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Integrating Biophysical and Economic Information to Guide Land Conservation Investments

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I. Introduction

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 has focused on the conservation of biological diversity. Targeting approaches favored by biological scientists and conservationists emphasize the environmental amenities that a given land unit produces, while often ignoring the costs of acquiring those amenities. For example, Dobson et al. (1997), based on their finding that endangered species in the United States were concentrated spatially, suggest conservationists should focus their efforts on a small number of geographic areas. In response, 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 that 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 et al. 2000). Other studies by economists have also demonstrated the importance of integrating biophysical and economic data, as illustrated by Polasky et al. (2001) for the case of species conservation in Oregon, and Babcock et al. (1996, 1997) for the case of the Conservation Reserve Program.

This chapter extends these previous analyses 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.; Polasky et al.; Babcock et al.) have tended to focus on a single biophysical attribute (e.g., 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 (USDA 1999) or World Wildlife Fund's Global 200 initiative (Olson et al. 2000), identify multiple biophysical attributes of interest.

In the context of habitat protection, Prendergast et al. (1999) point out that practitioners and policymakers 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 policymakers. To address this oversight, the empirical application of this chapter 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 geographic scale at which decisions are being made: individual parcels rather than large administrative districts or GIS polygons on the landscape.

Unlike previous work, we recognize that there is often little agreement about the appropriate way to estimate the environmental benefits provided by a single parcel and thus use multiple methods to guide the empirical analysis. Finally, there is increasing scientific information that suggests 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 analyses of conservation investments, however, have incorporated such thresholds (notable exceptions include Farzin 1996; Wu et al. 2000; and Bulte and van Kooten 2001). This chapter demonstrates how such thresholds can be incorporated into the decision-making process. In the empirical analysis, we compare the conservation contract portfolios selected with and without threshold constraints.

In the next section, the case study for the empirical analysis is introduced. In section III, the data are characterized and the decision model is developed. The results of the empirical analysis are then presented in section IV. In section V, the model of Section III is adapted to incorporate thresholds, and in Section VI, the effects that thresholds have on the selection of the optimal conservation contract portfolio are examined. Section VII explores reasons why economic approaches to targeting land conservation investments are not applied in practice.

II. 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 et al. 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 (NRC 2000, 213-239). Examples of other contracting initiatives for water quality include North Carolina's $30 million Clean Water Management Trust Fund, Massachusetts's $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 policymakers 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 intakes 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) Surface Water Treatment Rule. In 1994, the City signed a Memorandum of Agreement (MOA) with the New York State Department of 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 part of the

[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.

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 a way that will have the greatest effect on maintaining and improving water quality in the lake (Myers et al. 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.

III. Case Study: data and conceptual approach

Each riparian parcel in the watershed, when protected by an easement, is assumed to generate 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 assumed uniformly distributed. In other words, each acre in the parcel is equally as valuable, whether measured for

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

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 et al. 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 et al. 2002), are also used in the empirical analysis and are described in the appendix.

The interval-scale, ratio-scale, and categorical scoring equations use the same biophysical characteristics but weigh and normalize them differently (the characteristics have to be normalized so that parcel scores are not fundamentally altered by changes in the characteristics' units of measurements). The Parcel-Polluting-Weighting scoring equation differs from the other three because it combines information on biophysical characteristics and results from pollution modeling in order to score each parcel. Neither theory nor extant empirical evidence argue for the superiority of one scoring method over the others.

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., USFWS 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; MDC 1999; Hruby et al. 2000; FDEP 2000), and in the multi-billion dollar conservation efforts of the U.S. Conservation Reserve Program (Feather et al. 1998), land trusts (e.g., The Nature Conservancy; Master 1991), international habitat protection groups (e.g., World Wildlife Fund; see Olson et al.), national wildlife protection initiatives (e.g., Partners in Flight, documented by Carter et al. 1999), and farmland protection initiatives (e.g., American Farmland Trust).[3]

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.[4] 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 includes 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 section IV. As observed from Table 1, the Spearman correlations among the parcel scores assigned by each scoring method are strongly positive.

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[3] Ferraro (2004) explores an alternative way to assign priority to conservation investments when the ecological benefits from investment cannot be collapsed into a single value.

[4] 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.

[Table 1 about here]

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 that the City of Syracuse would have to pay between 40% and 60% of a parcel's assessed land value to obtain an easement. An estimate of 50% is used in this analysis. 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, a transaction cost of $5000/easement is also assumed. Varying the transaction cost from $2500 to $12,500 did not generate dramatic changes in the parcel rankings.[5] Future analyses can incorporate new information on 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 (Cummings et al. 2003).

Optimal Easement Portfolio Selection Problem

The City of Syracuse's optimal easement acquisition program can be viewed as maximizing the total benefit score subject to a budget constraint (see appendix for a more formal representation). This maximization problem is equivalent to ranking parcels from highest to lowest based on their $e_i/(c_i+t_i)$ ratio and accepting contracts until the budget is exhausted.

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

The City of Syracuse, however, did not formulate its approach to easement acquisition in this manner. Like many conservation initiatives (e.g., Mittermeir et al.), 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 (see appendix for a more formal representation).

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 optimal portfolio. How much lower is an empirical question.

IV. Case Study: empirical results

The City plans to spend \$1 - \$2.5 million dollars and then evaluate whether further easement acquisitions are required. We therefore solve the optimal easement portfolio problem 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 2002).

Table 2 presents, for each benefit-scoring method, the percentage of total environmental benefits available in the watershed that are secured by the optimal portfolio and the percentage of total environmental benefits available in the watershed that are secured by the portfolio that ignores opportunity costs (i.e., funds are allocated based on benefit scores alone). Consistent with previous research, large efficiency losses are associated with ignoring costs in the funding allocation decision. For a budget of \$1 million, the benefit-only approach achieves 16 to 42 percent of what the optimal approach achieves; for a budget of \$2.5 million, it achieves 36 to 65 percent of what the optimal approach achieves. The large efficiency gains from incorporating economic costs explicitly in the decision-making 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 2003; more on this at the end of this section).

While the formulation that integrates benefit and cost data is clearly beneficial, each scoring method generates a different "optimal" portfolio. As mentioned in the previous section, one way to proceed would be to identify the parcels that are selected for acquisition under all four scoring methods. These parcels might be regarded as "high priority" for an easement acquisition program because they are found 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 that 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 budget, one can identify a set of priority parcels that exhausts the budget by changing the value of the budget under which the optimal buffers are derived.

[Table 2 about here]

For example, solving for the portfolios when the budget is $1 million, 11 parcels are found in each of the four optimal buffer solutions and these easements can be acquired for $210,900. Solving for the portfolios when budget is $2.5 million, 46 parcels are found in each of the four optimal buffer solutions and these easements can be acquired for $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 the budget is $210,900 and $1,445,150.

For example, the high-priority portfolio, were its parcels to be scored according to the interval-scale scoring equation, achieves 92% of the benefits that are achieved by the optimal portfolio at a budget of $1,445,150. The data in Table 3 suggest that 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.

[Table 3 about here]

Thus, as in previous analyses that looked at conservation investments in other contexts, we find that integrating both cost and benefit information explicitly into the decision-making in Lake Skaneateles can be vital to ensuring that scarce funds go as far as they can toward achieving policy objectives. The costs of acquiring and analyzing such information, however, can be substantial. Under which conditions is integrating cost and benefit information likely to be vital to effective decisionmaking, and under which the conditions will the failure to use both cost and benefit data result in little, if any, losses in efficiency?

Assigning priority to land conservation investments on the basis of biophysical data alone would be appropriate only if (1) benefits and costs were negatively correlated across sites **and** (2) the relative spatial variability of benefits was greater than the relative spatial variability of costs. If these two conditions do not hold, as they do not in Lake Skaneateles, an approach that ignores the heterogeneity of conservation costs across sites would perform poorly in ensuring that every dollar spent achieves the maximum environmental benefits that were possible.

Thus, in a habitat restoration program, for example, we would expect that the greater the positive spatial correlation between environmental benefits and restoration costs, and the greater the spatial variability of restoration costs compared with the variability of environmental benefits, the greater will be the efficiency losses if conservation agents ignore costs when making decisions on where to restore habitat. Even if costs and benefits were negatively correlated, but relative cost variability was much greater than relative benefit variability, there could be large gains from integrating restoration costs into the prioritization process.

In the case of investments in endangered species recovery in the United States, Ferraro (2003) demonstrates that the policy context has attributes similar to the City of Syracuse case: (1) benefits, reflected in the priority scores, and recovery costs are positively correlated, and (2) recovery costs are more variable than priority scores across species. In such a situation, allocating funds based on priority scores alone would be quite inefficient. In fact, Ferraro shows that policy analysts examining expenditure decisions in this environment may find little or no positive relationship between benefit measures and the extent and likelihood of funding for species recovery when funds are being spent to maximize the environmental benefits of every dollar spent.

Data from Balmford et al. (2003) suggest that, at the global scale, the costs of habitat protection are spatially **negatively** correlated with the spatial benefits (using bird species density as a proxy for the benefits of habitat protection). High biodiversity areas are typically found in low-income nations in which the opportunity costs of conservation are low. In such a context, focusing only on benefits may not yield a substantially inefficient conservation investment portfolio. The authors, however, also note that the habitat acquisition cost measures are much more variable than the benefit measures. Thus, their data suggest that ignoring benefit data entirely and acquiring more detailed cost data with which to target global habitat conservation investments may be the most effective way of spending scarce conservation funds.

The same ideas can be applied to contexts in which benefits are ignored and only economic data are used to target conservation funds. For example, Ferraro (2003) examines

Georgia's Environmental Protection Division (EPD) 2001 irrigation auction, in which the state compensated farmers who voluntarily agreed to stop irrigating their crops during the year. The budget was not sufficient to pay all farmers in the region and thus the EPD asked economists at Georgia State University to design an auction to allocate the state's scarce procurement budget (Cummings et al. 2003).

Given that Georgia's irrigation water is not metered, and time and money for data collection were limited, a decision was made to allocate the "no-irrigation" contracts according to cost alone. Farmers bid the amount of money per acre they were willing to accept to forgo irrigation on their lands, the bids were ordered from lowest to highest and the state procured contracts until the budget was spent. The decision to focus only on cost measures was justified based on agronomic expertise that suggested water use and contract costs are negatively correlated and thus the parcels that experience the greatest water use are also the low-cost parcels. Even with positive correlation between water use and contract costs, however, a high relative variability of water use compared to the relative variability of contract costs could have greatly decreased the cost-efficiency of the auction that assigned priority to contracts on the basis of cost alone (no data on the spatial variability of anticipated water use among auction participants exist).

V. Thresholds: concepts and problem formulation

The emphasis on parcel-level attributes in the analysis above 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 et al. 2000) and water quality protection (Schueler 1994, 1995; Zoner and Limitz 1994; Wang et al. 1997, 2000), but only a few economic analyses have incorporated biophysical thresholds (e.g., Farzin 1996; Wu et al. 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. 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 (1) 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 (2) 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 that "thresholds 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 way in which biophysical thresholds can be incorporated into the targeting process, 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 has determined that each easement will be designed to secure a 100-foot-wide riparian buffer along the entire stream length of the property. The next section examines the effect of

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

imposing a threshold requirement on the area of 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. Thus a decision-maker must now select not only the parcels on which to establish a conservation contract, but also the catchments in which to establish contracts.

Unlike the targeting approach in Section III, targeting conservation investments cost-efficiently in the presence of threshold effects is not as simple as ranking parcels by their benefit-cost ratio. One must have some basic understanding of constrained optimization and linear programming. However, the approach used below and outlined in the appendix can be implemented in Microsoft Excel's Solver algorithm, which allows practitioners a relatively straightforward way to program a constrained optimization problem.

VI. Thresholds: empirical results

As in section IV, we solve for the optimal easement portfolio 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 2002). Table 4 presents the percentage of parcels in the optimal buffer portfolio that incorporates thresholds that were also found in the optimal portfolio derived without threshold constraints.

[Table 4 about here]

For a given scoring method, the spatial concentration 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 when acquiring contracts, we compare the scores of the portfolio that incorporates threshold effects to the scores of the portfolio that ignores such effects. 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, 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% - 59% of what the portfolio derived under explicit threshold constraints can achieve.

Thus the data from Lake Skaneateles suggest that the failure to recognize interdependent relationships among parcels that contribute to achieving conservation objectives can substantially lower the effectiveness of conservation investments per dollar expended. Ignoring threshold effects, particularly when available funds are few, can result in large foregone environmental benefits. Interventions tend to be scattered over the landscape and funding levels in any given target area are inadequate to reach the threshold needed to maintain current water quality levels or to achieve significant environmental improvements

[Table 5 about here]

The efficiency losses are even more substantial when one compares the scores of the portfolio that recognizes threshold constraints and opportunity costs with the scores of the portfolio that ignores threshold constraints and opportunity costs (i.e., targeting on the basis of benefit scores alone). 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.

[Table 6 about here]

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 of section IV and focus on parcels that are 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 4 exceed the required buffer-area threshold, 3 are less than 7% below the threshold, 2 are less than 19% below the threshold and 1 is less than

45% below the threshold. In the 80% threshold scenario, the high-priority portfolio (cost = $1.22 million) spans 5 catchments, of which 2 exceed the threshold and 3 are less than 8% below the threshold. In the 90% threshold scenario, the high-priority portfolio (cost = $1.67 million) spans 4 catchments, of which 2 exceed the threshold and 2 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 comes close to meeting the required thresholds, although the degree to which this method is successful will be case specific.

VII. If These Ideas Are So Great, Why Isn't Anyone Applying Them?

To many readers, the idea that integrating economic and biophysical data can produce better results than simply using biophysical data alone seems straightforward. If so, why is such an idea rarely applied in practice? As noted in Section IV, there are conditions under which acquiring and using economic data will not generate substantial improvements in efficiency. However, the empirical studies cited in this chapter imply that such conditions are not widespread. Five obstacles to integrating economic and biophysical data are likely to be much more important factors explaining why so few conservation initiatives attempt to incorporate biophysical and economic data explicitly in their decision-making.

The first and most obvious obstacle is the lack of awareness among conservation practitioners about the basic concepts outlined above. Conservation practitioners are rarely trained in economic theory and tend to read natural science journals in which few or no economists publish. In conservation journals (e.g., *Biological Conservation*), articles on targeting conservation investments continue to be published without any reference to the opportunity costs of each investment. As noted in the introduction, academics often do not take into account the objectives and approaches of practitioners and policymakers. Furthermore, even with an awareness of the basic concepts, practitioners may be unaware of the methods through which biophysical and economic data can be integrated. Although the simple methods presented in Section III do not require technical training, more complicated analyses that incorporate the interdependent nature of landscape-level processes (e.g., biophysical thresholds) require more sophisticated methods of analysis in which practitioners may lack training.

Second, despite many publications on sophisticated biophysical criteria-based conservation targeting, practitioners have not adopted them. Prendergast et al. (1999) argue that practitioners often have a "general antipathy toward what is seen as a prescriptive approach to conservation….(p.484)." Incorporating economic data into sophisticated targeting approaches only exacerbates the sense that the practitioner's flexibility to make decisions has been reduced. Based on conversations with practitioners, it seems as if practitioners often believe they are implicitly incorporating economic costs into the decision-making and thus do not need to formally enter these costs into the targeting algorithm.

Third, obtaining relevant economic data can often be more difficult than obtaining relevant biophysical data because the latter is based on observable environmental characteristics while the former is based on unobservable landowner characteristics such as preferences. Practitioners often use two cost discovery methods: (1) wait for a landowner to express interest in a conservation contract and then negotiate over the contract price (often the approach used by land trusts); or (2) estimate *ex ante* the likely willingness-to-accept of a small subset of landowners, typically through real estate appraisal methods, and then negotiate with landowners sequentially by parcel rank. An integrated targeting approach requires that practitioners have reasonably accurate cost data for all parcels on which one could potentially secure a contract.

This chapter used coarse appraisal data to proxy for the actual willingness-to-accept of landowners, but it is uncertain how well such data represent the true underlying distribution of willingness-to-accept. Practitioners already stretched to characterize biophysical characteristics on each parcel may find it too onerous to characterize the cost characteristics *ex ante*.

Fourth, conservation practitioners who make the decisions on the ground are often judged not on the efficiency with which they spend scarce conservation dollars, but rather their ability to achieve given objectives. For example, in the Lake Skaneateles initiative and the New York City watershed initiative, local agents are being evaluated based largely on their ability to spend funds and meet acreage and farmer participation levels. Platt et al. (2000) report that New York City "is obligated to commit $250 million during the next 10 years to acquiring up to 335,000 acres."[7] The land conservation portfolio that achieves these objectives may not be the same as the portfolio that meets an environmental quality objective at least cost.

The fifth, and most difficult to tackle, obstacle lies in the quality of the data themselves. Many conservation initiatives have budgets well below the budgets of large cities like Syracuse, New York City and Boston. In many of these initiatives, adequate biophysical and economic data simply do not exist. When quantitative data are poor, it is unclear whether any gains can be achieved through formalization of the decision-making process. Indeed, such formalization might lead to egregious errors. The use of subjective expert opinion to guide decision-making might be more appropriate in such cases.

VII. Conclusion

[7] Under the agreement it has with the EPA, New York City efforts must also entice at least 85 percent of the farmers in the watershed to join the pollution reduction program.

Policymakers and conservation practitioners throughout the world seek flexible tools that permit the integration of biophysical and economic data into cost-effective conservation plans. This chapter 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. To ensure that the results from this application were useful, the data selected for this application came from the decision-makers themselves. Furthermore, the analysis explicitly considers the methods being used by decision-makers and approaches the problem at the geographic scale at which decisions are being made. This chapter also demonstrates a way in which conservation agencies can incorporate concerns about biophysical thresholds in their decisionmaking. 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. In Section VI, reasons why practitioners may not desire or be able to integrate biophysical and economic data in their decision-making are explored.

The actual decision process is emphasized in this chapter 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 chapter improve upon current practitioner methods.[8] 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 that 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: (1) the 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), (2) 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 (3) uncoordinated efforts to establish riparian buffers across the watershed are likely to lead to little or no water quality benefits. Collectively, these factors suggest that if practitioners fail to integrate the available biophysical and economic data, currently popular conservation contracting approaches for watershed protection may achieve far fewer environmental benefits than expected.

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[8] Although the use of scoring functions like those used in this paper 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 et al., 1993). See Ferraro (2004) for an alternative.

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Appendix

A1. Interval-Scale Scoring Equation. The interval-scale scoring equation is:

Environmental Benefit Score (EBS) = 0.20 *Acreage* + 0.20 *Priority Zone* + 0.25 (*Distance to Intake*)$^{-1}$ + 0.25 *Acres of Hydrologically Sensitive Land* + 0.10 *Stream Length*

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). *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. *Stream Length* is the length of the stream frontage in each parcel, and *Acres of Hydrologically Sensitive Land* includes hydric soils, steeply sloped soil, frequently flooded soils and wetlands. 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*: $Interval-Scale\,Score_{ij} = \frac{OBS_{ij} - MIN_i}{MAX_i - MIN_i}$. See Ferraro (2001) for more details.

A2. Ratio-Scale Scoring Equation. The ratio-scale scoring equation uses the attributes found in the interval-scale equation, but its form and normalization differs:

Environmental Benefit Score (EBS) = 0.27 *Acreage* + 0.27 *Priority Zone* - 0.27 *Distance to Intake* + 0.33 *Acres of Hydrologically Sensitive Land* + 0.13 *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 *i*th attribute is scaled so that the most-favorable observed value generates a score of one and every other parcel is compared to that parcel: $Ratio - Scale\,Score_{ij} = \frac{OBS_{ij}}{MAX_i}$

A3. Categorical Scoring Equation. The categorical scoring equation 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 paper 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.

A4. Parcel-Pollutant-Weighting Model. The Parcel-Pollutant-Weighting (PPW) Model is based on the approaches used by the New York State Department of Health (1999) and Hermans (1999), and is developed and explained in Azzaino et al. (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 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: 136). Equal weights are used on reductions in pathogens and phosphorous loadings.

A.5 Optimal Easement Portfolio Selection Problem. The easement acquisition program of the City of Syracuse can be viewed as a linear optimization problem:

$$\max_{p_i} \sum_i p_i \, e_i \qquad \text{[A1]}$$

$$s.t.$$

$$\sum_i p_i \, (c_i + t_i) \leq D \qquad \text{[A2]}$$

$$0 \leq p_i \leq 1 \qquad \text{[A3]}$$

where

p_i = Share of parcel *i* under conservation contract (p_i = 1 if parcel is fully contracted)

e_i = Environmental benefit score for parcel *i* (a scalar)

c_i = 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)[9]

D = Contracting agency’s budget

Other characteristics of this targeting formulation are detailed in Ferraro (2002).

A.6 Biophysical-based Easement Portfolio Selection Problem. 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.,

[9] Transaction costs may be fixed regardless of how much of the parcel is contracted, or they 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.

$$p_i^{\ B} = 1 \ when \ e_i > \bar{e} \qquad [A4]$$
$$p_i^{\ B} = 0 \ when \ e_i < \bar{e} \qquad [A5]$$
$$p_{\bar{e}}^{\ B} \in [0,1] \ when \ e_{\bar{e}} = \bar{e}$$
$$where \ p^{B}{}_{\bar{e}} = \frac{D - \sum p^{B}{}_{i} e_i}{c_{\bar{e}} + t_{\bar{e}}} \qquad [A6]$$

A.7 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 *j*th catchment is designated as b^{j}_{i}. In order to receive any environmental benefits from contracts in the *j*th catchment, the conservation agent must contract for at least $\mathbf{B}^{\mathbf{j}}$ 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:

$$\max_{p_i^{\ j}, Y^j} \ \sum_{j=1}^{N} \sum_{i} p_i^{\ j} \ e_i^{\ j} \qquad [A7]$$
$$s.t.$$

$$\sum_{j=1}^{N} \sum_{i} p_i^{\ j} \ c_i^{\ j} \le D \qquad [A8]$$

$$\sum_{i} p_i^{\ j} \ b_i^{\ j} \le M \, Y^{\ j} \qquad j = 1, 2, ..., N \qquad [A9]$$

$$\sum_{i} p_i^{\ j} \ b_i^{\ j} \ge B^{\ j} \ Y^{\ j} \qquad j = 1, 2, ..., N \qquad [A10]$$

$$p^{\ j} \in [0,1]; \ Y^{\ j} = \{0,1\} \qquad [A11]$$

where

p^{j}_{i} = Parcel *i* in catchment *j*; $p^{j}_{i} \in [0,1]$ (p^{j}_{i} = 1 if 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^j_i = Environmental benefit score of parcel i in catchment j.

b^j_i = Acres of 100-foot-wide riparian buffer in parcel i in catchment j.

c^j_i = Contract cost for parcel i in catchment j (includes transaction costs)

B^j = Minimum acres of 100-foot-wide buffer that must be secured in catchment j for any benefits to be obtained from contracts in that catchment (i.e., the threshold).

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^j_i), 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^j_i variables. This constraint indicates that if you are contracting on the ith parcel ($p^j_i = 1$), you must be working in the corresponding jth catchment ($Y_j = 1$); otherwise the constraint would be violated. Expression [10] indicates that 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 Microsoft 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.

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

Table 1 – Correlations Among Parcel Scores by Scoring Method

		D = $1 million	D=$2.5 million
Scoring Method	**Acquisition Method**	**% of Total Watershed Benefits (** $\sum_{i=1}^{202} p_i\, e_i \Big/ \sum_{i=1}^{202} e_i$ **)**	**% of Total Watershed Benefits (** $\sum_{i=1}^{202} p_i\, e_i \Big/ \sum_{i=1}^{202} e_i$ **)**
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%

Table 2 – Portfolio Performance when Opportunity Costs are Ignored

Percentage of Total Benefits Achieved by High-Priority Portfolio				
Budget	**Interval-Scale**	**Ratio-Scale**	**Categorical**	**PPW**
$210,900	72%	82%	78%	82%
$1,445,150	92%	79%	82%	92%

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

	D = $1 million				D = $2.5 million			
Threshold	**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 4 – Percentage of Parcels in Optimal Portfolio under Threshold Constraints that are found in Original (No-threshold) Portfolio

		D = $1 million			**D=$2.5 million**		
Scoring Method	**Acquisition Method**	**% of Total Watershed Benefits Achieved Under Each Threshold**			**% of Total Watershed Benefits Achieved Under Each Threshold**		
		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%

Table 5 – Portfolio Performance when Thresholds are Ignored

		D = $1 million			D=$2.5 million		
Scoring Method	**Acquisition Method**	**% of Total Watershed Benefits Achieved Under Each Threshold**			**% of Total Watershed Benefits Achieved Under Each Threshold**		
		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%

Table 6 – Portfolio Performance when Opportunity Costs and Thresholds are Ignored