total harvest cost.

Methodology

Using GIS in Land Classification.--GIS analysis starts with thematic layers of information that are overlaid to produce maps. These maps contain information that may be manipulated to answer management questions. For example, Fig. 1 shows a 68.4 hectare tract (Crosl) that is bounded on four sides by roads, and a stream, with its associated SMZ flowing through it. We specified the SMZ width as 20 meters on each side of the stream. Additionally, there are four assigned landing zones. GIS algorithms have the ability to sum the pixels in each land use category and to print out a report of their frequency (Clark Labs, 1995). Table 1 shows the allocation of area by land use. For the six stands we analyzed, SMZs occupied 3%, 4%, 8%, 8%, 8%, and 10%, for an average of 7%. While 7% does not appear to be a large proportion of the total area to remove from the productive land base in exchange for the ecological benefits obtained, the actual loss is slightly greater. For example, in Cros 1, the pre-SMZ area usable for growing trees was 60.3 hectares (forestland + SMZ). Reducing this area by the SMZ exclusion produces a loss of 9.4% instead of 8.3% when all land on the tract is used as the timber base. Obviously, the percentage of land lost from production will vary somewhat with physiography and stand. The value loss of this exclusion is the value of the periodic series of timber revenues from this land. Additionally, this land is probably of higher productivity because of higher site index near streams. Clearly, the one-time loss to forest managers in timber producing area is significant.

Using GIS to Determine Changes in Operating Costs.--A Simple Case - Digital elevation models (DEMs) are a fundamental building block of most GIS analysis. DEMs give immediate clues to the "lay of the land". When DEMs are overlain with thematic layers for roads and hydrology, a map that is usable for operational analysis emerges (Fig. 2). Figure 3 is a cost surface which depicts the two-way cost to skid timber from each pixel of the 68.4 hectare tract to the closest landing. This surface is calculated by taking the sum of individual pixel travel costs from each pixel to the nearest landing zone. A "cost-shed" is produced. This is the optimal geometric solution. There is an operational assumption of no restriction on skidder movement in this solution. An additional algorithm sums the individual cell costs yielding total skidding cost for the tract. However, when we impose the SMZs demonstrated in Fig. 1 on this tract, the total skidding cost is increased significantly (Fig. 4). Additionally, because in this demonstration, there is a "non-penetration" restriction on the SMZ, the assignment of individual pixels to landing zones is sub-optimal compared to the optimal geometric solution (Fig. 3). In this scenario SMZ penetration was prevented by assessing an exorbitantly high pixel travel cost to the pixels in the SMZ.

Harvesting engineers wrestled with the problem of SMZ crossings for a number of years before portable bridges came into wide-scale use (Blinn et al., 1996). The advantages of portable bridges include keeping skidders out of streams, reduced turbidity, concentrating stream-crossing traffic at controllable points, re-usability and the relatively low cost of these structures (Blinn et al., 1996; Bates, 1995; Tornatore, 1995). Disadvantages include increases in set-up time and a requirement to prepare bridge approaches within the SMZ (Blinn et al., 1996; Bates, 1995).

To determine whether bridging the SMZs was operationally cost efficient, the SMZ pixel travel cost was successively reduced until it became cheaper to incur this cost than to go around the SMZ or to haul directly to the nearest non-SMZ-restricted landing zone. The locations on the SMZ where crossings occurred were designated as bridge locations and the total skidding cost for all pixel locations was computed. As SMZ pixel travel cost was successively lowered, more SMZ penetrations occurred and more bridges were installed. This process continued until the SMZ pixel travel cost converged with the estimated bridge two-way pass cost. This value was developed from published information about portable bridge cost and expected life, based on traffic and wear (Blinn, 1996). Figure 5 shows the locations of five bridges placed on the tract. Note that the lines delineating the allocation of each pixel to a landing zone approach the optimal geometric solution depicted in Fig. 3.

Table 2 shows the cost to skid for the demonstration tract under the three different scenarios of no restrictions (no SMZ), SMZ restrictions and SMZs with bridges. Note that the cost to skid with the SMZ is lower than with no SMZs imposed. This is due to the 5.7 hectare reduction in total area (that went from forest land into the SMZs) that must be skidded. However, note also that there is a reduction in total cost attributable to using the bridges. Figure 4 shows the locations of five bridges on the tract. Note that the lines delineating the allocation of each pixel to a landing zone approaches the optimal geometric solution depicted in Figure 2.

Stream Locked Areas.--Figure 6 depicts a tract (POW1) on which there are two streamlocked areas. This land-use-allocation map, similar to Fig. 1, shows a road with an associated landing zone and a stream. Note that there are two stream-locked areas: one in the inter-stream confluence and a second, north of the stream. These areas are inaccessible under the SMZ impenetrability restriction. However, when bridges are located using the travel cost reduction technique, two bridges are placed, and subsequently, a much larger area becomes accessible (Fig. 7).

Harvest Values.--Table 2 shows the cost to skid and the harvestable timber values for the two demonstration tracts under the three different scenarios of no restrictions (no SMZs), SMZs with restrictions, and SMZs with bridges. Skidding cost was established through an algorithm established by Kluender and Stokes (1996). Timber land was uniformly valued at $2,966 per hectare based on an assumption of 9.9 thousand board feet of timber per hectare times a market price of $300 per thousand board foot. While this

Table 1. Allocation of area in the 68.4 hectare study tract, by land use.

Use	Area	% of area
Forest land	54.6	79.8
Roads	6.9	10.1
SMZ	5.7	8.3
Landing zones	1.2	1.8
Total area	68.4	100.0

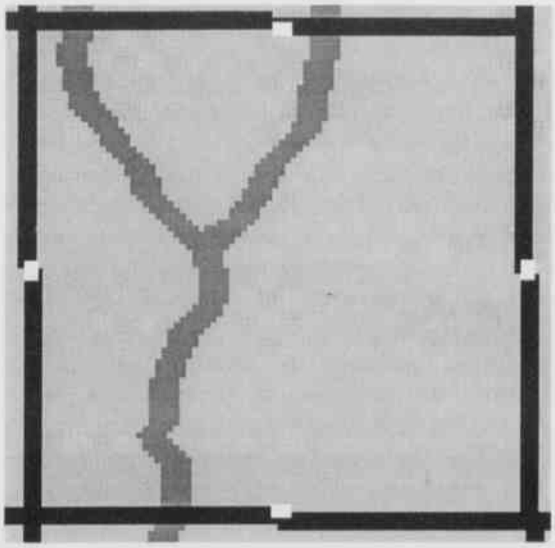

Fig. 1. Land use allocation map for the 68.4 hectare tract (Cros1).

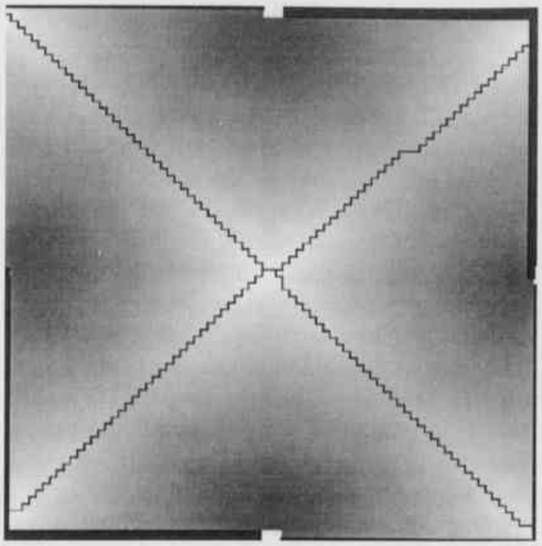

Fig. 3. Optimal geometric harvesting cost model for the Cros1 tract.

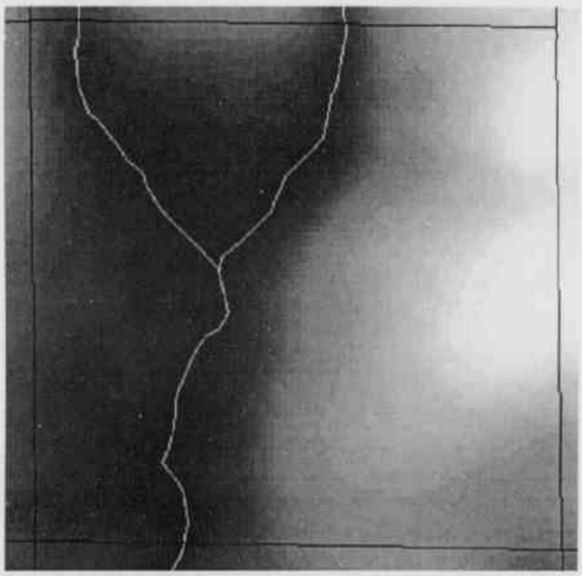

Fig. 2. Shaded digital elevation model (DEM) with roads and hydrologic features for the Cros1 tract.

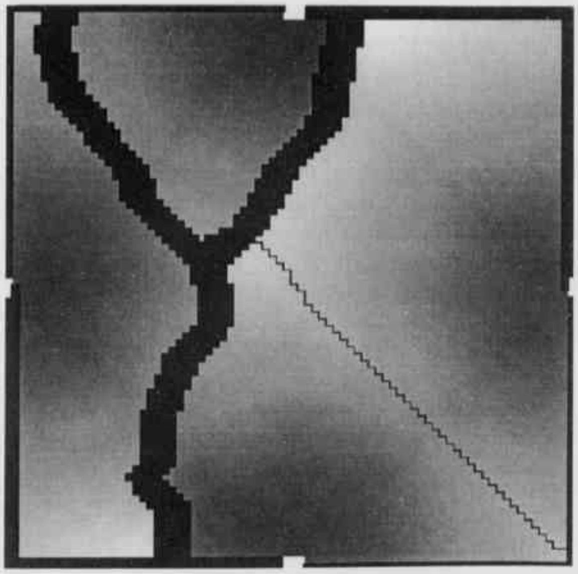

Fig. 4. Sub-optimal harvest layout required by the SMZ non-penetration requirement for the Cros1 tract.

perhaps produces a conservative per-hectare estimate, it yields a number that may be compared across several tracts.

Skidding cost with no SMZ is the optimal harvesting configuration. The cost to skid with the SMZ impenetrability restriction includes the opportunity cost of the unharvestable timber that is tied up in the SMZ itself, and in the stream locked areas. The cost to skid when the SMZ's are bridged includes the cost to skid and the cost of timber tied up in the SMZ. Value for the no-SMZ scenario is the total value of the tract. Value for the tracts when SMZs are in place includes all accessible timber (not in an SMZ or stream-locked area). Timber value for the SMZ-with-bridges scenario included all timber on the tract except for that reserved into the SMZs.

Benefit/Cost Relations.--One way to better understand the relation between value loss and costs concurrent with the addition of SMZs (Table 2) is the use of benefit/cost ratios (B/C) (Gregory, 1987). To demonstrate shifts in B/C

Table 2. Cost to skid and associated timber values ($) for the 68.4 hectare and the 57 hectare tracts under three harvesting conditions.

	68.4 Ha. Tract (Cros1)				57.0 Ha. Tract (POW1)			
	Cost	Timber Value	B/C Ratio	Marginal B/C Ratio	Cost	Timber Value	B / C Ratio	Marginal B/C Ratio
No SMZ	49,216	178,060	3.62		53,729	165,220	3.08	
SMZ Restriction	62,226	161,633	2.60	0.72	99,959	95,005	0.95	0.31
SMZ With Bridges	61,225	161,633	2.64	1.02	67,544	148,200	2.20	2.31

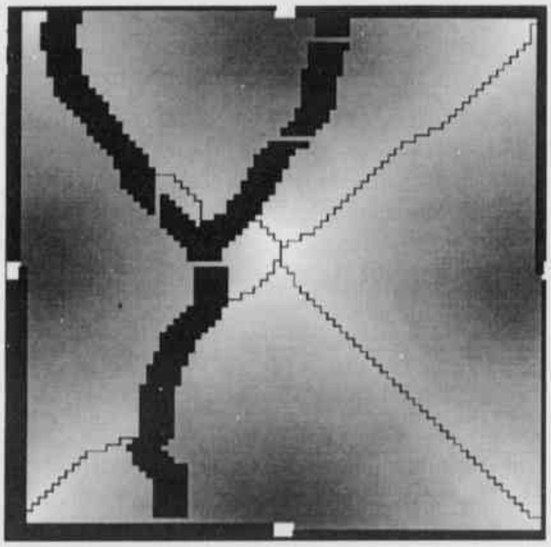

Fig. 5. Near optimal harvesting layout depicting bridge locations for the Cros1 tract.

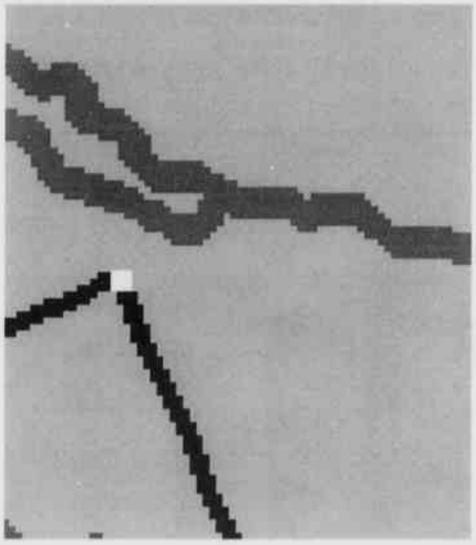

Fig. 6. POW1 tract showing near optimal harvest layout with two bridges.

ratios, Fig. 8 depicts the B/C ratios for the six tracts that we studied (including Cros1 and POW1 described above). A better understanding of the problem is provided, first, by realizing that all B/C ratios are strongly positive; in all cases examined, the timber is worth many times more than its retrieval cost. Second, additional understanding is gained by comparing the B/C ratios in moving from the no-SMZ to the SMZ scenario and from the SMZ to bridged SMZ scenario (Fig. 9). This statistic takes on the quality of an elasticity or marginal B/C ratio (Gregory, 1987). It summarizes the loss in the move from unrestricted movement to the restrictions of the SMZ and then, the benefit of adding the bridges to the SMZs to relieve movement restrictions. For all tracts the B/C ratio of going from unrestricted movement to the SMZ restrictions is less than one. In other words, there is always some loss inherent in SMZ placement. Minimal losses were associated with tracts where only the SMZ area was lost, and very little additional harvesting cost was incurred. In these cases, the marginal B/C ratio of adding the bridge was only slightly higher than 1.0. In situations were significant area is stream-locked by the SMZ, the marginal B/C ratio associated with adding a SMZ is very low (<0.5). However, in these cases the marginal B/C of adding bridges was very high, close to 2.5. However, this condition will only exist where significant areas are isolated by SMZs. Under these circumstances, product prices and harvesting costs become more important in the decision about bridging and accessing areas of a tract that are marginally accessible

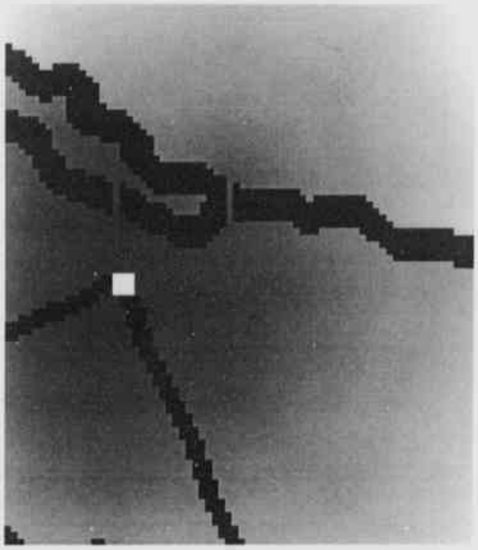

Fig. 7 POW1 tract showing near optimal harvest layout with two bridges.

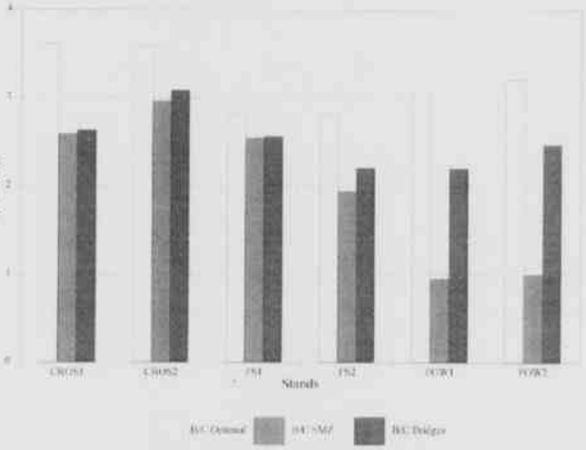

Fig. 8. Benefit / Cost ratios for the optimal harvest solution, SMZ restricted harvesting and bridged SMZs for six study tracts.

at best.

Conclusions

This study demonstrates that PCs and PC-based GIS software can be used effectively in the solution of spatial analysis problems. Depending on physiography, SMZs may tie up 3 - 10% of the total operating area of a tract. SMZs are formed from that part of a tract allotted to timber production and may be entirely out of production, depending on how the BMP is implemented. SMZs may 'stream-lock' significant areas of operational land not actually included in the SMZ itself if non-penetration requirements exist. In situations where the imposition of an SMZ greatly effects operational area and movement, portable bridging to cross the SMZ becomes an increasingly good investment.

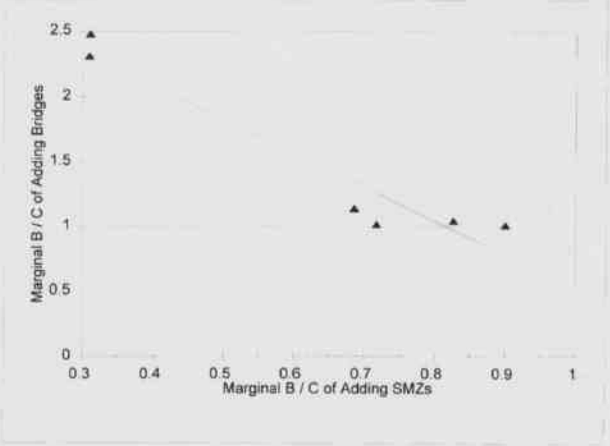

Fig. 9. Marginal B/C ratios for going to bridged SMZ plotted against marginal B/C ratio of adding SMZ restrictiosn for six study tracts.

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