Conservation Contracting in Heterogeneous Landscapes: an application to watershed protection with threshold constraints

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Abstract

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, we illustrate how one can identify a set of priority land parcels for conservation investment. We also demonstrate a way in which conservation agencies can incorporate concerns about biophysical thresholds in the identification of their priority land parcels. We apply these methods using Geographic Information System data from a New York conservation easement acquisition initiative for water quality protection.

Key words: Conservation, water quality, spatial, threshold

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 2001a]. 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 that a given land unit produces, while often ignoring the costs of acquiring those amenities. For example, Dobson et al. [1997] found that endangered species in the United States were concentrated spatially and suggested that conservationists focus their efforts on a small number of geographic areas. Ando et al. [1998] responded by pointing out that variability in economic factors was just as important as ecological variability in efficient species conservation: an approach that considered both economic and ecological variability could cost less than one-sixth the cost of the approach that only considers ecological variability. A similar debate 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: 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 paper 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 our empirical analysis support previous empirical work suggesting that 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; Babcock et al. 1996] 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 or amenities of interest. In this study, we consider the case of multiple biophysical attributes, a case that easily generalizes to multiple amenities.

In the context of habitat protection targeting, Prendergast et al. [1999] noted that field practitioners and policymakers rarely use the tools and results that have been developed in the academic literature. In large part, the tools and results are not adopted because they are not developed and applied with the objectives and approaches of practitioners and policymakers in mind. In the empirical application of this paper, we use data available to decision-makers and consider explicitly the actual approaches used by decision-makers in the field. We also approach the problem at the geographic scale at which decisions are being made; i.e., 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 economic analyses, however, have incorporated such thresholds [Farzin 1996; Wu et al. 2000; Bulte and van Kooten 2001]. We demonstrate how simple linking constraints in the optimization problem can be used to model the effect of biophysical thresholds on decisions. In the empirical analysis, we compare the conservation contract portfolios selected with and without threshold constraints.

In the next section, we introduce the case study for the empirical analysis. In section III, we characterize the data and introduce the optimization model. In section IV, we present the results of the empirical analysis. In section V, we adapt the model of Section III to incorporate thresholds, and in Section VI, we consider the effects that thresholds have on the selection of the optimal conservation contract portfolio.

II. Case Study: 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 ten 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 dollar 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 that covers three counties, seven townships and one village. The population of the watershed is about 5000 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 percent) and agricultural land (48 percent), 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 that allows 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

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[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.

pathogen, chemical, nutrient and sediment loading into the lake. An important part of the management program is a conservation easement acquisition program through which up to $5 million will be spent over the next seven years (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 [Meyers *et al.* 1998].

In the analysis, we focus on prioritizing the acquisition of easements from an available population of 202 riparian parcels in the upper watershed of Lake Skaneateles (see Figure 1). Biophysical and economic data on these parcels were obtained from the Geographic Information Systems database of the City of Syracuse's Department of Water. 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 model

We assume that each riparian parcel in the watershed, when protected by an easement, generates environmental benefits, b_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, and each parcel is assumed to be homogenous. 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 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) equation [Azzaino et al. 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., USFWS 1982; Terrell et al. 1982; Allen 1983; McMahon 1983; Allen and Hoffman 1984; FDEP 1999], in water quality protection initiatives [e.g., Smith et al. 1995; Rowles and Sitlinger 1999; MDC 1999; 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; Olson et al. 2000], national wildlife protection initiatives [e.g., Partners in Flight; Carter et al. 1999], and farmland protection initiatives (e.g., American Farmland Trust).

In the absence of sophisticated hydrological models for the Skaneateles watershed, one is unable to determine which of the four parcel scoring methods is best.[2] If there is positive correlation among the different scoring methods (which one would expect 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 that each optimal portfolio has in common across the parcel-scoring methods). We apply this approach in section IV. As one can see in Table 1, the (Spearman) correlations among the parcel scores assigned by each scoring method are strongly positive.

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

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[2] 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.

Cost Data

A regional appraising company estimated that easements around Lake Skaneateles would typically cost between 40 percent and 60 percent of the assessed land value of a parcel [Gardner 2000]. In our analysis, we use 50 percent. 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. There were not enough observations on sales of properties with easements in the region to estimate a hedonic equation of easement costs. Based on transaction cost information from the Finger Lakes Land Trust, which operates in the region, we also assume that there is a transaction cost of $5000/easement. Varying the transaction cost from $2500 to $12,500 did not generate dramatic changes in the parcel rankings.[3]

Optimal Easement Portfolio Selection Problem

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

$$\max_{p_i} \sum_i p_i e_i \qquad [1]$$

$$s.t.$$

$$\sum_i p_i (c_i + t_i) \leq D \qquad [2]$$

$$0 \leq p_i \leq 1 \qquad [3]$$

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* (private opportunity cost of conservation)

t_i = Transaction costs for a contract on parcel *i* (e.g., legal fees, monitoring)

D = Contracting agency's budget

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

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 regardless of whether or not he or she has knowledge of programming techniques. Other characteristics of this targeting formulation are covered in the appendix.

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.,

$$p_i^B = 1 \text{ when } e_i > \bar{e} \qquad [4]$$

$$p_i^B = 0 \text{ when } e_i < \bar{e} \qquad [5]$$

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

$$\text{where } p^B{}_{\bar{e}} = \frac{D - \sum p^B{}_i e_i}{c_{\bar{e}} + t_{\bar{e}}} \qquad [6]$$

The City's prioritization formulation ignores the opportunity costs of contracted parcels and, as suggested by previous empirical analyses (see references in 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.

IV. 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. The portfolios are presented spatially in Figures 2 - 9.

In Table 2, for each benefit-scoring method, we compare the percent of total environmental benefits available in the watershed that are secured by the optimal portfolio (i.e., $\sum_{i=1}^{202} p^*{}_i\, e_i \Big/ \sum_{i=1}^{202} e_i$) to the percent of total environmental benefits available in the watershed that are secured under the method that ignores opportunity costs and allocates funds based on benefit scores alone (i.e., $\sum_{i=1}^{202} p^{*B}{}_i\, e_i \Big/ \sum_{i=1}^{202} e_i$). Consistent with previous research, we observe 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 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 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 2002].

Using the formulation that integrates benefit and cost data is clearly beneficial, but as one can see in Figures 2-5, 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 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 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 (L. Myers, pers. comm. 2000). 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 *D* under which the optimal buffers are derived.

		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

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. Solving for the portfolios when D = \$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 D = \$210,900 and D = \$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 derived under the formulation in expressions [1]-[3] at D = \$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.

Percentage of Total Benefits Achieved by Optimal 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

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 one can expect little, if any, water quality protection. 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 1994a, 1995; Zoner and Limitz 1994; Wang et al. 1997, 2000], but few economic land use analyses have incorporated biophysical thresholds [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. 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 that (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;[4] 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 are no general rules of thumb that have been developed specifically for riparian areas, and thus the empirical analysis below is intended to demonstrate a simple way in which one can incorporate biophysical thresholds into the formulation in expressions [1]-[3], rather than to claim that 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. We examine the effect of imposing a threshold requirement on the area of 100-foot-wide riparian buffer in a given catchment. Empirically, we examine the threshold 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

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

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.

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 *i*th 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 $\boldsymbol{B^j}$ 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:

$$\max_{p_i^j, Y^j} \sum_{j=1}^{N} \sum_i p_i^j e_i^j \qquad [7]$$

s.t.

$$\sum_{j=1}^{N} \sum_i p_i^j c_i^j \le D \qquad [8]$$

$$\sum_i p_i^j b_i^j \le M Y^j \qquad j = 1,2,....,N \qquad [9]$$

$$\sum_i p_i^j b_i^j \ge B^j Y^j \qquad j = 1,2,....,N \qquad [10]$$

$$p^j \in [0,1];\ Y^j = \{0,1\} \qquad [11]$$

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 but also the catchments in which to establish contracts. 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.

VI. Thresholds: results

As in section IV, we solve the optimal easement portfolio problem under each scoring method for budgets of D = \$1 million and D = \$2.5 million. The solutions are presented spatially in Figures 6-11 for the PPW scoring method. As one would expect, threshold constraints result in spatial concentration of contracts on the landscape. Table 3 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]).

	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 3 – Percentage of Parcels in Optimal Portfolio under Threshold Constraints that are found in Original (No-threshold) Portfolio

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 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 4. 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.

		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 4 – Portfolio Performance when Thresholds are Ignored

The efficiency losses are even more substantial when one compares the portfolio scores achieved under the optimization formulation in expression [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 5. 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.

		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 5 – Portfolio Performance when Opportunity Costs and Thresholds are Ignored

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. Conclusion

Policymakers and conservation practitioners throughout the world seek flexible tools that permit the integration of biophysical and economic data into cost-effective conservation plans. In this paper, we demonstrate 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, we illustrate how one can identify a set of priority land parcels for contracting. In an empirical application, we use data from a Geographic Information System (GIS) to identify a set of priority land parcels for a riparian buffer contracting initiative in upstate New York. In this empirical application, we use data available to decision-makers, explicitly consider actual approaches used by decision-makers, and approach the problem at the geographic scale at which decisions are being made. We also demonstrate 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. We demonstrate that the potential efficiency losses associated with ignoring biological thresholds are also large.

Integrating biophysical and economic data 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. All of these factors indicate 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

A1. Interval-Scale Scoring Equation

The interval-scale scoring equation developed by the City of Syracuse is:

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

The attribute *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. The closer to the pipes, the more desirable is the parcel of land. *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. In order that parcel attributes can be meaningfully compared to each other and that the units of measurement do not affect the scores, each attribute is scaled so that the least-favorable observed value generates a score of zero and the most-favorable observed value generates a score of one. For example, the smallest parcel in the data set was 0.17 acres, and thus this parcel received a standardized score of zero for the acreage attribute. The largest parcel was 136 acres and thus received a standardized score of one for the acreage attribute. Intermediate values receive a standardized score based on the relative position between the high and low values:

$$Interval - Scale\,Score_{ij} = \frac{OBS_{ij} - MIN_i}{MAX_i - MIN_i}$$

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 values for attribute *i*.

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 (represented by a negative coefficient on *Distance to 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). Each attribute is scaled so that the most-favorable observed value generates a score of one and every other parcel is compared to that parcel; i.e., for the *j*th parcel and the *i*th attribute,

$$Ratio - Scale\,Score_{ij} = \frac{OBS_{ij}}{MAX_i}$$

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. We separate each attribute into three or four categories (e.g., 0-10 acres, 11-50 acres, 50+ acres) and allow up to 300 total points to 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 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]. We summarize the model briefly. Each parcel is assigned a land-use classification based on GIS data collected from New York's Real Property database. 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 Easement Acquisition Problem – additional characteristics

Recall that the choice variables are $\underline{p}_i$ = parcel *i* ($\underline{p}_i \in [0,1]$; $\underline{p}_i = 1$ if parcel is fully contracted) and the parameters are: e_i = Environmental Benefit Score (EBS) for parcel *i*, c_i = Contract cost for parcel *i* (easement value), t_i = Transaction cost for contracting parcel *i* (e.g., lawyer fees, monitoring), and D = Contracting agency budget. The maximization problem is

$$\max_{p_i,\lambda,\mu_1,\mu_2} L = \sum_i p_i\, e_i + \lambda(D - \sum_i p_i\,(c_i + t_i)) + \mu_1 p_i + \mu_2(1 - p_i) \qquad \text{[A1]}$$

One can interpret λ^* as a shadow value at the optimum denoting the increase in environmental quality associated with an increase in the budget constraint. When one allows partial parcel contracting, a positive shadow value is generated for all budgets less than the total contract value of all available parcels.

Complementary slackness requires that:

$$p_i^* = 1 \ \text{when} \ e_i > \lambda^*(c_i + t_i) \quad \text{(parcel is contracted)} \qquad \text{[A2]}$$

$$p_i^* = 0 \ \text{when} \ e_i < \lambda^*(c_i + t_i) \qquad \text{[A3]}$$

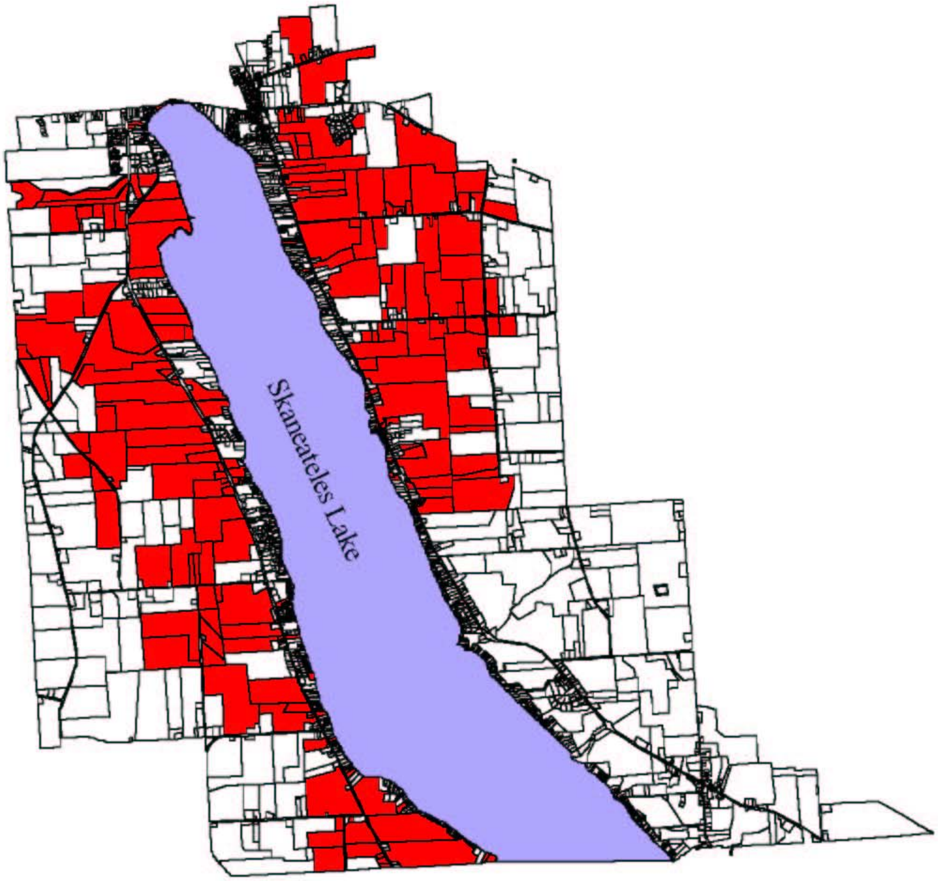
$$p_i^{*\lambda} \in [0,1] \ \text{when} \ e^{\lambda}{}_i = \lambda^*(c_i^{\lambda} + t_i^{\lambda}) \qquad \text{[A4]}$$

$$\text{where} \ p_i^{*\lambda} = \frac{D - \sum p_i^*(c_i + t_i)}{(c_i^{\lambda} + t_i^{\lambda})}$$

In other words, if one unit in parcel *i* is valuable enough to be acquired, every other unit in parcel *i* is good enough to be contracted (by the parcel homogeneity assumption). One parcel, $p_i^{*\lambda}$, may end up with a partial contract because budget constraints prevent contracting on every acre in the parcel. The shadow value, $\lambda^* > 0$, is the threshold ratio of environmental benefits to contract cost ($e^{\lambda}_i/c^{\lambda}_i$) that indicates which parcels are contracted and which are not. One also knows that $\frac{\partial \lambda^*}{\partial D} < 0$ and that $1/\lambda^*$ is the unit price of the environmental amenity (i.e., a unit of environmental benefit score) if there existed a uniform-price market for water quality in the Lake Skaneateles watershed. In such a market, the City of Syracuse would pay $(1/\lambda^*)\ \Sigma\ p_1 e_1$ for its contracted land portfolio. Because there is no such market and the City of Syracuse acts as a discriminating monopsonist, the City reaps a surplus of $(1/\lambda^*)\ \Sigma\ p_1 e_1 - D$.

One could change the above problem to a binary specification that only allows for full parcel contracting (i.e., no partial contracting allowed; see Azzaino et al. [2002] for an example). With a probing procedure, the model is not difficult to solve even for hundreds of parcels. When partial contracting is not allowed, one typically obtains two results: (1) the budget is not exhausted at the optimum and thus the shadow value of a unit of environmental benefit at the optimum is zero; and (2) the solution includes small parcels with low environmental benefits simply because there is money available and better parcels are not affordable. Since partial contracting is a potential choice to decision-makers, the non-binary specification will generally be preferable.

Figure 1 - Upper Skaneateles Lake Watershed



🟥 **Riparian Parcels**

Map Information

Data Sources:
Department of Water,
City of Syracuse
(Unprojected)

Figure 2 - Contracted Easement Portfolio, Interval-Scale Scoring Equation ($1 million & $2.5 million)

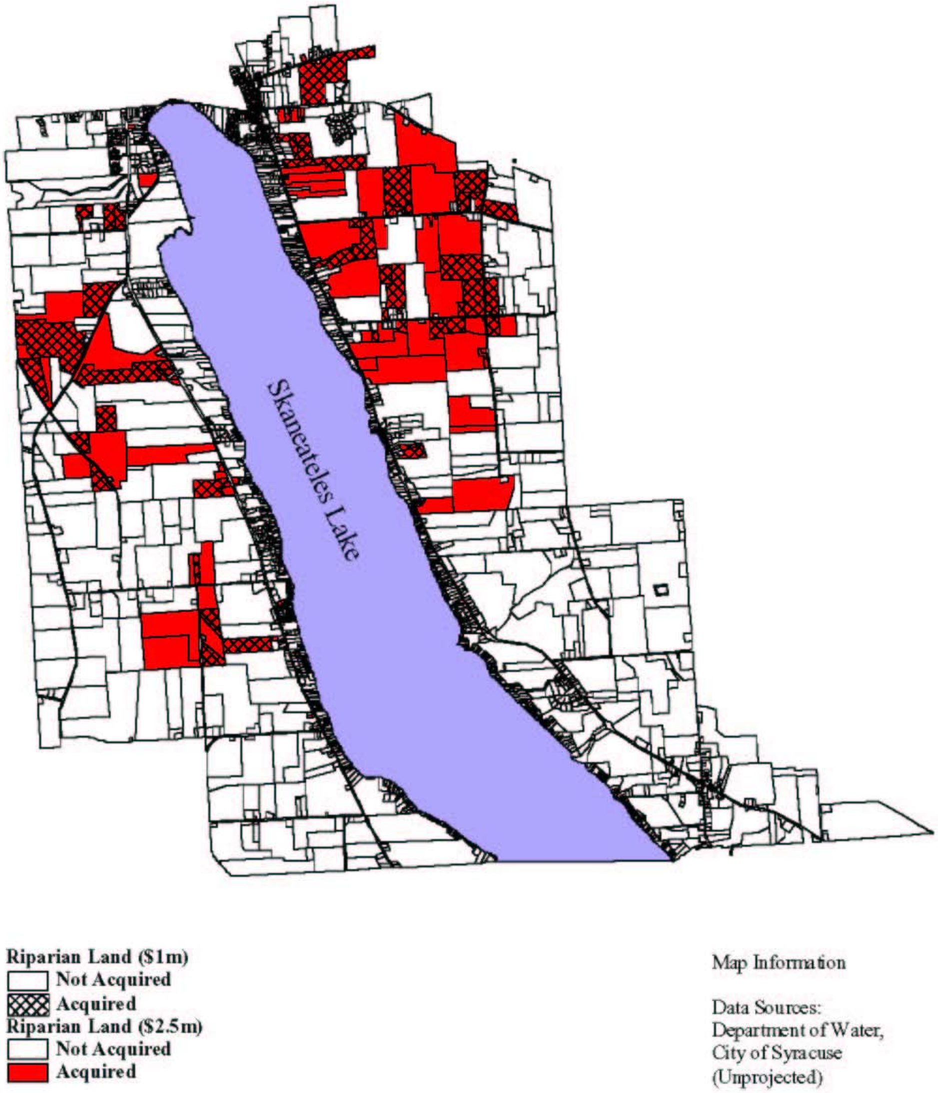
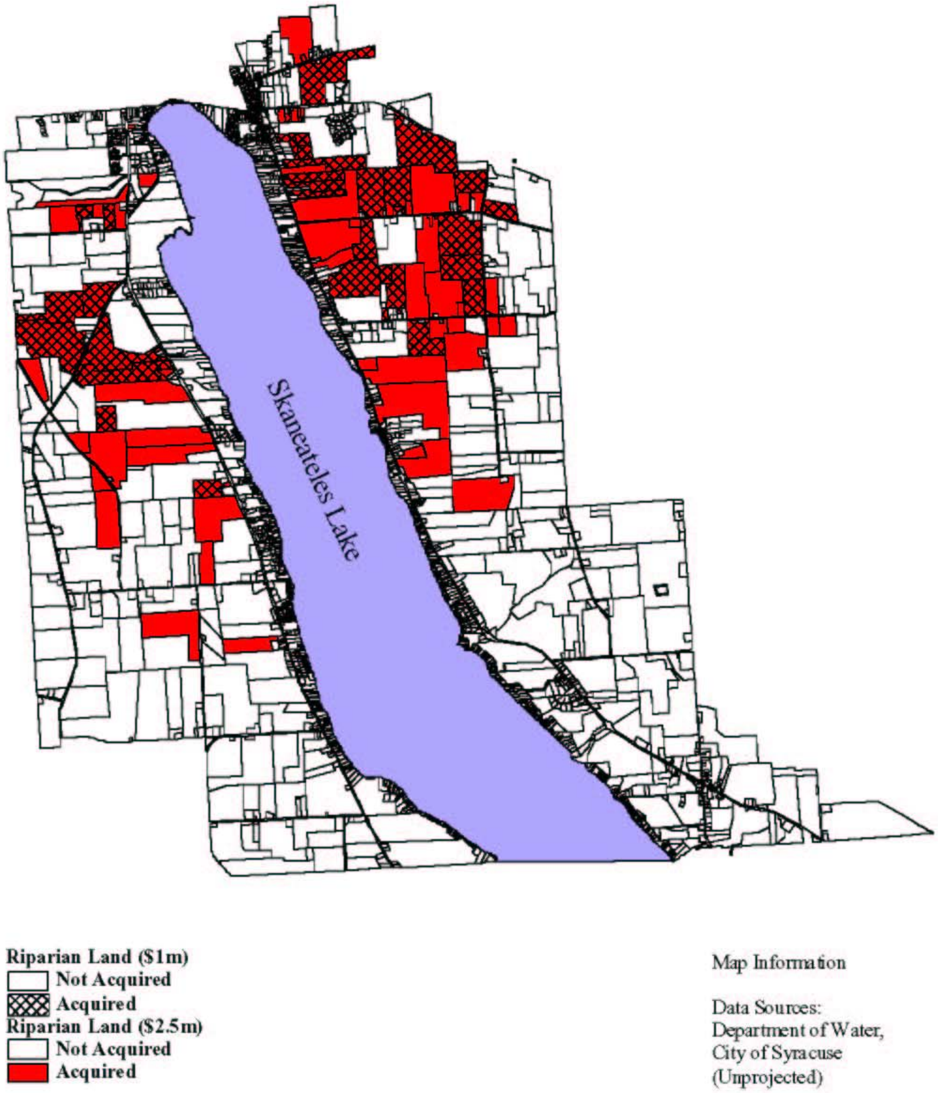


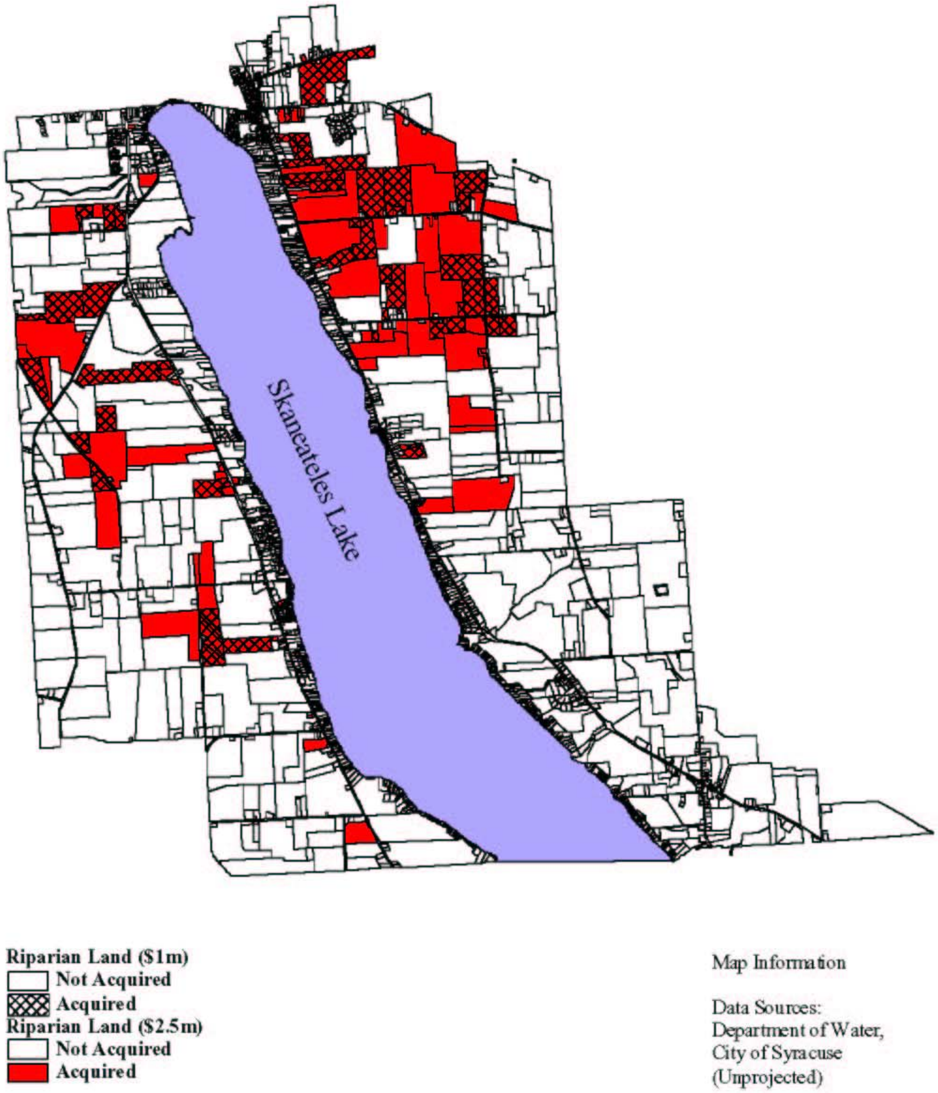
Figure 3 - Contracted Easement Portfolio, Ratio-Scale Scoring Equation ($1 million & $2.5 million



Map Information

Data Sources:
Department of Water,
City of Syracuse
(Unprojected)

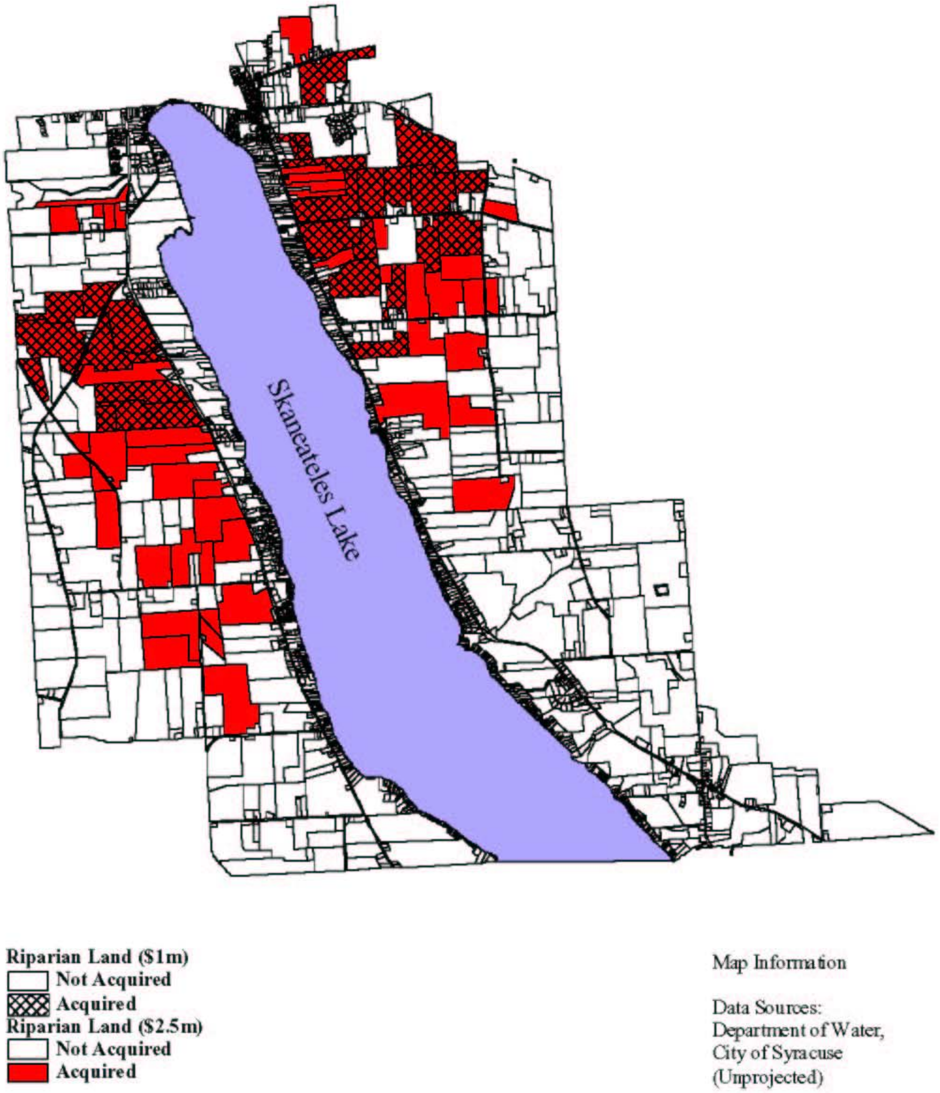
Figure 4 - Contracted Easement Portfolio, Categorical Scoring Equation ($1 million & $2.5 million)



Map Information

Data Sources:
Department of Water,
City of Syracuse
(Unprojected)

Figure 5 - Contracted Easement Portfolio, PPW Scoring Equation ($1 million & $2.5 million)



Map Information

Data Sources:
Department of Water,
City of Syracuse
(Unprojected)

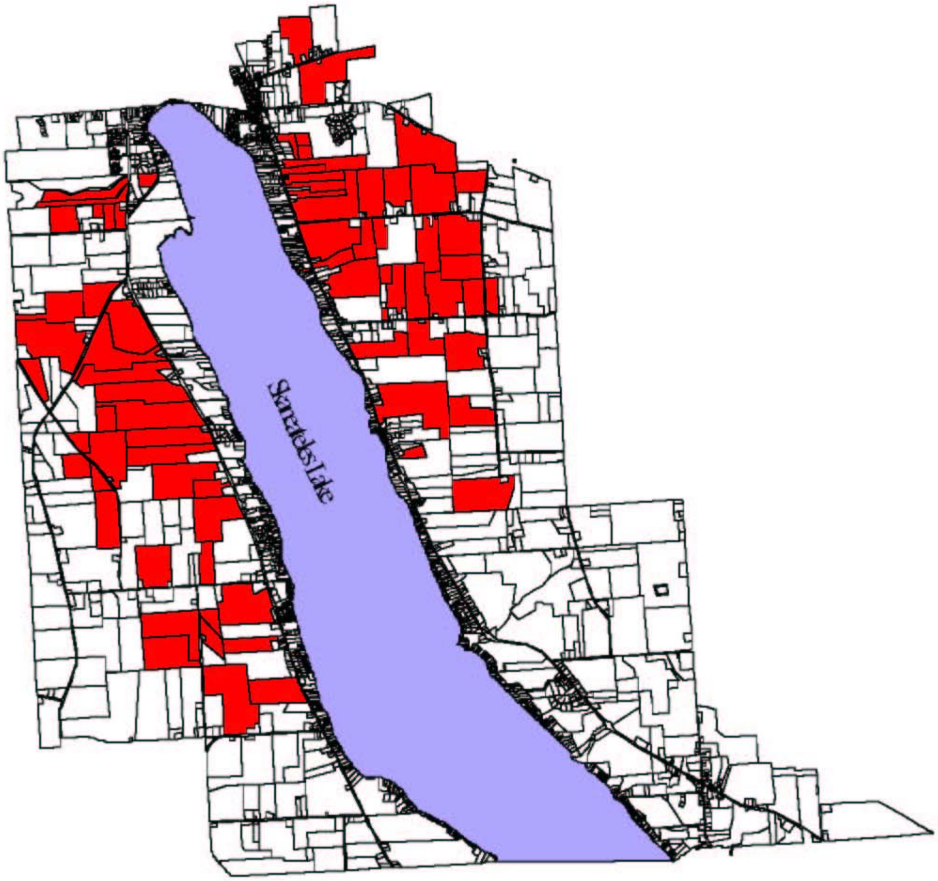
Figure 6 - Contracted Easement Portfolio, PPW Scoring Equation ($1 million) with 50% Threshold

Riparian Land
☐ **Not Acquired**
🟥 **Acquired**

Map Information

Data Sources:
Department of Water,
City of Syracuse
(Unprojected)

Figure 7 - Contracted Easement Portfolio, PPW Scoring Equation ($2.5 million) with 50% Threshold



Riparian Land

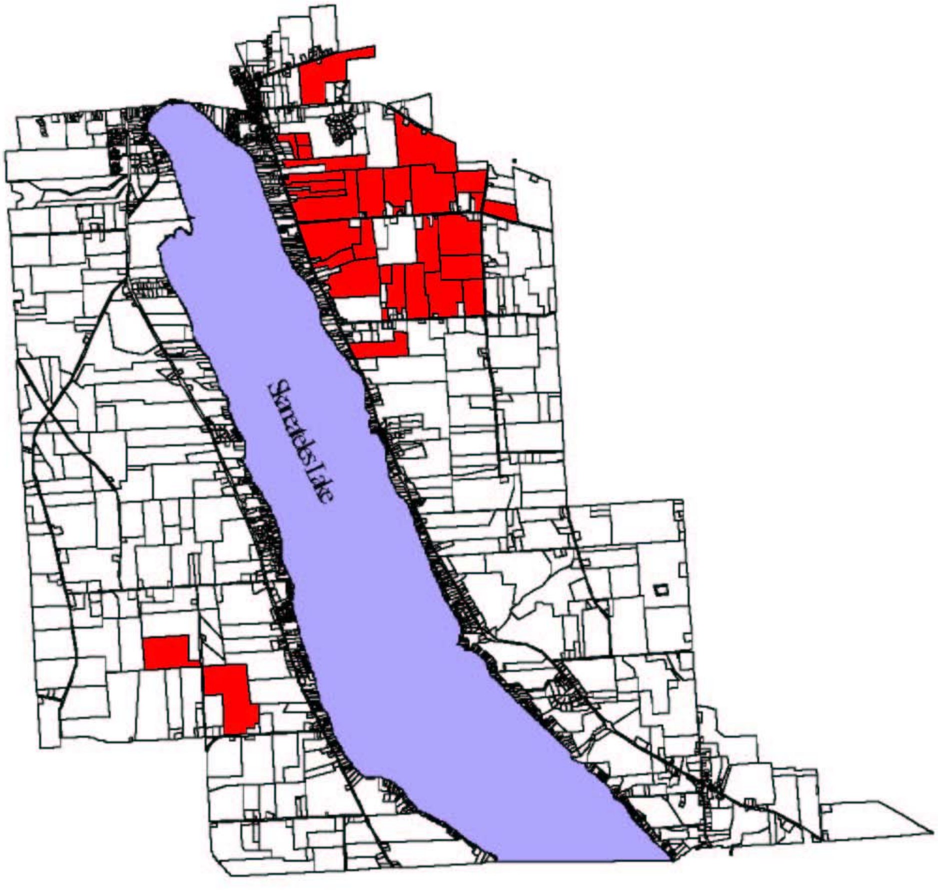
☐ **Not Acquired**

🟥 **Acquired**

Map Information

Data Sources:
Department of Water,
City of Syracuse
(Unprojected)

Figure 8 - Contracted Easement Portfolio, PPW Scoring Equation ($1 million) with 80% Threshold



Riparian Land

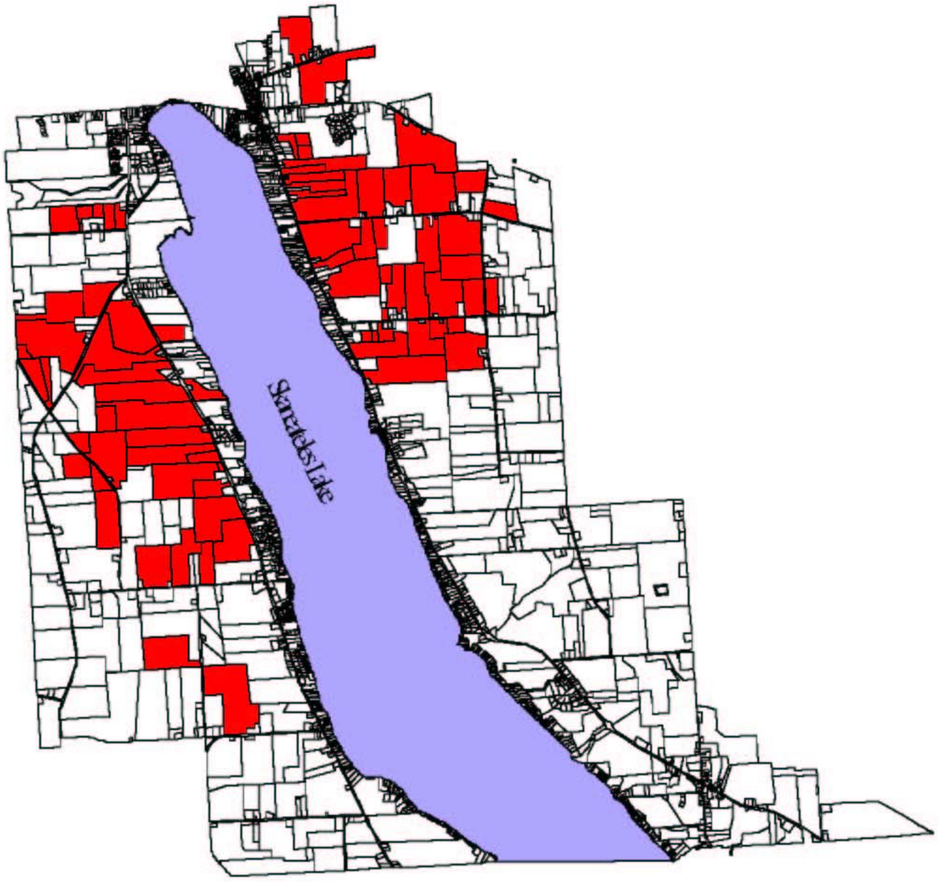
☐ **Not Acquired**

🟥 **Acquired**

Map Information

Data Sources:
Department of Water,
City of Syracuse
(Unprojected)

Figure 9 - Contracted Easement Portfolio, PPW Scoring Equation ($2.5 million) with 80% Threshold



Riparian Land

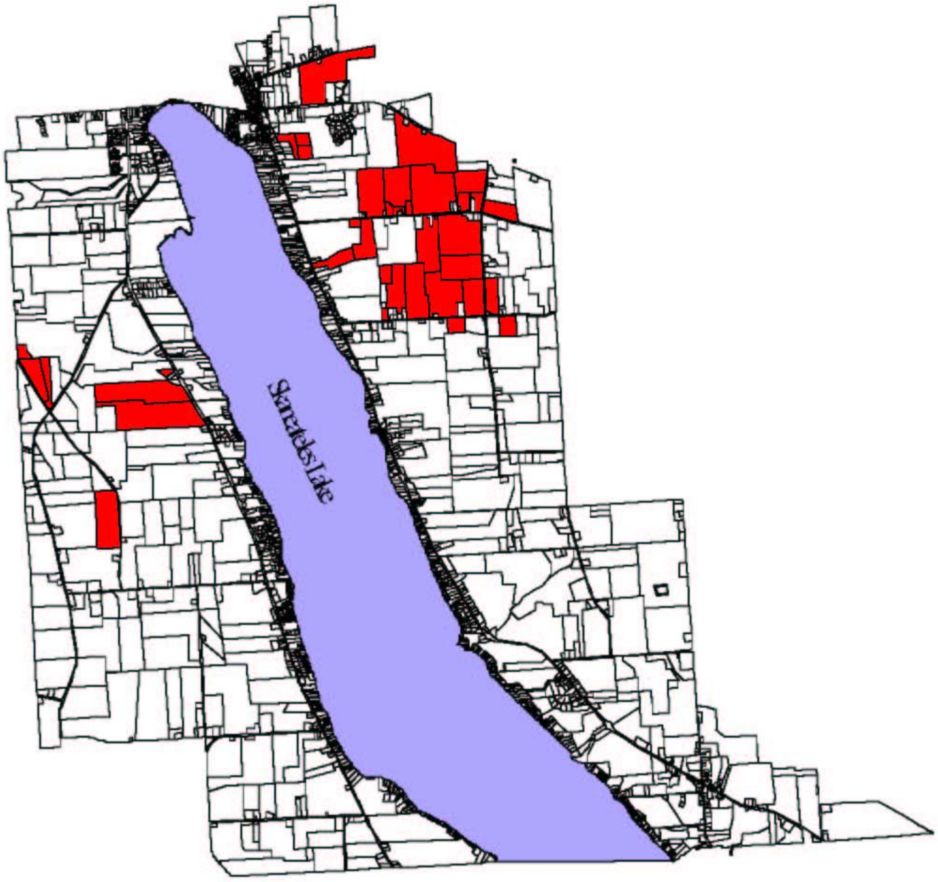
☐ **Not Acquired**

🟥 **Acquired**

Map Information

Data Sources:
Department of Water,
City of Syracuse
(Unprojected)

Figure 10 - Contracted Easement Portfolio, PPW Scoring Equation ($1 million) with 90% Threshold



Riparian Land
☐ **Not Acquired**
🟥 **Acquired**

Map Information

Data Sources:
Department of Water,
City of Syracuse
(Unprojected)

Figure 11 - Contracted Easement Portfolio, PPW Scoring Equation ($2.5 million) with 90% Threshold