Conservation Contracting in Heterogeneous Landscapes: An Application to Watershed Protection with Threshold Constraints

Paul J. Ferraro

A key issue in the design of land use policy is how to integrate information about spatially variable biophysical and economic conditions into a cost-effective conservation plan. Using common biophysical scoring methods, in combination with economic data and simple optimization methods, an illustration is provided for how to identify a set of priority land parcels for conservation investment. This study also demonstrates a way in which conservation agencies can incorporate concerns about biophysical thresholds in the identification of their priority land parcels. These methods are applied using Geographic Information System data from a New York conservation easement acquisition initiative for water quality protection.

Key Words: conservation, spatial, threshold, water quality

Concerns over the effect of private land use on the supply of environmental amenities have led to an increasing global reliance on conservation contracting initiatives (Ferraro and Kiss, 2002). The term "conservation contracting" describes the contractual transfer of payments from one party (e.g., government) to another (e.g., landowner) in exchange for land use practices that contribute to the supply of an environmental amenity (e.g., biodiversity, water quality). Examples of conservation contracts include easements and short-term conservation leases. A key issue in the design of conservation contracting initiatives, like any conservation policy, is how to integrate information about spatially variable biophysical and economic conditions into a cost-effective conservation plan.

Much of the previous work on targeting scarce conservation funds in heterogeneous environments has focused on the conservation of biological diversity. Targeting approaches favored by biological scientists and conservationists emphasize the environmental amenities a given land unit produces, while often ignoring the costs of acquiring those amenities. For example, based on their finding that endangered species in the United States were concentrated spatially, Dobson et al. (1997) suggested conservationists should focus their efforts on a small number of geographic areas. In response to this argument, Ando et al. (1998) assert that variability in economic factors is just as important as ecological variability in efficient species conservation, specifically noting an approach which considers both economic and ecological variability could cost less than one-sixth the cost of an approach considering only ecological variability.

A similar debate has developed over targeting ecosystem conservation investments at the global scale (Mittermeir et al., 1998; Balmford, Gaston, and Rodrigues, 2000). Other studies by economists have also demonstrated the importance of integrating biophysical and economic data, as illustrated by Polasky, Camm, and Garber-Yonts (2001) for the

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case of species conservation in Oregon, and Babcock et al. (1996, 1997) for the case of the Conservation Reserve Program.

This study adds to the existing literature in several ways. First, the analysis focuses on an increasingly common, but little studied, conservation initiative: conservation contracting for water quality objectives. The results of the empirical analysis support previous empirical work suggesting the failure to incorporate cost data in conservation investment decisions can lead to large efficiency losses. Moreover, studies of cost-efficient targeting (e.g., Ando et al., 1998; Polasky, Camm, and Garber-Yonts, 2001; Babcock et al., 1996, 1997) have tended to focus on a single biophysical attribute (such as species absence or presence, erodibility of soil, distance to water). A narrow focus on a single attribute, however, fails to consider the full range of biophysical attributes that are critical to the supply of an environmental amenity. Most conservation initiatives, like the U.S. Conservation Reserve Program [U.S. Department of Agriculture (USDA), 1999] or the World Wildlife Fund's Global 200 initiative (Olson et al., 2000), identify multiple biophysical attributes of interest.

In the context of habitat protection targeting, Prendergast, Quinn, and Lawton (1999) point out that field practitioners and policy makers rarely use the tools and results published in the academic literature. In large part, these tools and results have not been adopted because their development and application do not take into account the objectives and approaches of practitioners and policy makers.

To address this oversight, the empirical application of this analysis uses data available to decision makers, and considers explicitly the actual approaches used by decision makers in the field. The problem is also approached at the specific geographic scale at which decisions are being made—individual parcels rather than large administrative districts or Geographic Information System (GIS) polygons on the landscape.

Unlike previous work, we recognize there is often little agreement about the appropriate way to estimate the environmental benefits provided by a single parcel, and thus multiple methods are used in this investigation to guide the empirical analysis. Finally, there is increasing scientific information to suggest biophysical thresholds are important when designing conservation initiatives (e.g., a riparian buffer has little effect on water quality unless it achieves a minimum size). Few economic analyses, however, have incorporated such thresholds (notable exceptions include Farzin, 1996; Wu, Adams, and Boggess, 2000; and Bulte and van Kooten, 2001). This study demonstrates how simple linking constraints in the optimization problem can be used to model the effect of biophysical thresholds on decisions. In the empirical analysis, a comparison is provided of the conservation contract portfolios selected with and without threshold constraints.

The remainder of the article proceeds as follows. The case study for the empirical analysis is introduced. Next, the data are characterized and the optimization model is developed. The results of the empirical analysis are then presented. Following the discussion of the empirical results, a section is devoted to the adaptation of the optimization model to incorporate thresholds. An examination of the effects of threshold constraints on the selection of the optimal conservation contract portfolio provides further results. Concluding remarks are offered in the final section.

Case Study: The Lake Skaneateles Watershed Program

The use of conservation contracts to achieve water quality objectives is becoming an increasingly popular policy tool (Johnson, Revenga, and Echeverria, 2001). For example, the New York City Watershed Management Plan will spend $250 million on conservation contracting with private landowners in the Catskill-Delaware watershed over the next 10 years to protect the City's water supply and maintain its filtration waiver from the Environmental Protection Agency (National Research Council, 2000, pp. 213–239). Examples of other contracting initiatives for water quality include North Carolina's $30 million Clean Water Management Trust Fund, Massachusetts' $80 million effort to acquire riparian land to protect Boston's Wachusett Reservoir, and Costa Rica's $16 million per year effort to secure conservation contracts in (among other areas) the watersheds of municipal water supplies and hydroelectric dams.

In particular, scientists and policy makers have identified the establishment of vegetated riparian zones that protect surface waters from inputs of nutrients, pesticides, eroded soil, and pathogens as an important policy for improving water quality (Tilman et al., 2001). One such riparian buffer acquisition initiative is currently underway in upstate New York. The City of Syracuse (population 163,860) obtains its drinking water from Lake Skaneateles, which is located outside of the City's regulatory jurisdiction. The lake is 16 miles long, less than one-mile wide on average, and has a 60 square mile watershed covering three counties, seven townships, and one village. The population of the watershed is about 5,000 residents, concentrated largely in the northern half of the lake where the City's intake pipes are located. Land use is mainly a mix of forest (40%) and agricultural land (48%), on which cropping and dairy farming are most common.

The water from the lake is of exceptionally high quality and the City, using only disinfection by chlorination, meets drinking water standards without coagulation or filtration.[1] In recent years, however, the City has come under increasing pressure to consider filtration in order to satisfy the provisions of the Environmental Protection Agency's (EPA's) Surface Water Treatment Rule. In 1994, the City signed a Memorandum of Agreement (MOA) with the New York State Department of Public Health, allowing the City to avoid filtering water from the lake. The MOA requires that the City commit to a long-term watershed management program to reduce pathogen, chemical, nutrient, and sediment loading into the lake.

An important component of the management program is a conservation easement acquisition program through which up to $5 million will be spent over a seven-year period (2001–2008) to secure easements on privately owned riparian parcels. By securing easements on riparian buffers in the watershed, the City hopes to avoid, or delay, the estimated $60–$70 million cost of a new filtration plant. The City wants to allocate its limited budget across the watershed in such a way as to have the greatest effect on maintaining and improving water quality in the lake (Myers, MacBeth, and Nemecek, 1998).

The focus of this analysis is on prioritizing the acquisition of easements from an available population of 202 riparian parcels in the upper watershed of Lake Skaneateles. Biophysical and economic data on these parcels were obtained from the Geographic Information Systems database of the City of Syracuse's Department of Water.[2] The southwestern end of the lake is protected public land and is thus excluded from the analysis. Data on parcels in the southeastern end of the lake were not available at the time of analysis, but because these parcels are far from the City's intake pipes, excluding them will have only minor effects on the final results.

[1] An estimated 20–65 million Americans drink unfiltered surface water (DeZyane, 1990), including citizens in the cities of New York, Boston, and San Francisco.

[2] These data can be downloaded at http://epp.gsu.edu/pferraro/research/workingpaper/workingpapers.htm.

Case Study Data and Optimization Model

We assume each riparian parcel in the watershed, when protected by an easement, generates environmental benefits, e_i, to the City of Syracuse at a cost of $c_i + t_i$, where c_i represents the reservation price of the landowner for accepting an easement on his or her property, and t_i is the transaction cost associated with creating and monitoring a contract. The unit of analysis is the parcel. Within each parcel, environmental benefits and costs are uniformly distributed so that acres within a parcel are homogeneous. In other words, each acre in the parcel is equally as valuable, whether measured for environmental benefits or for productive uses. These are the same assumptions used by the City of Syracuse in its easement acquisition program.

Benefit Data

The City wishes to reduce sediment, chemical, pathogen, and nutrient loading into its water supply. Sophisticated hydrological models, however, are not available for the Lake Skaneateles watershed. To measure the contribution of each parcel to the City's water quality objectives, the City's Department of Water convened a scientific panel to help it develop a parcel-scoring system based on known land attributes in the watershed (Myers, MacBeth, and Nemecek, 1998). The panel developed two potential systems: an interval-scale scoring equation and a ratio-scale scoring equation.

The equations, which are described in the appendix, assign a score to each parcel; the higher the score, the higher the benefit from easement acquisition. Two other common parcel-scoring methods, the categorical scoring system (similar to that used by the U.S. Conservation Reserve Program) and the parcel-pollutant-weighting (PPW) model (Azzaino, Conrad, and Ferraro, 2002), are also used in the empirical analysis and are described in the appendix.

All four benefit-measuring methods generate parcel scores either from weighted linear functions of the attributes or by assignment of points to each parcel based on its biophysical attributes or land uses. Such scoring methods are quite common in the academic literature (e.g., Voogd, 1983; Lemunyon and Gilbert, 1993), in federal agency guidelines (e.g., U.S. Fish and Wildlife Service, 1981; Terrell et al., 1982; Allen, 1983; McMahon, 1983; Allen and Hoffman, 1984), in water quality protection initiatives (e.g., Smith et al., 1995; Rowles and Sitlinger, 1999; Boston Metropolitan District Commission, 1999; Hruby et al., 2000; Florida Department of Environmental Protection, 2000), and in the multi-billion dollar conservation efforts of the U.S. Conservation Reserve Program (Feather, Hellerstein, and Hansen, 1998), land trusts [e.g., the Nature Conservancy, as discussed by Master (1991)], international habitat protection groups [e.g., the World Wildlife Fund (see Olson et al., 2000)], national wildlife protection initiatives [e.g., Partners in Flight, documented by Carter et al. (1999)], and farmland protection initiatives (such as the American Farmland Trust).

In the absence of sophisticated hydrological models for the Skaneateles watershed, it is not possible to determine which of the four parcel-scoring methods is best.[3] If there is positive correlation among the different scoring methods (which would be expected if they are all attempting to measure the same amenity), a simple approach to prioritizing easement acquisition would be to identify the optimal buffer portfolios selected under several scoring methods and then identify a set of "high-priority" parcels that include only parcels found in every portfolio (i.e., parcels in common within each optimal portfolio across the parcel-scoring methods).

This approach is applied in the following section describing the empirical results. As observed from table 1, the Spearman correlations among the parcel scores assigned by each scoring method are strongly positive.

Table 1. Spearman Correlations Among Parcel Scores by Scoring Method

Scoring Method	Interval-Scale	Ratio-Scale	Categorical	PPW
Interval-Scale	1			
Ratio-Scale	0.96	1		
Categorical	0.94	0.92	1	
PPW	0.75	0.81	0.77	1

Cost Data

There were not enough observations on sales of properties with easements in the region to estimate a hedonic equation of easement costs. A regional appraising company (Gardner, 2000) estimated the City of Syracuse would have to pay between 40% and 60% of a parcel's assessed land value to obtain an easement. For purposes of this analysis, we use an estimate of 50%. A change in the percentage would affect only the number of parcels that can be acquired for a given budget, not the order in which the parcels are acquired.

Based on transaction cost information from the Finger Lakes Land Trust, which operates in the region, we also assume there is a transaction cost of $5,000/easement. Varying the transaction cost from $2,500 to $12,500 did not generate dramatic changes in the parcel rankings.[4] Future analyses can incorporate new information on transaction costs and easement costs gathered by practitioners in the course of contacting landowners. The City of Syracuse may also want to consider using a procurement auction to solicit reservation prices from landowners (Laury, 2002).

Optimal Easement Portfolio Selection Problem

The easement acquisition program of the City of Syracuse can be viewed as a linear optimization problem, written as follows:

$$(1) \quad \max_{p_i} \sum_i p_i e_i$$

subject to:

$$(2) \quad \sum_i p_i (c_i + t_i) \leq D,$$

$$(3) \quad 0 \leq p_i \leq 1,$$

where p_i = the share of parcel i under conservation contract ($p_i = 1$ if parcel is fully contracted); e_i = the environmental benefit score for parcel i (a scalar); c_i = the contract cost for parcel i (the private opportunity cost of conservation); t_i = transaction costs for a contract on parcel i (e.g., legal fees, monitoring);[5] and D = the contracting agency's budget.

This approach is equivalent to ranking parcels from highest to lowest based on their e/c ratio and accepting contracts until the budget is exhausted. Thus a conservation practitioner can solve this problem, even without possessing specific knowledge of

[3] Even if sophisticated models existed for estimating sediment, chemical, pathogen, and nutrient loading, one would have to somehow combine these measures to derive a measure of "water quality" benefits from an easement on a given parcel.

[4] The exceptions were a few small, inexpensive parcels for which a change in transaction costs can have a large relative effect on easement cost.

[5] Transaction costs may be fixed regardless of how much of the parcel is contracted, or these costs may be variable as in the formulation in (2). Making transaction costs fixed would complicate the analysis, but would have an inconsequential effect on the solution because only the last parcel to enter the solution would be affected.

programming techniques. Other characteristics of this targeting formulation are covered in detail in Ferraro (2002a).

The City of Syracuse, however, did not formulate its approach to easement acquisition in the manner of expressions (1)–(3). Like many conservation initiatives (e.g., Mittermeir et al., 1998), the City planned to allocate its funds by ranking parcels from the highest score (e_i) to the lowest, and acquiring easements until the budget was exhausted. In this approach, there is a critical level of environmental benefit ($\bar{e}$) for which all parcels with $e_i > \bar{e}$ are contracted. If partial parcel contracting is permitted, a portion of a single parcel with $e_i = \bar{e}$ will be contracted until the budget is exhausted (the marginal parcel); i.e.,

(4) $p_i^B = 1$ when $e_i > \bar{e}$,

(5) $p_i^B = 0$ when $e_i < \bar{e}$,

(6) $p_{\bar{e}}^B \in [0,1]$ when $e_{\bar{e}} = \bar{e}$,

$$\text{where } p_{\bar{e}}^B = \frac{D - \sum p_i^B e_i}{c_{\bar{e}} + t_{\bar{e}}}.$$

The City's prioritization formulation ignores the opportunity costs of contracted parcels and, as suggested by previous empirical analyses (refer to citations in the introduction), its portfolio for any given budget will generate lower benefit scores than the portfolio generated from the formulation of expressions (1)–(3). How much lower is an empirical question.

Empirical Results

The City plans to spend \$1 to \$2.5 million dollars and then evaluate whether further easement acquisitions are required. Therefore, the optimal easement portfolio problem is solved under each scoring method for budgets of D = \$1 million and D = \$2.5 million [maps of the corresponding optimal portfolios can be found in Ferraro (2002a)].

For each benefit-scoring method, table 2 reports the percentage of total environmental benefits available in the watershed which are secured by the optimal portfolio compared to the percentage of total environmental benefits available in the watershed which are secured under the method that ignores opportunity costs and allocates funds based on benefit scores alone, i.e.:

$$\sum_{i=1}^{202} p_i^* e_i \div \sum_{i=1}^{202} e_i \quad \text{vs.} \quad \sum_{i=1}^{202} p_i^{B} e_i \div \sum_{i=1}^{202} e_i.$$

Table 2. Comparison of Portfolio Performance: Optimal Method vs. Method when Opportunity Costs Are Ignored

		Percent of Total Watershed Benefits $\left(\sum_{i=1}^{202} p_i e_i \div \sum_{i=1}^{202} e_i\right)$	
Scoring Method	Acquisition Method	Budget (D) = \$1 mil.	Budget (D) = \$2.5 mil.
Interval-Scale	***Optimal***	***31%***	***62%***
	Ignoring Costs	8%	22%
Ratio-Scale	***Optimal***	***37%***	***72%***
	Ignoring Costs	15%	41%
Categorical	***Optimal***	***31%***	***61%***
	Ignoring Costs	5%	26%
PPW	***Optimal***	***39%***	***72%***
	Ignoring Costs	9%	47%

Consistent with previous research, observations show large efficiency losses associated with ignoring costs in the funding allocation decision. For a budget of \$1 million, the benefit-only approach achieves 16% to 42% of what the optimal approach achieves; under a budget of \$2.5 million, the corresponding values rise to 36% to 65%. The large efficiency gains from using the approach in expressions (1)–(3) rather than the approach in expressions (4)–(6) derive from the moderate positive correlation between benefit (e_i) and cost (c_i) measures and the greater relative heterogeneity of costs compared with that of benefits (Ferraro, 2002b).

While it is clearly beneficial to use the formulation in which benefit and cost data are integrated, each scoring method generates a different "optimal" portfolio. As noted in the previous section, one way to proceed would be to identify those parcels selected for acquisition under all four scoring methods. These parcels might be regarded as "high priority" for an easement acquisition program because they were included in all four optimal buffers.

Such an approach would fit well with the City of Syracuse's approach to easement acquisition. Although the City has estimated it might spend up to \$5 million for easement acquisition, it plans to begin acquiring easements sequentially, and periodically evaluate whether or not more easements will need to be acquired. Thus the City wants to know with which parcels it should begin its acquisition efforts.

The set of "high priority" parcels would be a reasonable place to start. For any given available

Table 3. High-Priority Portfolio Performance Under Four Parcel-Scoring Methods

	Percent of Total Benefits Achieved, by Scoring Method			
Budget	Interval-Scale	Ratio-Scale	Categorical	PPW
$210,900	72%	82%	78%	82%
$1,445,150	92%	79%	82%	92%

budget, a set of priority parcels can be identified that exhaust the budget by changing the value of D under which the optimal buffers are derived.

For example, solving for the portfolios when D = $1 million, 11 parcels are found in each of the four optimal buffer solutions, and these easements can be acquired for $210,900. Similarly, solving for the portfolios when D = $2.5 million, 46 parcels are found in each of the four optimal buffer solutions, with an acquisition cost of $1,445,150.

Table 3 demonstrates how well the "high priority" set of parcels performs compared to the optimal portfolios chosen under the four scoring equations when D = $210,900 and D = $1,445,150. For example, the high-priority portfolio, if its parcels were scored according to the interval-scale scoring equation, achieves 92% of the benefits achieved by the optimal portfolio derived under the formulation in expressions (1)–(3) at D = $1,445,150. Based on the data in table 3, even if one of the scoring equations were the "true" measure of parcel benefits, the City of Syracuse would not lose a substantial amount of efficiency by selecting the "high-priority" portfolio of parcels.

Concepts and Problem Formulation Under Threshold Constraints

The emphasis on parcel-level attributes in the above analysis may be inappropriate if there exist thresholds of riparian buffer area below which little, if any, water quality protection can be expected. The importance of biophysical thresholds in conservation policy design has been noted in a variety of contexts, including endangered species conservation (Shaffer, 1981; Lande, 1987; Wu, Adams, and Boggess, 2000) and water quality protection (Schueler, 1994, 1995; Zoner and Limitz, 1994; Wang et al., 1997, 2000), but only a few economic land use analyses have incorporated biophysical thresholds (e.g., Farzin, 1996; Wu, Adams, and Boggess, 2000; Bulte and van Kooten, 2001).

Ignoring threshold effects, particularly when the available budget is small, may result in a substantial loss of environmental benefits. In such a context, interventions will be scattered over the landscape and funding levels in any given target area may be inadequate to reach the threshold needed to maintain current water quality levels or to achieve significant environmental improvements.

In an empirical study, Wang et al. (1997) found (*a*) indicators of water quality were negatively correlated with the amount of agricultural land in the entire watershed and in a 100-meter-wide buffer along streams;[6] and (*b*) the relationship between agricultural land and water quality was nonlinear—a substantial decline in water quality occurred after agricultural land use exceeded 50%. With more intensive agricultural use or urban uses, the threshold value decreased to between 10% and 20%.

A recent EPA (1999) report noted: "[T]hresholds for a decline in water quality can take the form of size and amount of riparian buffer zones. Condition of riparian zones and changes in percent of buffer areas can indicate a decline in water quality due to soil erosion, sediment loading, and contaminant runoff." However, there have been no general rules of thumb developed specifically for riparian areas. Consequently, the empirical analysis below is intended to demonstrate a simple way in which biophysical thresholds can be incorporated into the formulation in expressions (1)–(3), rather than to claim such thresholds exist in the Lake Skaneateles watershed.

The Lake Skaneateles upper watershed is made up of 16 sub-watersheds, or catchments. The City of Syracuse has determined that each easement will be designed to secure a 100-foot-wide riparian buffer along the entire stream length of the property. This section examines the effect of imposing a threshold requirement on the area of the 100-foot-wide riparian buffer in a given catchment. Empirically, the threshold is examined at three levels: 50%, 80%, and 90% of the available riparian buffer in the catchment. For example, if there is a 50% threshold, no water quality benefits can be achieved in a catchment through conservation contracting unless at least 50% of the available 100-foot-wide riparian buffer is protected through easements.

[6] Correlations were generally stronger, however, for the entire watershed than for the buffer.

Optimal Easement Portfolio Selection with Thresholds

A watershed is made up of $j = 1, ..., N$ sub-watersheds, or catchments. A conservation agent has $\$D$ to spend on conservation contracts and wants to allocate these funds to maximize environmental benefits. Conservation contracts are used to secure easements on 100-foot-wide riparian buffers. The number of acres in a 100-foot-wide riparian buffer on the ith parcel in the jth catchment is designated as b_i^j. In order to receive any environmental benefits from contracts in the jth catchment, the conservation agent must contract for at least B^j acres of the available 100-foot-wide riparian buffer in the catchment.

The optimal riparian buffer contract portfolio, in the presence of threshold constraints, is the solution to the following problem:

$$(7) \quad \max_{p_i^j, Y^j} \sum_{j=1}^{N} \sum_i p_i^j e_i^j$$

subject to:

$$(8) \quad \sum_{j=1}^{N} \sum_i p_i^j c_i^j \leq D,$$

$$(9) \quad \sum_i p_i^j b_i^j \leq M Y^j, \qquad j = 1, 2, ..., N,$$

$$(10) \quad \sum_i p_i^j b_i^j \geq B^j Y^j, \qquad j = 1, 2, ..., N,$$

$$(11) \quad p^j \in [0, 1]; \; Y^j \in \{0, 1\},$$

where p_i^j = parcel i in catchment j, $p_i^j \in [0, 1]$ ($p_i^j = 1$ if the parcel is fully contracted); Y^j = presence or absence of contracting in catchment j, $Y^j = \{0, 1\}$ ($Y^j = 1$ if there is contracting in catchment j); e_i^j = environmental benefit score of parcel i in catchment j; b_i^j = acres of 100-foot-wide riparian buffer in parcel i in catchment j; c_i^j = contract cost for parcel i in catchment j (including transaction costs); B^j = minimum acres of 100-foot-wide buffer which must be secured in catchment j for any benefits to be obtained from contracts in that catchment (i.e., the threshold); and M = a very large number (= total riparian exposure of the Skaneateles Lake watershed in feet).

Thus a decision maker must now select not only the parcels on which to establish a conservation contract (p_i^j), but also the catchments in which to establish contracts (Y_j). Expression (9) establishes the link between the value of the Y_j variables and the value of the p_i^j variables. According to this constraint, if contracting is being done on the ith parcel ($p_i^j = 1$), contracting must be taking place in the corresponding jth catchment ($Y_j = 1$); otherwise the constraint would be violated. From expression (10), if $Y_j = 1$, the acres of buffer in the catchment must exceed the threshold.

The problem remains linear in the objective and constraints, and thus is easily solved with standard linear programming packages (e.g., a practitioner could use Excel's Solver algorithm to solve the problem). The problem is not restricted to one threshold constraint; for example, one might want to add a threshold corresponding to a specific percentage of the drainage area in a catchment that must be buffered if there are to be any benefits from easements in the catchment.

Portfolio Results Under Threshold Constraints

As in the empirical results section, the optimal easement portfolio problem is solved under each scoring method for budgets of D = \$1 million and D = \$2.5 million. As one would expect, threshold constraints result in spatial concentration of contracts on the landscape [spatial representation of the solutions can be found in Ferraro (2002a)]. Table 4 presents the percentage of parcels in the buffer portfolio derived using expressions (7)–(11) that were also found in the optimal portfolio derived without threshold constraints [expressions (1)–(3)].

For a given scoring method, the spatial effect of thresholds on the optimal contract portfolio is generally greatest at low budget levels and high thresholds. For example, using the PPW scoring method with a budget of \$1 million and a threshold of 50%, 85% of the parcels in the new threshold-constrained portfolio are also in the original optimal portfolio derived without threshold constraints. When the threshold is increased to 90%, only 44% of the parcels in the optimal portfolio are also found in the original portfolio. At a threshold of 50%, a larger budget of \$2.5 million increases the overlap to 92%. There are, however, anomalies, such as the greater overlap at a 90% threshold than at an 80% threshold under the interval-scoring method and a \$1 million budget. Such anomalies can result because, as the threshold increases, the number of acquired parcels, in comparison to the original, no-threshold portfolio, may increase or decrease non-monotonically.

To examine the efficiency losses that arise when a conservation agency ignores threshold constraints

Table 4. Percentage of Parcels in Optimal Portfolio Under Threshold Constraints that Are Found in Original/No-Threshold Portfolio

	Budget (D) = $1 million				Budget (D) = $2.5 million			
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Scoring Method	None	50%	80%	90%	None	50%	80%	90%
Interval-Scale	100%	75%	65%	75%	100%	94%	89%	78%
Ratio-Scale	100%	92%	71%	58%	100%	97%	87%	78%
Categorical	100%	80%	71%	68%	100%	93%	89%	85%
PPW	100%	85%	55%	44%	100%	92%	83%	77%

Table 5. Portfolio Performance when Thresholds Are Ignored

		Budget (D) = $1 million			Budget (D) = $2.5 million		
		% of Total Watershed Benefits Achieved, by Threshold			% of Total Watershed Benefits Achieved, by Threshold		
Scoring Method	Acquisition Method	50%	80%	90%	50%	80%	90%
Interval-Scale	***Optimal***	***28%***	***26%***	***25%***	***61%***	***56%***	***55%***
	Ignoring Thresholds	17%	0%	0%	49%	33%	8%
Ratio-Scale	***Optimal***	***36%***	***33%***	***31%***	***72%***	***68%***	***62%***
	Ignoring Thresholds	8%	0%	0%	67%	44%	31%
Categorical	***Optimal***	***28%***	***26%***	***25%***	***60%***	***56%***	***54%***
	Ignoring Thresholds	16%	0%	0%	45%	38%	37%
PPW	***Optimal***	***38%***	***33%***	***26%***	***72%***	***68%***	***60%***
	Ignoring Thresholds	11%	3%	0%	67%	9%	0%

when acquiring contracts, we compare the portfolio scores generated under the optimization formulation of expressions (1)–(3), which ignores thresholds, and the optimization formulation of expressions (7)–(11), which incorporates thresholds. If the threshold constraint is not met in a catchment, contracts in that catchment yield no water quality benefits. The results are presented in table 5.

The efficiency losses associated with ignoring thresholds are substantial, particularly at low budget levels and high thresholds. For example, from table 5, under a $1 million budget and an 80% threshold requirement, the portfolio derived without considering the threshold constraints achieves zero benefits under three of the four scoring methods. A lower threshold at 50% improves the portfolio's performance a little, but it still achieves only 24% to 59% of what the portfolio derived under explicit threshold constraints can achieve.

The efficiency losses are even more substantial when one compares the portfolio scores achieved under the optimization formulation in expressions (7)–(11), which recognizes opportunity costs and threshold constraints, with the portfolio scores achieved under the benefit-ranking formulation in expressions (4)–(7), which ignores opportunity costs and threshold constraints. The results of this comparison are presented in table 6. With a budget of $1 million, the City of Syracuse would likely generate no environmental benefits if it were to acquire easements based on parcel scores alone.

Of course, the practitioner still faces the problem of choosing among the different optimal portfolios identified under each scoring rule. The practitioner could try the "high-priority" approach described in the earlier section on empirical results, and focus on those parcels found in the solution of each scoring method, but the portfolios chosen through this approach will not necessarily achieve the thresholds in each catchment.

In the Lake Skaneateles case, the "high priority" portfolio of parcels selected from the optimal buffers when D = $2.5 million would come quite close to satisfying the threshold requirements. In the 50% threshold scenario, the high-priority portfolio (cost = $1.52 million) spans 10 catchments, of which four exceed the required buffer-area threshold, three are less than 7% below the threshold, two are less than 19% below the threshold, and one is less than 45% below the threshold.

Table 6. Portfolio Performance when Opportunity Costs and Thresholds Are Ignored

		Budget (D) = $1 million			Budget (D) = $2.5 million		
		% of Total Watershed Benefits Achieved, by Threshold			% of Total Watershed Benefits Achieved, by Threshold		
Scoring Method	Acquisition Method	50%	80%	90%	50%	80%	90%
Interval-Scale	***Optimal***	***28%***	***26%***	***25%***	***61%***	***56%***	***55%***
	Ignoring Costs & Thresholds	0%	0%	0%	15%	5%	0%
Ratio-Scale	***Optimal***	***36%***	***33%***	***31%***	***72%***	***68%***	***62%***
	Ignoring Costs & Thresholds	0%	0%	0%	22%	6%	0%
Categorical	***Optimal***	***28%***	***26%***	***25%***	***60%***	***56%***	***54%***
	Ignoring Costs & Thresholds	0%	0%	0%	23%	3%	0%
PPW	***Optimal***	***38%***	***33%***	***26%***	***72%***	***68%***	***60%***
	Ignoring Costs & Thresholds	6%	0%	0%	17%	9%	0%

In the 80% threshold scenario, the high-priority portfolio (cost = $1.22 million) spans five catchments, of which two exceed the threshold and three are less than 8% below the threshold. In the 90% threshold scenario, the high-priority portfolio (cost = $1.67 million) spans four catchments, of which two exceed the threshold and two are less than 3% below the threshold. By increasing the budget or thresholds under which the contract portfolios are chosen, a practitioner is more likely to derive a high-priority set of parcels that come close to meeting the required thresholds, although the degree to which this method is successful will be case specific.

Conclusion

Policy makers and conservation practitioners throughout the world seek flexible tools that permit the integration of biophysical and economic data into cost-effective conservation plans. This analysis demonstrates a way in which conservation agencies can integrate spatially variable biophysical and economic data in the absence of sophisticated biophysical modeling.

Using common biophysical scoring methods, in combination with economic data and simple optimization methods, a set of priority land parcels can be identified for contracting. In an empirical application, data from a Geographic Information System (GIS) are used to identify a set of priority land parcels for a riparian buffer contracting initiative in upstate New York.

A primary objective of this analysis was to specifically take into account approaches helpful to practitioners and policy makers. Toward that end, the data selected for this study are available to decision makers. Further, the analysis explicitly considers actual methods used by decision makers, and the problem is approached at the geographic scale at which decisions are being made.

This study also demonstrates a way in which conservation agencies can incorporate concerns about biophysical thresholds in their decision making. The results corroborate previous empirical work suggesting that the failure to consider economic data in environmental investment decisions can lead to large losses in efficiency. Moreover, findings reveal that the potential efficiency losses associated with ignoring biological thresholds are also large.

The actual decision process is emphasized here rather than the biophysical modeling, but clearly the results are only as good as the biophysical and economic information on which the analysis is based. We take as given the data available to the City of Syracuse and the way in which the City's practitioners express their preferences and objectives. However, if the reliability of the parcel-scoring functions or the threshold estimates is poor, there is no guarantee the tools developed in this analysis improve upon current practitioner methods.[7]

The same caveat holds for the estimates of contracting costs. The use of "high-priority" portfolios, like those identified here, may mitigate errors in benefit and cost estimation, but scholars and practitioners need to ensure they have reliable information to feed into the decision analysis.

Integrating reliable biophysical and economic information is particularly important in the context of watershed conservation for three reasons: (*a*) the

[7] Although the use of scoring functions like those used in this study is widespread, there is evidence that linear preference functions may be a poor proxy for decision-maker preferences (Keeney and Raiffa, 1976) and that the identification of criteria weights is complicated even for experts (Borcherding, Schmeer, and Weber, 1993).

level of environmental amenities and the costs of obtaining the amenities are likely to be positively correlated (e.g., conservation on large parcels with extensive waterfront and located near infrastructure are likely to be important for water quality objectives, but are also likely to be expensive); (*b*) in rapidly developing watersheds, the relative spatial variability of conservation contract costs is likely to be greater than the relative spatial variability of conservation benefits; and (*c*) uncoordinated efforts to establish riparian buffers across the watershed are likely to lead to little or no water quality benefits. Collectively, these factors confirm that if practitioners fail to integrate the available biophysical and economic data, the currently popular approaches to conservation contracting for watershed protection may achieve far fewer environmental benefits than expected.

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Appendix: Description of Parcel-Scoring Systems Used in the Analysis

■ As noted in the text, to measure the contribution of each parcel to the City's water quality objectives, the City's Department of Water convened a scientific panel to help it develop a parcel-scoring system based on known land attributes in the watershed (Myers, MacBeth, and Nemecek, 1998). The panel developed two potential systems (as detailed below): an interval-scale scoring equation and a ratio-scale scoring equation. These equations assign a score to each parcel. The higher the score, the higher the benefit from easement acquisition.

The Interval-Scale Scoring Equation

The interval-scale scoring equation determines the environmental benefit score (*EBS*) as follows:

$$\text{(A1)}\quad EBS = 0.20\,Acreage + 0.20\,Priority\ Zone + 0.25\,(Distance\ to\ Intake)^{11} + 0.25\,Acres\ of\ Hydrologically\ Sensitive\ Land + 0.10\,Stream\ Length,$$

where *Priority Zone* is a categorical variable, converted to a numeric scale, that captures the development potential and land use intensity of the zone in which a parcel is found; *Distance to Intake* measures the planametric distance from the geometric center of the parcel to a point exactly midway between the City's two water intake pipes (closer parcels are more desirable); *Acres of*

Hydrologically Sensitive Land includes hydric soils, steeply sloped soil, frequently flooded soils, and wetlands; and *Stream Length* is the length of the stream frontage in each parcel. The higher the parcel score (EBS), the more desirable the parcel is for water quality protection. The standardized score of attribute i for parcel j, called an interval-scale score, derives from subtracting the minimum observed value for the attribute from the observed value and dividing this number by the difference between the maximum and minimum observed values for attribute i [refer to Ferraro (2000a) for additional details]:

$$\textit{Interval-Scale Score}_{ij} = \frac{OBS_{ij} - MIN_i}{MAX_i - MIN_i}.$$

The Ratio-Scale Scoring Equation

The ratio-scale scoring equation uses the attributes found in the interval-scale equation (A1), but its form and normalization differ:

$$\text{(A2)} \quad EBS = 0.27\,\textit{Acreage} + 0.27\,\textit{Priority Zone} - 0.27\,\textit{Distance to Intake} + 0.33\,\textit{Acres of Hydrologically Sensitive Land} + 0.13\,\textit{Stream Length}.$$

Excluding the *Distance to Intake* weight, all the weights sum to one. Each parcel is then penalized for its distance from the intake. All parcel scores are assumed to be greater than or equal to zero (a parcel that generates a negative score from the ratio-scale scoring function is scored as zero). The ith attribute is scaled so that the most-favorable observed value generates a score of one, and every other parcel is compared to that parcel:

$$\textit{Ratio-Scale Score}_{ij} = \frac{OBS_{ij}}{MAX_i}.$$

▪ Two other common parcel-scoring methods, the categorical scoring system and the parcel-pollutant-weighting (PPW) model, are also used in the empirical analysis and are described below.

The Categorical Scoring System

The categorical scoring system is similar to what the U.S. Department of Agriculture uses in its Conservation Reserve Program (CRP). For each parcel, the CRP scoring system assigns points to a parcel's attributes. The total amount of points achievable for each attribute is determined by relative weights (e.g., up to 10 points can be awarded for proximity to wetlands, and up to 15 points can be awarded for endangered species habitat).

The categorical scoring equation applied in this analysis uses a similar point-scoring system for each land attribute listed in the interval-scale scoring equation. Each attribute is separated into three or four categories (e.g., 0–10 acres, 11–50 acres, 50+ acres) and up to 300 total points can be allocated to each parcel. The maximum amount of points possible for each attribute is determined by the same weights used in the interval-scale scoring equation.

The Parcel-Pollutant-Weighting Model

The parcel-pollutant-weighting (PPW) model is based on the approaches used by the New York State Department of Public Health (1999) and Hermans (1999), and is developed and explained in Azzaino, Conrad, and Ferraro (2002).

Briefly, each parcel is assigned a land-use classification. Based on this classification, the biophysical attributes of the land parcel (e.g., drainage area, distance to intake), and the results of a published water quality study (New York State Department of Public Health, 1999), each parcel's potential loading of phosphorus and pathogens is assessed qualitatively. This qualitative assessment is then assigned an index number ranging from 10 for a qualitative assessment of "high," to 3.33 for a qualitative assessment of "low." If a parcel is acquired for the riparian buffer easement, a percentage reduction in pollutant loading is assumed, based on the current qualitative assessment and data in Hermans (1999, p. 136). Equal weights are used on reductions in pathogens and phosphorous loadings.