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Aggregating high-priority landscape areas to the parcel level: An easement implementation tool

Michael P. Strager[a,*], Randall S. Rosenberger[b]

[a]Division of Resource Management, West Virginia University, 2006 Agricultural Science Building, Morgantown, WV 26506-6108, USA
[b]Department of Forest Resources, Oregon State University, 109 Peavy Hall, Corvallis, OR 97331-5703, USA

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Abstract

Landscape characteristics and parcel ownership information are often collected on different spatial scales leading to difficulties in implementing land use plans at the parcel level. This study provides a method for aggregating highly resolute landscape planning information to the parcel level. Our parcel prioritization model directly incorporates a Land Trust's conservation goals in the form of a compromise programming model. We then demonstrate the use of our approach for implementation decisions, including parcel selection under a budget constraint and the estimation of a total conservation budget necessary to meet specific conservation goals. We found that these cost constraints significantly alter the composition of the 'best' parcels for conservation and can also provide guidance for implementation. The model's results were integral to a local Land Trust's ability to further define and achieve their goals.

Keywords: Land conservation; Multicriteria analysis; Compromise programming; Geographic information systems

1. Introduction

Much attention has been focused in the literature on how land use change can affect climate, biodiversity, regional economies, and social well-being (Beinat and Nijkamp, 1998; Watson et al., 2000; Theobald and Hobbs, 2002; Mannion, 2002). Specific conservation plans are needed to guide efforts to protect productive ecological systems, conserve native biological diversity and associated ecological processes, and maintain wild species of interest (Davis et al., 2003). Various conservation planning frameworks have been developed to address these issues at different spatial scales (Noss, 2000; Steinitz, 1990; Kautz and Cox, 2001; Groves et al., 2002; Greer, 2004; Wear et al., 2004; Hulse et al., 2002). In these frameworks and others, the typical approach is to evaluate land use alternatives and conservation targets at broad landscape levels ranging from a county to an entire ecoregion.

At these regional extents, implementation of the alternatives or the conservation targets is often not discussed. For example, Cowling et al. (2003) proposed a framework for protecting biodiversity, but they did not evaluate how to implement their strategies. Hyman and Leibowitz's (2000) framework for prioritizing land for ecological protection and restoration provides important regional perspectives to conservation issues, but it does not address the important issue of implementation at local scales. The Nature Conservancy uses a seven-step conservation planning framework that identifies conservation elements and generates a list of priority sites, but they essentially ignore issues related to the implementation of their framework when selecting specific parcels for protection (Groves et al., 2002). Greer (2004) provides valuable lessons learned from 5 years of implementation of conservation planning to protect endangered, threatened, and other sensitive species at the landscape level but does not discuss how to prioritize properties for conservation at the parcel level.

One of the reasons for few local or parcel level implementation studies is that at the regional extent, the identified areas for conservation are likely to cover or extend over a large number of parcels. In this case, a simple

*Corresponding author. Tel.: 304 293 4832x4453; fax: 304 293 3752.
E-mail addresses: mstrager@wvu.edu (M.P. Strager), r.rosenberger@oregonstate.edu (R.S. Rosenberger).

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spatial overlay in a geographic information system (GIS) can identify the parcels and ownership information for implementation.

When the identified areas for conservation are at a scale that is smaller than parcels, aggregation to the parcel level must be performed. How the aggregation should be done and how to include additional parcel criteria such as size, adjacency, etc. are important questions in implementation. Because higher resolution priority landscape areas have natural or continuous boundaries, they will rarely if ever correspond exactly in size and shape to ownership or other political boundaries such as parcels. As spatial data layers continue to become more available and at finer resolutions, aggregating up to the parcel scale will become even more common.

This paper addresses aggregating highly resolute spatial data to the parcel level when this is the appropriate scale for conservation planning. Our method integrates GIS/spatial analysis, a compromise programming model, and an economic framework as a tool to aid in parcel comparisons. We illustrate our method by applying it to the circumstances of an actual Land Trust in the Cacapon River Watershed of West Virginia. We conclude by evaluating our approach under four main implementation questions: (1) Do high-priority areas identify locations with multifunctional characteristics and represent the land conservation goals and objectives? (2) How successfully were the high-priority areas aggregated to parcels for easement selection? (3) Where are the ''best'' parcels that fit a conservation budget? (4) How large of a conservation budget is needed to meet a goal of protecting large, contiguous, high-priority areas in the watershed?

2. Method

Our model consists of three components—multicriteria analysis, compromise programming, and cost evaluation (Fig. 1). Parcel level prioritization is essentially a multicriteria analysis problem (Malczewski, 1999). The common procedure for solving multicriteria problems is the integration of an evaluation matrix with a vector consisting of weights corresponding to the assigned priority of the criteria (Jankowski and Richard, 1994; Carver, 1991). The evaluation matrix E and weight vector W can take the following forms:

$$E = \begin{bmatrix} f_{1l} & \cdots & f_{1j} \\ \vdots & & \vdots \\ f_{il} & \cdots & f_{ij} \end{bmatrix}, \quad (1)$$

$$W = (w_1, w_2, \ldots, w_i),$$

where f_{ij} is the evaluation score, J is the set of alternatives, and I is the set of criteria. Each value is expressed with respect to the ith criterion. The basic form of the objective function can be depicted in matrix notation:

$$\begin{bmatrix} A_1 \\ \vdots \\ A_j \end{bmatrix} \text{ function of } \begin{bmatrix} f_{1l} & \cdots & f_{1j} \\ \vdots & & \vdots \\ f_{il} & \cdots & f_{ij} \end{bmatrix} \text{ and } \begin{bmatrix} w_1 \\ \vdots \\ w_i \end{bmatrix}, \quad (2)$$

where A_j is the score for alternative J.

One of the many solving algorithms in the multicriteria literature that can be used to find a possible set of solutions is compromise programming. Compromise programming identifies non-dominated solutions under the most general conditions, allows specified goals, and most important, provides an excellent base for interactive programming (Tecle et al., 1988a). The concept of non-dominance is used in compromise programming to select the best solution or choice of alternative. A solution is said to be non-dominated if there exists no other feasible solution that will cause an improvement in a value of the objective or criterion functions without making a value of any other objective function worse (Tecle and Yitayew, 1990).

The ''best'' alternative from A_j may not contain the most preferred values for all objectives; it is a compromise solution that is better than all other feasible combinations. In compromise programming, the ''best'' solution is defined as the alternative that minimizes the distance from a goal point (often the ideal point is used) to the set of efficient solutions (Gershon and Duckstein, 1983; Romero and Rehman, 1989; Zeleny, 1982). Compromise programming algorithms have been used in many different multicriteria evaluation applications, including preference ranking of irrigation technologies (Tecle and Yitayew, 1990), water resource system planning (Duckstein and Opricovic, 1980; Gershon and Duckstein, 1983), developing forest watershed management schemes (Tecle et al.,

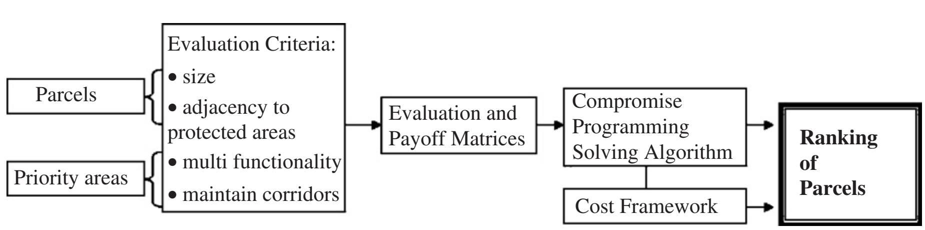

Fig. 1. A parcel prioritization model.

1988a), selecting wastewater management alternatives (Tecle et al., 1988b), defining hydropower operations (Duckstein et al., 1989), and river basin planning (Hobbs, 1983).

An ideal solution for the compromise programming algorithm, as defined by Tecle and Yitayew (1990), is the vector of objective functions' values, $f^* = (f_1^*, f_2^*, \ldots, f_I^*)$, where the individual maximum values for a criterion i, f_i^*, and minimum or worst value for criterion i, f_i^{**}, are determined using

$$f_i^* = \text{Max}(f_{ij}), i = 1, 2, \ldots, I \text{ and } j = 1, \ldots, J, \tag{3}$$

$$f_i^{**} = \text{Min}(f_{ij}), i = 1, 2, \ldots, I \text{ and } j = 1, \ldots, J. \tag{4}$$

The ideal point in a compromise programming procedure defines a reference point for evaluating the comparative performances of the different alternatives to achieve the desired objectives. The alternative that attains a solution "closest" to the ideal point becomes the most preferred alternative. The degree of closeness of a solution to the ideal point, f^*, is determined using a standardized family of L_p metric values (Tecle and Yitayew, 1990). The L_p metric as a compromise solution with respect to p can be expressed as

$$\text{Min}\left\{ L_p(A_j) - \left[\sum_{i=1}^{N} (W_i) \left[\frac{(f_i^* - f_{ij})}{(f_i^* - f_i^{**})} \right]^p \right]^{1/p} \right\}, \tag{5}$$

where $L_p(A_j)$ is the distance metric as a function of the decision alternative A_j and the parameter p (Tecle and Yitayew, 1990). W_i is the standardized form of the criterion weight, w_i, and represents the decision maker's relative preference structure among the i criteria where the sum of the criteria weights equal one. The symbol, f_i^*, represents the ideal or best value for criterion i as described in (3). The notation, f_i^{**}, is the minimum or worst value for criterion i as described in (4).

In (5), the parameter p can have values from zero to infinity and represents the concern of the decision maker over the maximum deviation (Tecle and Yitayew, 1990; Duckstein and Opricovic, 1980). The larger the value of p, the greater the concern becomes. For $p =$ one, all weighted deviations are assumed to compensate each other perfectly. For $p =$ two, each weighted deviation is accounted for in direct proportion to its size. As p approaches the limit of infinity, the alternative with the largest deviation completely dominates the distance measure (Zeleny, 1982). To solve the multicriterion problem using the compromise programming algorithm, the vectors of ideal point values f^*, and worst values, f^{**}, are determined using (3) and (4) from above. These values are then used in (5) to compute the L_p distance values from the ideal points. The preferred alternative has the minimum L_p distance value for each p and weight set that may be used. Thus, the alternative with the lowest value for the L_p metric will be the best compromise solution because it is the nearest solution with respect to the ideal point. The parameter p acts as a weight attached to the deviations according to their magnitudes. Similarly W_i becomes the weights for various deviations signifying the relative importance of each criterion (Romero and Rehman, 1989).

The evaluation matrix represents particular values of an ownership parcel in terms of the criteria. In order to evaluate the matrix, the values for each criterion are normalized to a zero to one scale. This transformation allows for the combination of the criteria by creating a standardized dimensionless scale. After the transformation to the standardized ranges, the data is referred to as a payoff matrix (Tecle and Yitayew, 1990).

The previously discussed compromise programming model assumes that all parcels can be eventually secured with easements. However, a conservation group typically must work within a budget constraint when securing parcels. Cost plays an important role in the selection of parcels that effectively and efficiently meet a group's goals. An important implementation decision is how to select parcels that maximize conservation objectives with a limited budget.

One traditional economic approach to evaluating alternatives is a cost benefit approach. A cost benefit approach can be useful in ranking projects, evaluating alternatives to meet a performance level, or determine the optimal output level of an operation (Layard, 1994). Beinat and Nijkamp (1998) note how cost benefit analysis can be an effective evaluation methodology and extremely valuable when complemented with other evaluation approaches. The cost benefit approach can be reduced to a cost-effectiveness analysis when it is impractical or impossible to derive monetary estimates of benefits; i.e., locating the least cost approach to secure a level of benefits (Munda, 1996; Hughey et al., 2003).

The approach we propose is similar to the non-parcel approaches used by Hyman and Leibowitz (2000), Davis et al. (2003), and Machado et al. (2003). The top ranked parcels from the compromise programming model become the set of possible investments or an index for benefits. Because conservation groups pursue easements at the parcel level, a conservation investment in a site is the easement price. The objective function can be defined as maximizing conservation value that remains for a given time in the future by investing a fixed level of conservation funds to protect a set of parcels. Expressed in notation format,

$$\begin{aligned} &\text{Maximize} \sum\nolimits_i V_i(X_i | \text{ Criterion } 1, 2, 3, 4) \\ &\text{Subject to} \sum\nolimits_i X_i C_i \leqslant Y, \end{aligned} \tag{6}$$

where V_i is the parcel conservation value at site i, X_i is the decision variable that identifies whether site i was selected or not, C_i is the easement price for parcel i and Y is the budget constraint. The compromise programming ranking can be used as a proxy for parcel conservation which then could be evaluated as possible investments.

3. Application

To apply our proposed model requires spatially referenced digital parcel boundaries acquired from West Virginia Department of Tax and Revenue (West Virginia Department of Tax and Revenue (WVDTR), 2005) and mapped high-priority landscape areas (discussion follows in Section 3.1). From these GIS data sets we were able to create a matrix of the evaluation criteria for each parcel. Two of the criteria (parcel size and adjacency to already protected areas) were easily calculated within the GIS for each parcel. Calculating multifunctionality and contiguous high-valued areas for each parcel required more sophisticated overlay and spatial analysis techniques in raster-based software (Environmental Systems Research Institute (ESRI), 1999).

3.1. Study area

We apply our method to the 2178 km^2 Cacapon River Watershed in West Virginia (Fig. 2). The Cacapon and Lost River Land Trust (hereafter Land Trust) has been conserving land in this watershed since 1995. However, their reactive approach to acquiring conservation easements has resulted in the conservation of small, fragmented areas in the watershed. In order to become more proactive, they identified the need for a method to aid in selecting parcels for conservation easements within the watershed.

Based on input from local stakeholders and technical experts, the Land Trust identified specific objectives and evaluation criteria (attributes) for targeting land for conservation. These objectives were to protect land with agricultural, forestry, water quality, and rural heritage characteristics. From these objectives 37 evaluation criteria were defined which consisted of criteria such as prime farmland soils, large contiguous forest tracts, streams with adequate riparian vegetation, and culturally or historically significant sites (Strager, 2002). Other studies have used criteria such as conservation hubs and corridors, interior forests, umbrella species, biodiversity hotspots, roadless areas, and others (Betrus, et al. 2005, Kiester et al. 1996, Wear, et al. 2004, Fahrig, 2001, Theobald, et al. 1997).

GIS was used (Environmental Systems Research Institute (ESRI), 1999) to score each location or 20 m grid cell for its relative conservation value (see Strager (2002) for a detailed description of the process). Using GIS is a typical exercise to score map layers and prioritize spatial areas (Johnson, 1995). The layers are often represented in a GIS raster model as gridded cells and combined to identify higher or lower priority areas as a suitability map (Pressey and Nicholls, 1989; Eastman, 1995).

The process combined the spatial data sets which represented each of the criteria using an additive linear weighted model approach within the GIS. Four category maps were created to show high-priority areas for agriculture, forestry, water quality and rural heritage. Combining all four maps produced a suitability mapping of priority landscape areas for conservation (Fig. 3). Suitability for each area is therefore a function of the preference weights and GIS spatial data. This approach is a

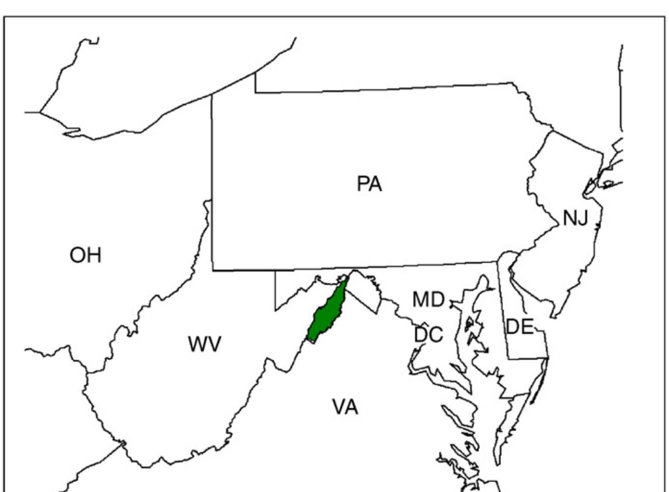

Fig. 2. Cacapon River Watershed in West Virginia.

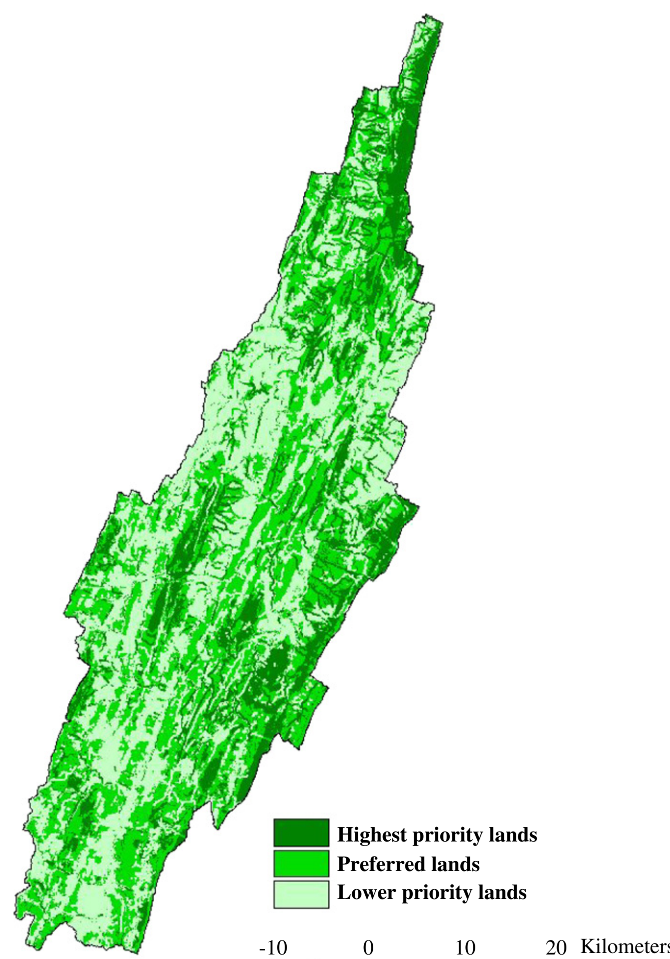

Fig. 3. Priority landscape areas for conservation.

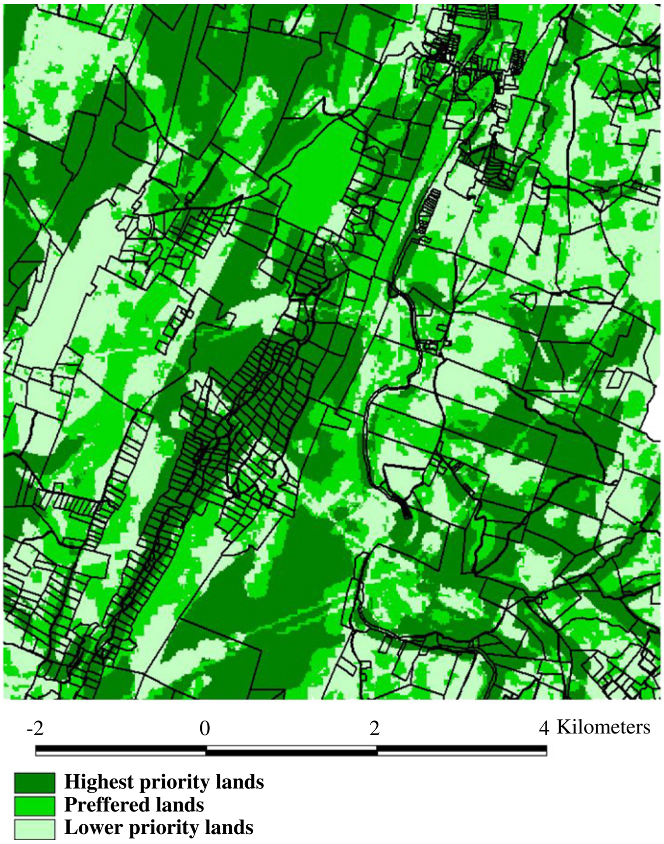

Fig. 4. Spatial difference between priority landscape areas for conservation and parcels.

popular method for combining raster data within a GIS (Eastman, 1995; Malczewski, 1999). However, high-priority mapping was at a resolution (a pixel) much smaller than the implementation scale (a parcel) (Fig. 4). The need to make parcel level implementation decisions for conservation forced us to develop additional criteria. Four parcel evaluation criteria were used in combination with the high-priority landscape areas.

(1) *Size*: The Land Trust determined that it requires nearly as much time and effort to protect a 2 ha parcel as one that is 600 ha. However, larger parcels may require additional costs in monitoring for easement compliance by landowners. The Land Trust is willing to make the size vs. monitoring cost tradeoff since they can more easily defend purchasing easements covering large areas. Smaller parcels would have to be of exceptional value and quality for them to be justified over a much larger parcel.
(2) *Adjacency*: To decrease fragmentation, it is important to protect parcels that are adjacent to existing easements or public land.
(3) *Multifunctionality*: Parcels that support more than one targeted characteristic (agriculture, forest, rural heritage, and water quality) provide the broadest range of social and ecological services. The Land Trust wanted their implementation decisions to account for parcels providing multiple conservation services. For example, a parcel with a high-priority score from forest, rural heritage and agriculture evaluation criteria would be preferred over a parcel with a high-priority score from just the agriculture criteria. This multifunctional evaluation criterion would reward parcels that intersected high-priority areas that were a function of three or all four of the targeted characteristics. Spatial analysis operations within a GIS provided the tools to calculate the percentage of parcel area that had three or four of the targeted characteristics. This information was recorded for each parcel and stored in the evaluation matrix.
(4) *Contiguity*: Contiguous areas provide many ecological benefits over smaller, isolated areas (Fahrig, 2001; Kareiva and Wennergren, 1995; Andren, 1994; Groves et al., 2002). Thus it is important to identify parcels that have the ability to protect and expand these rare large corridors of important features. Expanding the reserves can provide an important assurance toward future preservation (Cowling et al., 2003). To calculate a parcel score for this criterion, we used GIS to spatially find contiguous regions of high-priority areas. Parcels that intersected these large contiguous regions were assigned the total area of the region they intersected. For example, if a parcel intersected a contiguous 7 km^2 region, it would be assigned a 7 for its spatial pattern score. This criterion rewards those parcels that are part of large connected high-priority areas.

Values for each criterion in the evaluation matrix were normalized to a 0–1 range to create a payoff matrix with 1 being the highest or best value for a criterion across all the parcels. Using the values from the payoff matrix as f_{ij} and the maximum (best) and minimum (worst) values for each criteria using Eqs. (3) and (4), the compromise programming Eq. (5) was run for parameter values of $p = 1$ and 2 with equal weights of 0.25 for each of the four criteria. The highest ranked parcels will have the lower $L_p(A_j)$ metric score.

Parcel conservation value was calculated with the compromise programming model, which provided a rank ordering of all parcels. These parcels could then be evaluated as possible investments. However, easements are not costless. There were insufficient easement purchases in this watershed to allow a regression-based approach. Instead, the average price per hectare from past easement purchases in the watershed is assumed to equal future easement prices. In the Cacapon Watershed, the average conservation easement price was \$365(USD)/ha for full parcel easements. Sub-parcel easement costs are typically higher due to increased complexities and costs in their legal structure and monitoring. It should also be noted that the \$365(USD)/ha easement price is an index and obviously varies across parcels being evaluated. For example, landowner characteristics and willingness to aid in conservation

Table 1
Top ten parcel rankings and projected easement acquisition costs

Parcel ID	Rank when $p = 1$	Rank when $p = 2$	Sum rank	Final rank	Average $L_p(A_j)$ value*	Easement cost
352	1	1	2	1	0.96119	$237,573
1292	2	2	4	2	1.13573	$393,291
885	3	3	6	3	1.20247	$950,584
1257	4	4	8	4	1.29915	$46,382
1646	5	7	12	5	1.29758	$44,938
1367	6	10	16	6	1.33778	$17,690
1254	7	12	19	7	1.35734	$10,023
884	8	13	21	8	1.40108	$12,867
353	9	14	23	9	1.45686	$9,209
2	10	15	25	10	1.45511	$9,967

*From Eq. (5) for $p = 1$ and 2.

may constitute more land being donated that would reduce the conservation cost per hectare for a particular parcel.

4. Results

It should be noted that the parcel rankings provided in this paper are based on equal weights for each of the four criteria. This decision was driven by the desire of the Land Trust to consider the parcel size, adjacency, multifunctionality, and contiguity criteria equally important. A different set of weights may lead to a different ranking of the parcels. Because criteria weights were equal, we tested the robustness of the parcel rankings by using different parameter values of p in Eq. (5). The top parcels for each run of $p = 1$ and 2 were then rank ordered to arrive at a final top ten and summarized in Table 1. The locations of the top ten ranked parcels are shown in Fig. 5.

With the information on the ranked parcels the Land Trust could select the highest ranked parcels from Table 1 until their budget constraint is fully expended. Assuming easements are established on the parcels for the budget year, the new protected areas are noted and the compromise programming model is iterated with the new information to generate another listing for the following years' rankings. This approach is an application of a greedy heuristic algorithm to solve the optimization problem of Eq. (6) (Machado et al., 2003).

With an average annual budget of $100,000(USD), the Land Trust in any given year is not capable of purchasing easements on 12 out of the 100 parcels identified by the parcel prioritization model. The top three parcels have projected easement acquisition costs of $237,573, $393,291, and $950,584 respectively. Therefore, in order to protect many of the highest ranking parcels in the watershed, the Land Trust will either have to partner with other groups, rely on easement donations by the property owners, or relax their budget constraint. The Land Trust could relax their budget constraint through fund-raising efforts or carrying over their budget from year to year until enough funds have accumulated. Unfortunately, the top three ranked parcels would take many years of budget accumulations to purchase.

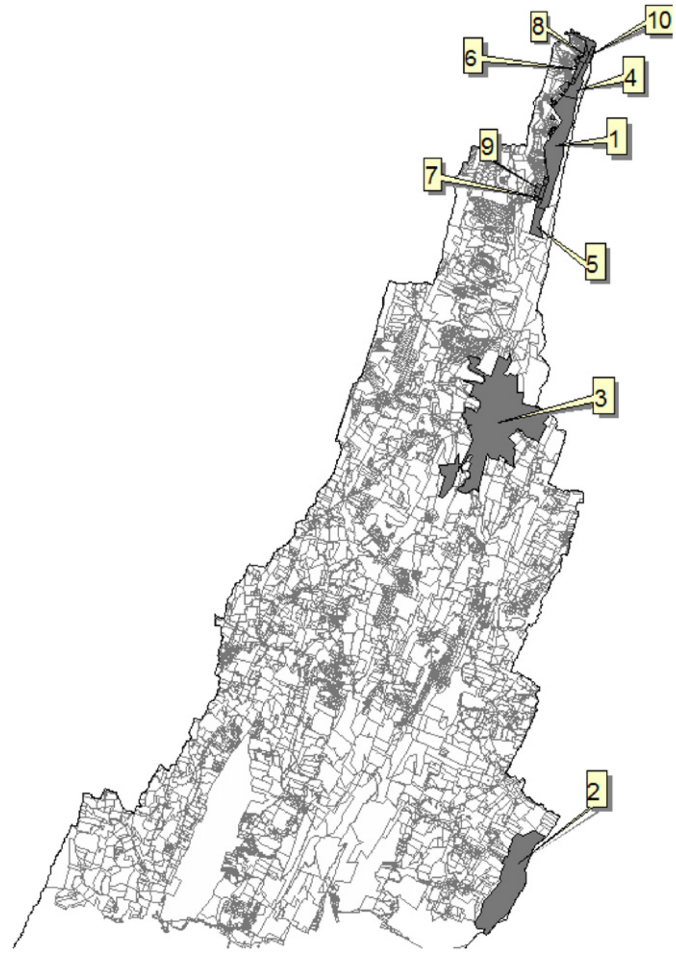

Fig. 5. Top parcel locations numbered in priority order.

The remaining parcels that are immediately affordable to the Land Trust can be evaluated to find the combinations that provide the greatest conservation value. We use the average $L_p(A_j)$ metric value from $p = 1$ and 2 in Eq. (5) as the conservation value or benefit for the parcel. Because

Eq. (5) is minimized, the lower the $L_p(A_j)$ metric calculation, the higher the conservation value for the parcel. In addition to the top three ranked parcels, those ranked fourth through ten would require approximately $151,076 of easement acquisition cost.

5. Discussion/conclusion

The broad scope of many conservation planning frameworks makes them difficult to implement. Some of the reasons can be attributed to a difficulty in balancing diverse factors of the natural environment and competing human interests (Chrisman, 1987), and a lack of required site-level patterns and local information (Theobald and Hobbs, 2002). Multiple landowners of private land can also make conservation implementation difficult (Ailes, 2004) as well as temporal or spatial scale differences in spatial data analysis (Goodchild et al., 1992). Janssen and van Herwijnen (1998) have noted spatial evaluation methods to help in the analysis of questions under consideration but these are only useful with complete identification of the alternatives.

There are four primary questions that may be used to evaluate successful implementation of conservation plans in our empirical application. (1) *Do high-priority areas identify locations with multifunctional characteristics and represent the land conservation goals and objectives?* With a multifunctional criterion explicitly in the parcel-ranking model, we were able to account for parcels that protected more than one of the targeted high-priority characteristics of agriculture, forest, rural heritage and water quality. Our approach identified the parcels that contained multiple characteristics that the Land Trust desired that otherwise may have been missed. While the high-multifunctional areas were more likely to exist on larger sized parcels, we balanced this effect by including a relative parcel cost per size.

(2) *How successfully were the high-priority areas aggregated to parcels for easement selection?* We believe caution should be taken when aggregating values from the high-priority areas to parcels due to scaling issues and spatial resolution. In this particular study area due to the rural landscape, only 8% of the total watershed area consisted of parcels less than 1 ha in size. Because many of these parcels were classified as urban or residential, their value for conservation was low.

(3) *Where are the "best" parcels that fit a conservation budget?* Based on the data available for this particular study, we were able to find parcels that fit a conservation budget. This study used the ratio of the Land Trust's past easement costs to parcel size in the watershed as an indicator. With more data, a regression analysis would provide more information on factors relating easement costs to parcel characteristics. It also would be important to include costs associated with monitoring to insure easement restrictions are being met. Other liability costs would also improve the projected easement cost.

(4) *How large of a conservation budget is needed to meet a goal of protecting large, contiguous, high-priority areas in the watershed?* We were able to identify the approximate easement acquisition costs needed to protect such areas in the watershed. Fig. 5 shows that the parcels ranked second and third are large high-priority areas by themselves with approximate conservation acquisition costs of $393,291 and $950,584, respectively. In addition to these two areas, the highest ranked parcel is adjacent to parcels ranked fourth through ten. If the Land Trust could combine these parcels, it would create another large, high priority, contiguous area in the watershed. The approximate acquisition cost would be $388,469. These costs give the Land Trust an idea of the conservation budget needed to meet this goal.

As a decision-making aid, our parcel prioritization model was a success. The Land Trust benefited greatly by using the tool, by increasing their effectiveness in selecting parcels for easements, becoming more proactive in their conservation efforts, and acquiring additional funding through better documentation of their decision-making process. Over the past 2 years, they have been able to increase the number of easements on private property by 26% to over 18,000 ha (Ailes, 2004).

While this approach has proven to be successful for the Land Trust, we must note some of the limitations that exist. The prioritization model did not have any criteria used to measure or adjust for risk of development. Decisions on acquisitions of parcel easements often involve the decision maker's personal knowledge of landowners' likelihoods to sell. Local knowledge of a place may significantly affect decisions (Strager and Rosenberger, 2005). Other factors such as real estate forces and speculation of future road development are difficult to model at the landscape scale.

Topographic characteristics may also make one parcel more or less likely to be developed. Factors influencing development potential may include the proximity to already developed areas, proximity to agricultural areas or other cleared land, and land with a favorable slope and road access. These factors were not part of our original parcel prioritization model; however, measures of parcel vulnerability could easily be integrated in the model contingent upon available data. Despite these limitations, the methodology used here provides a practical real world application of parcel level prioritization for land conservation.

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