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Working paper on

Achieving Cost Effective Conservation: ORES801 Case Studies of Applying Optimization To Protect Endangered Birds, Preserve Agricultural Lands, and Conserve Forested Lands.

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Case Studies
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ABSTRACT

The three following case studies were developed as research projects of the ORES801 course entitled "Optimization: Models and Methods" taught by Dr. Kent Messer in the Fall of 2007 and 2008. The first case study by Allison Borchers evaluates the cost effectiveness of applying optimization techniques to protect the Red Cockaded Woodpecker at the Camp LeJeune Marine Base in North Carolina. The second case study by Anand Kalambur evaluates the use of optimization in the context of agricultural land protection in Cecil County, Maryland. Finally, the third case study by Stela Stefanova applies optimization to identify cost effective project funding for the United States Department of Agriculture's Forest Legacy program.

ACKNOLWEDGEMENTS

The authors would like to acknowledge the partnering organizations for their assistance with this research in particular their willingness to share their data for this evaluation. In particular, the authors want to thank Will Allen of The Conservation Fund for his cooperation on the Camp LeJeane and Cecil County, Maryland projects.

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Table of Contents

Red Cockaded Woodpecker Habitat Protection Surrounding Camp Lejeune: Exploring Techniques to Select Optimal Parcels for Outright Purchase

Allison Borchers

Executive Summary

Camp Lejeune is the host of Marine Corps and Navy Corps commands on its 156,000 acre site along the North Carolina coast. Under the Endangered Species Act, the Red-Cockaded Woodpecker (RCW) recovery plan requires that this federal facility host a breeding pair of RCW for every 200 acres of land. The camp is not in compliance and therefore is searching for optimal ways in which to meet this federal requirement.

The Marine Corps has selected 84 parcels for possible purchase to meet this requirement, and are interested in methodology to further evaluate the selected parcels. This report will help to illustrate such methods.

From this research it is found that a Cost Benefit measure could provide a reasonable parcel selection criteria if a single benefit measure is determined to be an adequate representation of the parcels attributes. However, Binary Linear Programming will be preferred as Camp Lejeune continues work on this decision process and the parcel selection constraints increase in complexity.

The measures of ecological significance used in this report, are satisfactory. However, as the primary motivation for this research is to secure RCW habitat, improving these indicators may

be determined an important area for future work. The cost measures used in this report are basic, as real budget figures are developed, these values will need to be revisited.

This report is able to offer preliminary guidance in parcel selection. Comparison of the methods used and the parcels selected under different measures—which the maps can help to illustrate—will be useful as the parcel selection procedure is further refined.

1. Introduction

Camp Lejeune is the host of Marine Corps and Navy Corps commands on its 156,000 acre site along the North Carolina coast. Under the Endangered Species Act the Red-Cockaded Woodpecker (RCW) recovery plan requires that this federal facility host a breeding pair of RCW for every 200 acres of land. The camp is not in compliance and therefore is searching for optimal ways in which to meet this federal requirement. Camp Lejeune is located primarily in the coastal flood plain which is not the RCW's primary habitat. Furthermore the camp's commanders may not wish to trade-off training activities for RCW habitat within the current base boundaries. For these two reasons, Camp Lejeune is looking to support RCW breeding habitat outside of their installation. The Conservation Fund is working directly with Camp Lejeune on this project.

There are many potential approaches to obtain credits for the RCW habitat to meet this regulation—purchasing of credits from a third party, such as state land owners or from private entities which specialize in ecosystem restoration, restoration of habitat or outright land purchases. All methods will be explored by the Marine Corps. This report examines only the various methods with which to select parcels for outright purchase.

Potential parcels for purchase were identified by Camp Lejeune's Marine Corps. Selection objectives of the Marine Corps had a significant ecological component, and their ecological evaluation of each parcel is based on their own field surveys of land parcels. The identified properties have potential as RCW habitat, such as having appropriate soil, tree cover, or proximity to other appropriate habitat. The Marine Corps was also interested in properties neighboring their installation to ensure this land remained in compatible use—mainly farm, forest and wetlands. This selection process provided 84 parcels for consideration.

The Marine Corps is interested in methodology to further evaluate the selected parcels. This project will help to illustrate such methods. Ultimately, the results will offer policy guidance to The Conservation Fund as well as Camp Lejeune as they continue to consider their RCW Recovery Act compliance opportunities.

2. Data

The Marine Corps identified 84 parcels for consideration. These parcels are identified (in red) on a map of the region (Figure 1).

William Allen, at The Conservation Fund, has provided basic information on each of these parcels. He has also evaluated each of the parcels against three ecological indicator measures using GIS. Some discussion on this data is provided below, as well as summarized in Table 1.

2.1 Property Value and Acreage

The taxed property value of each parcel is known. The taxed improvement value was eliminated due to inconsistencies in this data field. Future work should revisit this value to ensure appropriate base valuations are used. This problem may be of no consequence if land appraisals are done on the properties. The acreage of the parcel is known and the assessed value per acre is calculated.

The taxed property values are inflated during the analysis by a factor of 1.3. This value was determined by Will Allen as his ‘professional best judgment’ based on his experience. While the absolute numbers are subject to verification, this inflation adds a degree of believability to the results as the numbers we will be looking at more closely resemble realistic and expected property values.

2.2 Ecological Benefits

The Southeastern Ecological Framework (SEF) was developed for EPA Region 4, which consists of eight southeast states, by the EPA Region 4 Planning and Analysis Branch and Researchers at the University of Florida. The Framework maps land areas of ecological significance, identifying critical landscapes. The Framework is intended to provide a foundation for effective conservation. For this reason the Framework is used in this project to measure the parcels' ecologically significant areas.

Three measures of ecological significance are used from the Framework—Primary ecological areas (PEA), Secondary ecological areas (SEA) and an overall SEF measure. PEA includes land areas of highest ecological significance. These are the primary building blocks of the green infrastructure plan—the Hubs. SEA are areas of ecological significance, but deemed of secondary importance. SEA are often landscape linking lands. Finally the SEF indicator is both the SEA and PEA areas, but also land areas which "smooth" the overall plan as well fill in any gaps. This report will aggregate these three measures in the analysis. Aggregation, in effect, weights areas in which these three measures overlap since these areas will be 'doubled counted' when the measures are aggregated. This may be desirable as it give less weight to areas which are linking or gap filling, and thus of less ecological significance, and more weight to areas of Primary and Secondary significance.

The Framework was primarily developed using GIS modeling. The information is available by 90 meter cells. This is equivalent to 2 acre cells. The benefit measure is calculated by summing the 90 meter cells which overlap on the parcel layer and the SEF (or SEA or PEA) layer. This measure is summarized in Table 1. To better understand what this overlap means, a percent coverage is also calculated. The percent coverage is calculated as follows:

Percent Coverage = (SEF sum * 2) / Parcel Acres (1)

where SEF sum is multiplied by 2 to convert 90 meter cells into acres. From this coverage measure it is shown that 35 of the 84 parcels are greater than 99% covered by SEF land. Sixty-one parcels are more then 90% contained in the SEF Framework. The environmental quality of the parcels should not come as a surprise. The Marine Corps selected the parcels as candidates after a field inspection to determine if they were appropriate for RCW habitat and if the parcel possessed general ecological significance.

2.3 Normalization

The benefit measures are incorporated into the modeling in two ways. The ways differ by their use of the acreage attribute. The first normalization favors large acreage, high total benefit parcels. Because the summation variables are correlated to the size of the parcel, use of this measure will favor larger parcels. The first benefit measure will use a normalized sum of the three indicators calculated as follows:

ECOBENEFITi = (SEFi + SEAi + PEAi) / Max (SEFj + SEAj + PEAj) (2)

This normalization will create a score of one for the largest parcel with the most coverage, and the score will decrease as the size and coverage of the parcel decrease.

The second normalization used eliminates the effect of absolute size of the parcel from the measure. Acreage can then be used as a separate attribute in the selection process if desired. This will create a different distribution of parcel selection. It is calculated as follows:

COVERAGEi =[(SEFi + SEAi + PEAi)*2] / (ACRESi *3) (3)

where, again the sums are multiplied by 2 to convert 90 meter cells into acres. This score is the average coverage (in percentage) of each of the three benefit measures.

3. Methods

Three selection methods are explored to select from among the 84 potential parcels for outright purchase—Benefit Targeting, Cost Benefit Ratios, and Binary Linear Programming. Each of these three methods are used with the above two benefit normalizations—ECOBENEFIT and COVERAGE. The intent of using two normalizations was to explore the change in distribution of parcel selection. This will be informative as improvements to the benefit measures are developed. Below the three selection methods are described.

3.1 Benefit Targeting

Benefit Targeting (BT) is the practice of choosing the most ecologically significant parcel. The parcels are listed in descending order of benefits. Parcels would be acquired in descending order of benefit—the parcel with the highest benefit score would be acquired first, the second highest score acquired second, and so on—until a target was met, or the acquisition funds were exhausted. This is intuitively appealing. This method will allow for the purchase of Priority Ecological Areas, but the method does not take into account costs of acquisition. Therefore the selected parcels may not maximize benefits if working with a limited budget.

3.2 Cost Benefit Ratio

A cost benefit ratio (CBR) is a simple, but useful score with which to evaluate the parcel. A lower cost-benefit ratio is desirable as this means the 'cost per benefit' are lower, a "good deal". For this report it is calculated as follows:

$$CBR_i = \text{Taxed Property Value}_i / (SEF_i + SEA_i + PEA_i) \quad (4)$$

To select parcels using this method, the parcels would be sorted in ascending order by their CBR. This method allows for the "cheapest" benefits to be purchased, until the funds are exhausted, or other objectives are met.

3.3 Binary Linear Programming

This report will investigate selection using the Binary Linear Programming (BLP) method, where the binary decision variables are limited to one or zero, which indicate purchase or not purchase a particular parcel. BLP will take into account attributes of the parcels, including cost and benefits. The general formulation of this method is to maximize the total benefits achieved:

$$\text{Max } \Sigma \text{ ECOBENEFITS}_i X_i \quad (5)$$

Subject to a budget constraint (B):

$$\Sigma C_i X_i \leq B \quad (6)$$

Alternatively the problem could be structured as follows:

$$\text{Min } B(X) = \Sigma C_i X_i \quad (7)$$

Subject to an acreage obligation,

$$\Sigma \text{ Acres}_i X_i \geq a \quad (8)$$

and/or a benefit requirement,

$$\Sigma \text{ SEF}_i X_i \geq s \quad (9)$$

Where $X_i = \{0,1\}$, indicating whether parcel i is purchased or not and C_i is the taxed parcel value.

4. Results

4.1 Benefit Targeting using ECOBENEFIT normalization

In this scenario the parcels were sorted in descending order based on the ECOBENEFIT normalization. Parcels were 'purchased' until the budget was exhausted. The budget was defined as a percentage of the cost to purchase all 84 of the selected parcels. The results of this BT model are shown in Table 2.

Figure 2 displays the parcels selected at 10%, 25% and 50% of total cost. The ECOBENEFIT measure creates a larger score for larger parcels with more overlap with one or more of the benefit measures.

When using the BT method, the ECOBENEFIT measure preference for large parcels should be obvious as this is the only decision variable. The largest parcel with the most overlap is chosen first, and in figure 2, this result is visually apparent. As a result of the preference for large parcels, none of the budget scenarios select a parcel less than 200 acres. This is desirable under the RCW recovery plan.

4.2 Benefit Targeting using COVERAGE normalization

In this scenario the parcels were sorted in descending order based on average percentage coverage (COVERAGE). Parcels were again 'purchased' until the budget was exhausted. The results of this BT method using the alternative normalization are summarized in Table 3. Figure 3 illustrates the parcels selected at 10%, 25% and 50% levels using this technique. The immediate difference between this normalization and the previous is that smaller parcels are favored. This is apparent from the increased number of parcels purchased and the greater selection of parcels under 200 acres. This technique captures a lower level of total available benefits at all budget level.

4.3 Cost Benefit Ratio Results

The CBR method makes a clear improvement over the BT method. At low levels of budget it is apparent that a greater number of acres are selected, and a greater percentage of the total available benefits are captured. This method is therefore achieves greater results in a more cost effective manner than the previous two. Table 4 and Figure 4 summarize the results. Only a single parcel at the 25% budget level is selected for purchase which is less than 200 acres. This parcel is however adjacent to several other selected parcels creating a block which is far greater than 200 acres. Its size is not then an immediate concern. At the 50% level, only two parcels are not contiguous to other selected parcels, and only one of these parcels is under 200 acres and therefore may not be eligible to meet RCW recovery plan requirements.

4.4 Binary Linear Programming

In this report the BLP results are not significantly different from the CBR method. This is due to our single constraint. Here, the benefits of BLP are more apparent at the margin. Since the CBR methods works down a list, this method, when used blindly, is unable to make efficient decisions when the budget dollars are getting scarcer. If the next parcel on the list exceeds the budget, purchasing stops. However, possibly if this parcel was skipped, there is another parcel to be purchased, which would remain within the budget and therefore increase benefits attained. Hopefully, the decision makers would not be using CBR blindly and recognize this problem. However, BLP does not encounter this problem. The program will select these final marginal parcels to exhaust the budget and maximize benefits. For this reason, BLP is able to yield superior results in this application.

Two BLP problems were run. The first maximized the ECOBENEFIT normalization, subject to budget constraints (see table5 and figure5). The second maximized COVERAGE, again subject to a budget constraint (see table6 and figure6). The comparative results of these two methods mirror the conclusions from above. The ECOBENEFIT measure favors larger parcels, while the COVERAGE measure selects a broader spectrum of the parcels.

The parcels selected under 200 acres are the same as the CBR method. Again, only two parcels at the 50% level are not contiguous to other selected parcels, and only one of these is less than 200 acres.

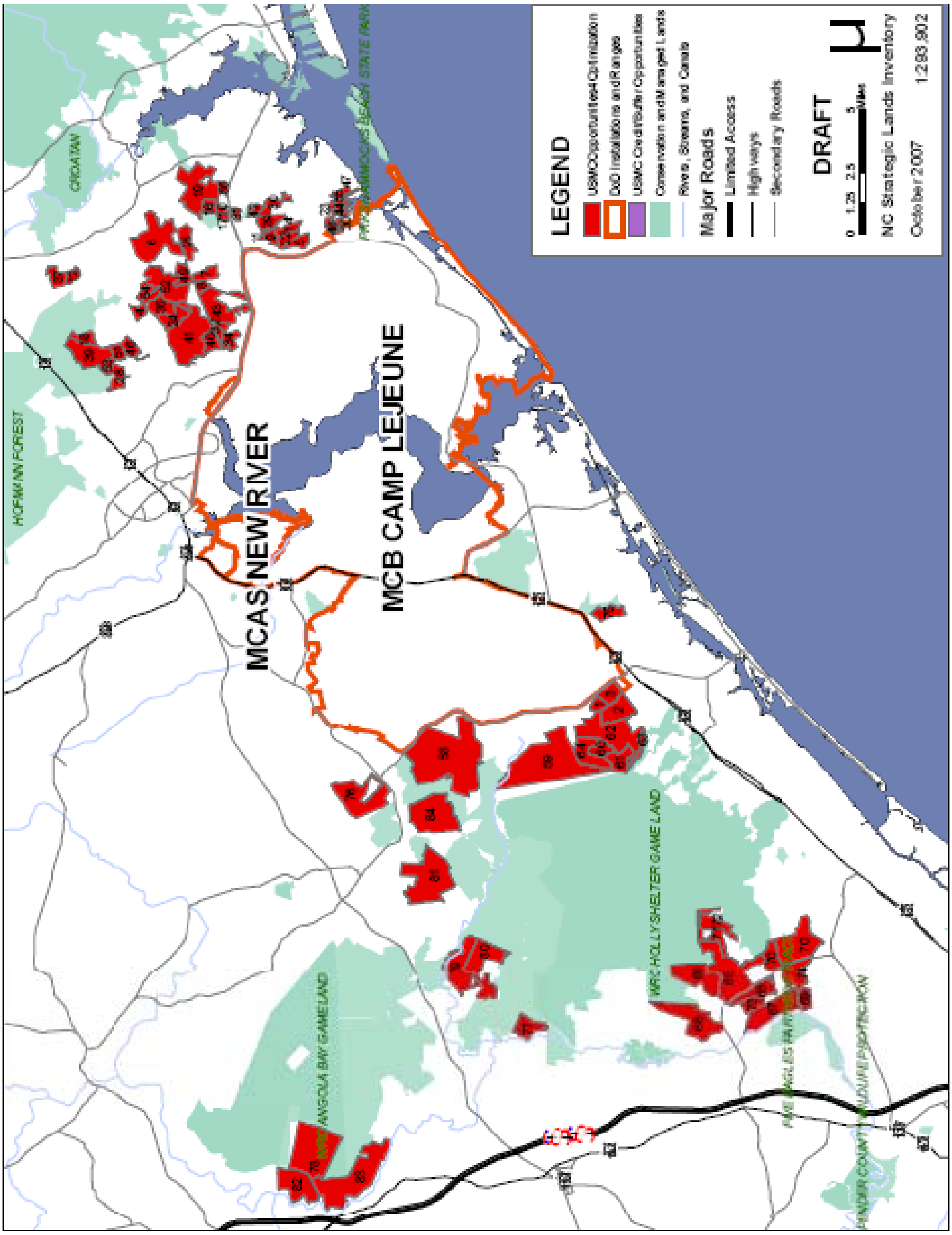
Given the actual results of this selection process, it is not determined to be necessary to create more complicated constraints on the parcel selection size (e.g. combining parcels to create contiguous acreage over 200 acres). However, should this be appropriate, BLP is capable of incorporating parcel combinations to meet size requirements, while the CBR could not integrate this more dynamic constraint. This is a distinct advantage of BLP.

5. Conclusions

The results of this report seem to favor the use of the ECOBENEFIT measure. This normalization incorporated size considerations which are desirable as the RCW recovery act require 200 contiguous acres. Whether the benefit measure of ECOBENEFIT or COVERGAGE is preferred (or adequate) will need to be determined by Camp Lejeune and The Conservation Fund. The motivation for this research is to secure RCW habitat, however only general ecological benefit measures were available at this time. This is an area ripe for further refinement. A better measure of RCW suitability will improve the results of any method intended for RCW parcel selection. In fact, as this work continues, Camp Lejeune will be evaluating parcel purchasing options against other RCW credit requirement compliance options. At a later time it may, or may not be desirable to focus exclusively on a benefit measure of RCW suitability as their needs are better understood. The measure used in this report does however allow the Marine Corps to capture the full array of potential ecological benefits, including wetland, habitat and forest, which may be desirable given the diverse environmental regulations they are subject to.

From this research it is found that a Cost Benefit measure provides reasonable parcel selection criteria. However, this measure requires an attentive analyst to interpret the results as the funds become increasingly limited. The BLP method is able to avoid this ambiguity. The BLP method will also be unrivaled as Camp Lejeune develops their parcel selection requirements, and the problem increases in complexity.

The maps offer informative illustrations of the results of each of the selection methods. This report is able to offer preliminary guidance in parcel selection.



Source: William L. Allen, III, Director of Strategic Conservation, The Conservation Fund

Figure 1. Parcels Identified By Camp Lejeune Marine Corps for Conservation (in Red)

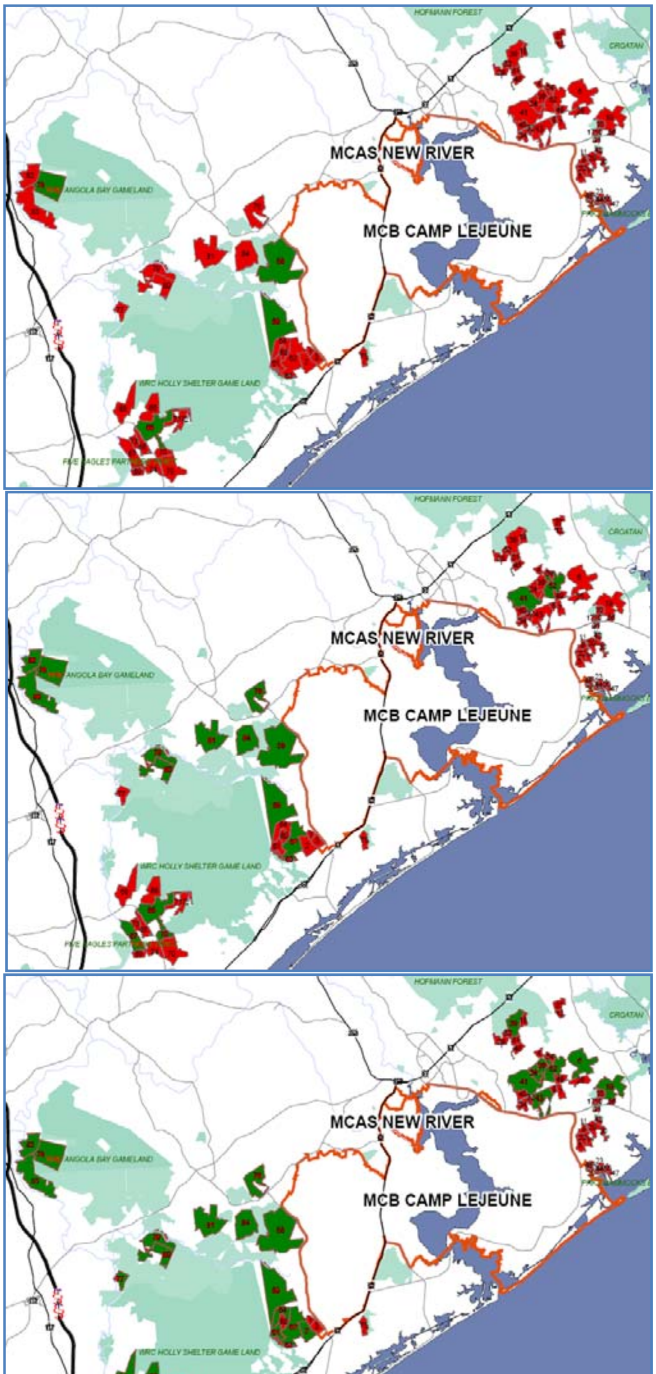


Figure 2. Benefit Targeting Using ECOBENEFIT at 10% (top), 25% (middle) and 50%(bottom) of Total Costs (Selected Parcels in Green)

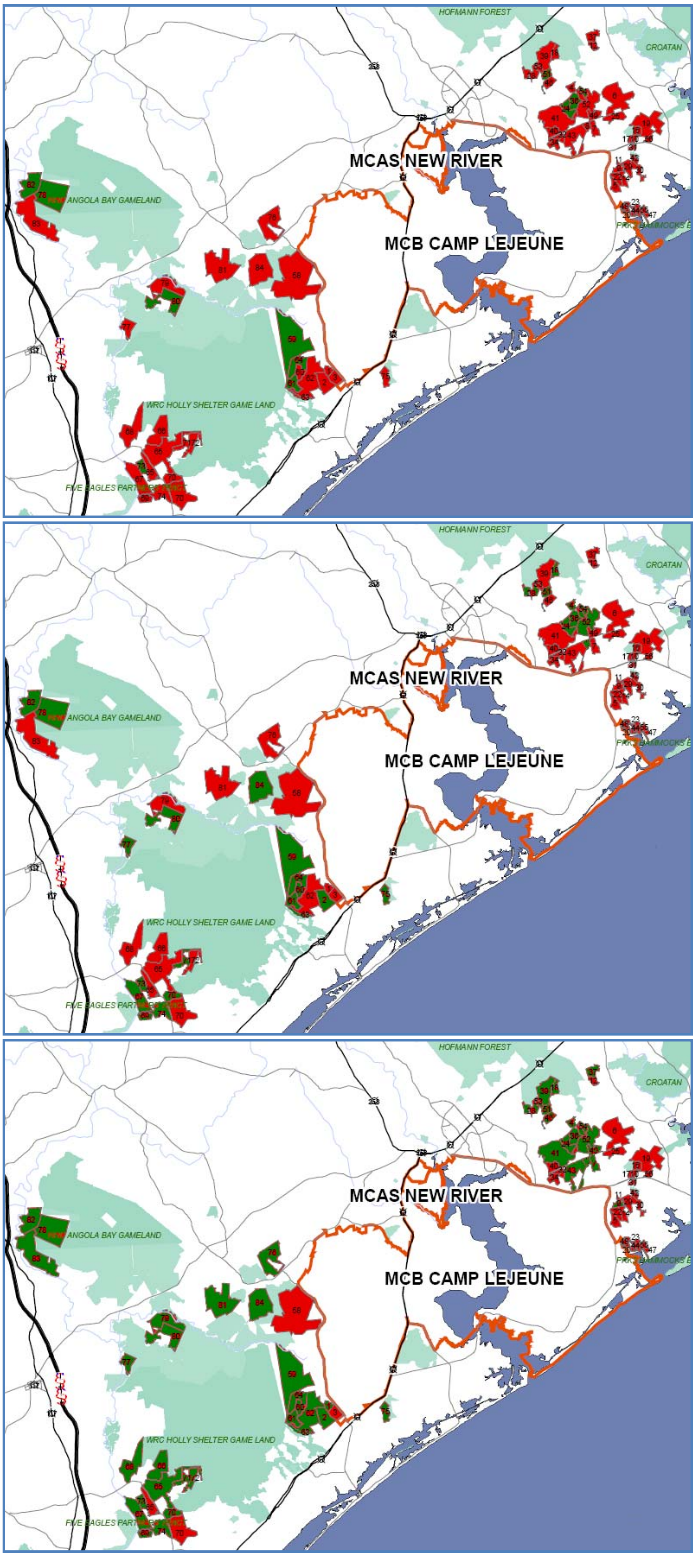


Figure 3. Benefit Targeting Using COVERING at 10% (top), 25% (middle) and 50% (bottom) of Total Costs (Selected Parcels in Green)

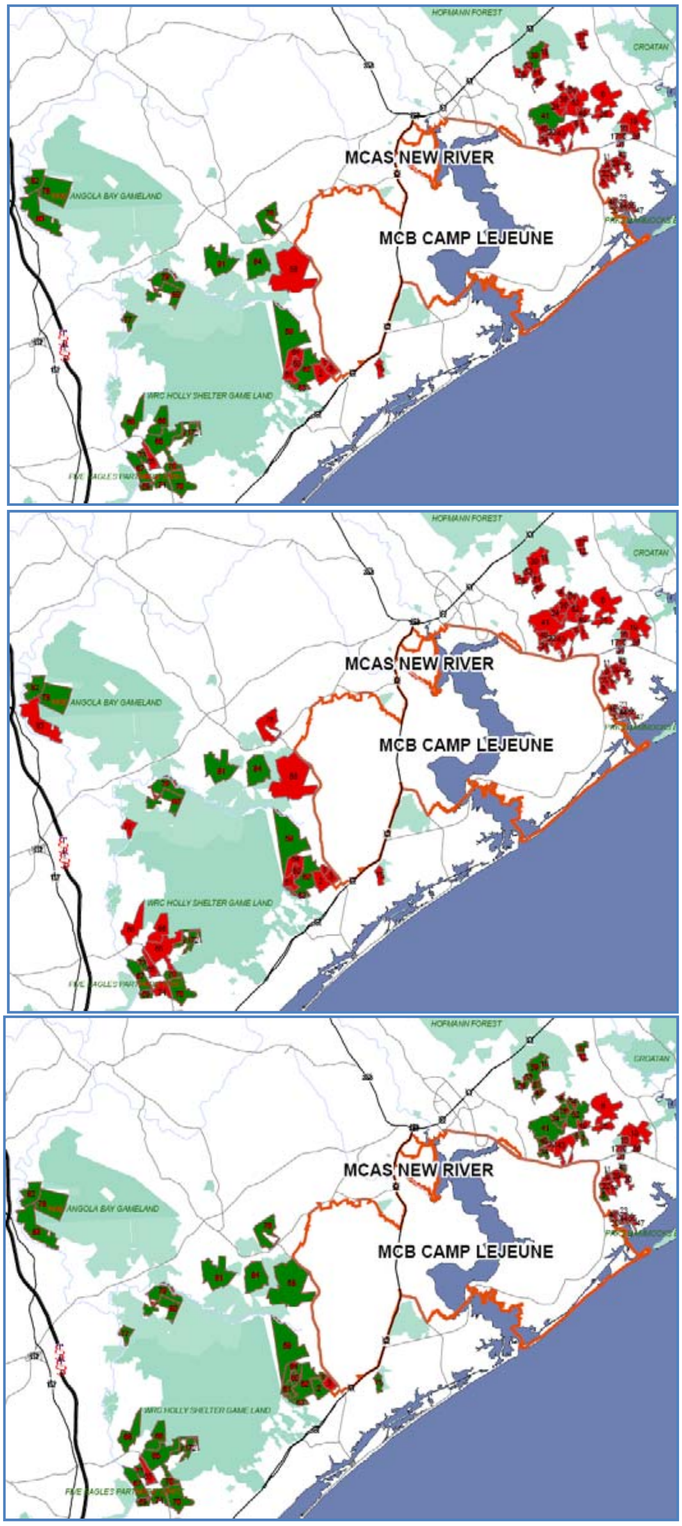


Figure 4. Cost Benefit Ratio at 10% (top), 25% (middle) and 50% (bottom) of Total Costs (Selected Parcels in Green)

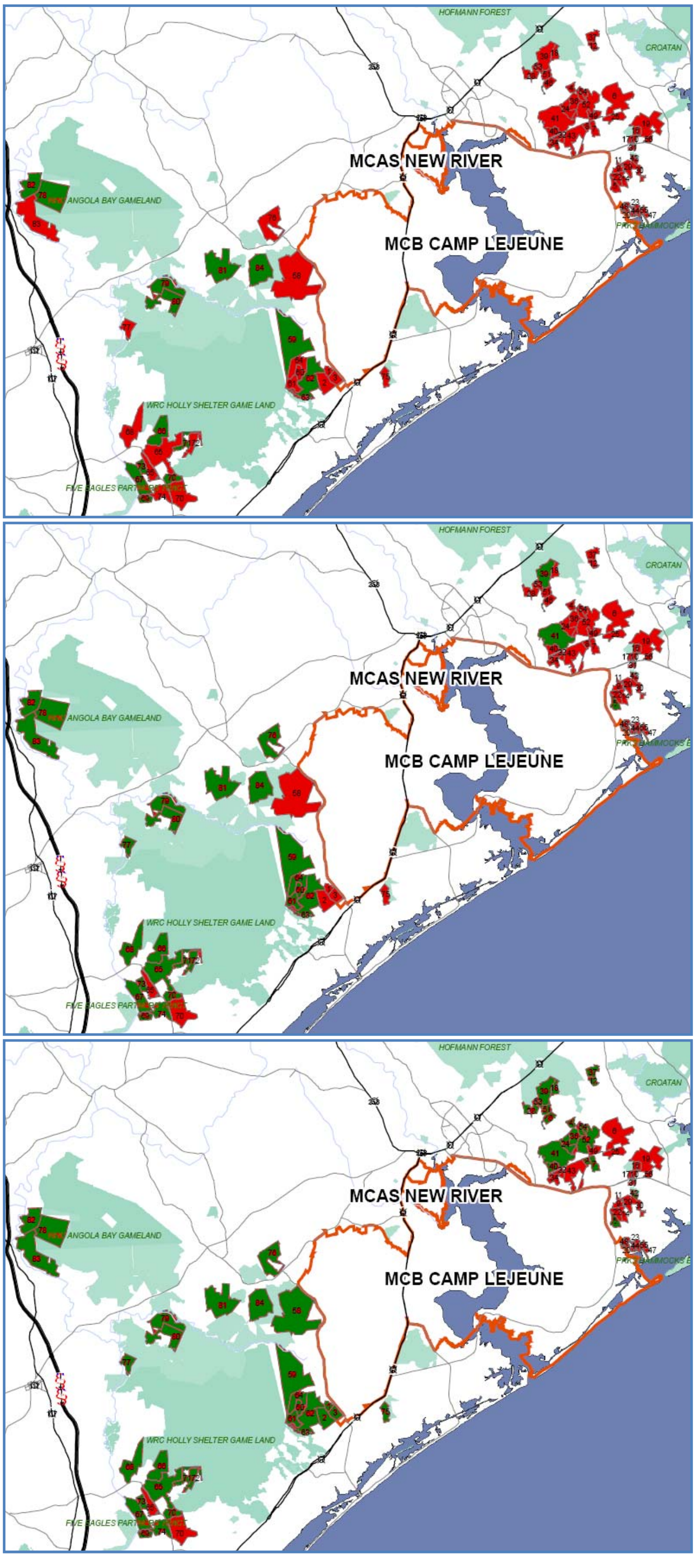


Figure 5. BLP Using ECOBENEFIT at 10% (top), 25% (middle) and 50% (bottom) of Total Costs (Selected Parcels in Green)

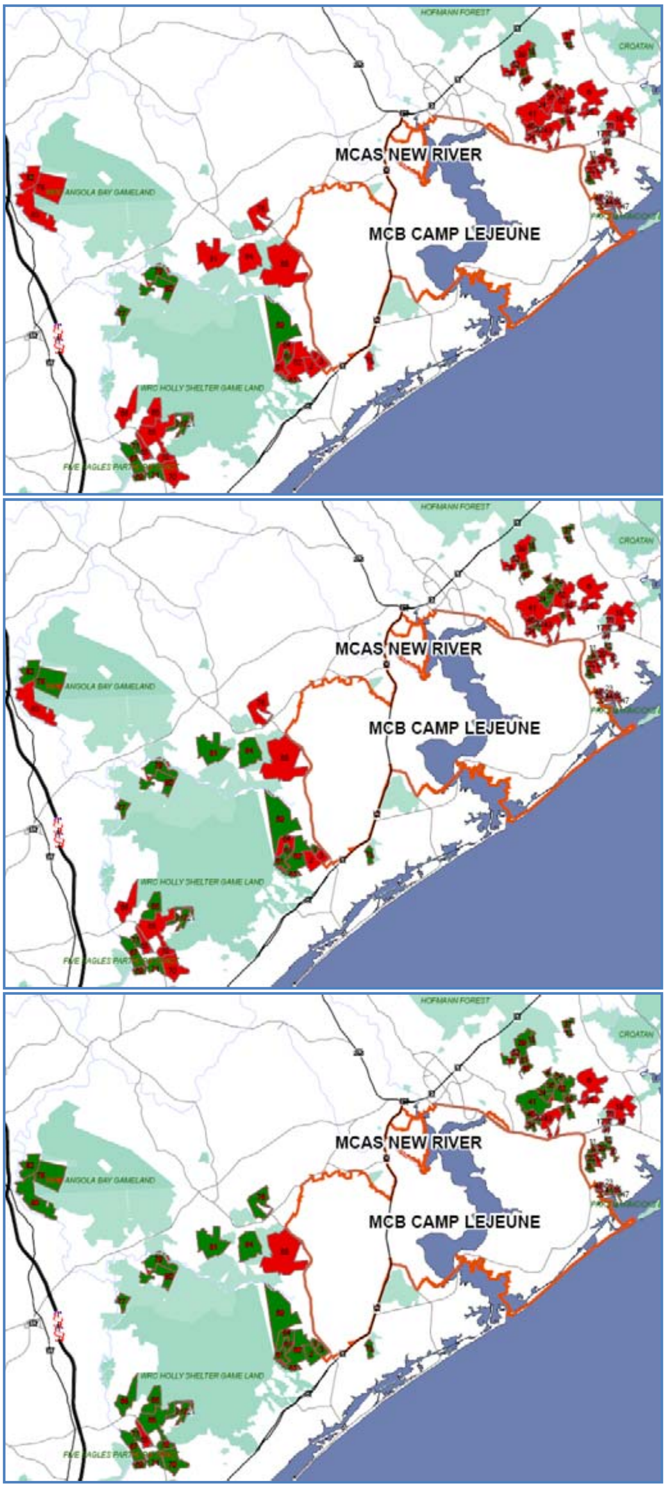


Figure 6. BLP Using COVERING at 10% (top), 25% (middle) and 50% (bottom) of Total Costs (Selected Parcels in Green)

Table 1 Parcel Data

	Value			
Parcel Data Description	Minimum	Average	Median	Maximum
Taxed Property Value	$26,215	$622,505	$452,284	$2,778,947
Acreage of Parcel	7	613	292	4,177
Taxed Value per Acre	$90	$3,558	$1,576	$33,603
SEF Overlap Summation	0	298	139	2,091
Parcel Coverage by SEF	0%	85%	98%	100%
SEA Overlap Summation	0	218	87	1571
Parcel Coverage by SEA	0%	51%	59%	100%
PEA Overlap Summation	0	212	99	1544
Parcel Coverage by PEA	0%	56%	77%	100%

Table 2 Benefit Targeting Selection Results using ECOBENEFIT Measurement

% Total Costs	Implied Budget	Dollars Spent	# Parcels Selected	Acres Purchased	Benefits Captured	# Parcels <200 Acres
50%	$33,988,774	$33,652,439	30	41,984	85%	0
25%	$16,994,387	$16,493,368	16	30,299	63%	0
10%	$6,797,755	$6,225,899	4	11,939	25%	0

Table 3 Benefit Targeting Selection Results using COVERAGE Measurement

Total Value	Implied Budget	Dollars Spent	# Parcels Selected	Acres Purchased	Benefits Captured	# Parcels <200 Acres
50%	$33,988,774	$33,858,870	47	39,853	78%	8
25%	$16,994,387	$16,561,188	28	20,435	50%	5
10%	$6,797,755	$6,304,761	11	10,267	20%	1

Table 4 Cost Benefit Ratio Selection Results

% Total Costs	Implied Budget	Dollars Spent	# Parcels Selected	Acres Purchased	Benefits Captured	# Parcels <200 Acres
50%	$33,988,774	$33,619,367	49	43,421	91%	8
25%	$16,994,387	$14,713,915	24	31,263	67%	1
10%	$6,797,755	$6,510,309	14	18,663	42%	0

Table 5 Binary Linear Programming Results using ECOBENEFITS Measure

Total Value	Implied Budget	Dollars Spent	# Parcels Selected	Acres Purchased	Benefits Captured	# Parcels <200 Acres
50%	$33,988,774	$33,953,379	49	43,596	91%	8
25%	$16,994,387	$16,925,069	28	32,988	70%	1
10%	$6,797,755	$6,781,932	14	19,307	43%	0

Table 6. Binary Linear Programming Results using COVERAGE Measure

Total Value	Implied Budget	Dollars Spent	# Parcels	Acres	Benefits Captured	# Parcels <200 Acres
50%	$33,988,774	$33,983,492	61	40,245	86%	16
25%	$16,994,387	$16,985,140	39	24,303	62%	13
10%	$6,797,755	$6,787,706	22	11,411	35%	8

Optimization Model for Land Acquisition based on the Green Infrastructure Plan for Conservation Efforts in Cecil County, Maryland

Anand Kalambur

Executive Summary:

Land conservation efforts in the United States are based on acquiring land that meet the desired conservation objectives while on a planned budget. Such efforts have traditionally centered on Benefit targeting (BT), or, a Rank-Based Model. In this model, land parcels available for acquisition are ranked based on their aggregate conservation benefits. The acquisition then proceeds from the highest ranked parcel that can be afforded and continues down the ranks until the available funds are exhausted. This methodology, based on greedy style heuristics, could lead to a possible sub-optimality in the solution. Recent studies1,2 have highlighted the effectiveness of optimization techniques using a Binary Linear Programming (BLP) Model for land acquisitions that maximize the aggregate conservation benefits.

The two models were applied to an ongoing land acquisition evaluation by the Conservation Fund in Cecil County, MD. The conservation value for the 122 land parcels in this study were based on four biophysical attributes, viz., GI Hub Rank (% of area within Green Infrastructure), Water Quality Score, Reforestation Model Score and Ecological Services Score. The models were based on aggregate values of all the 4 attributes.

The results show that the optimization model offers significantly higher conservation benefits as compared to the Rank based model while operating within the same budget. The Optimization model shows higher conservation benefits and protects more acreage, especially at lower

budget levels. At a $ 5 million budget level, the conservation benefits from the optimization model is almost 6 times as much as the rank based model and the acres protected is almost 25 times as much. Alternatively, the optimization model results in a savings of nearly $4.6 million while providing the same conservation value as a rank based model operating at $5 million.

Introduction:

Land acquisition, through both public and private efforts in the United States, has been used to achieve Conservation goals. The Land Trust Alliance has noted3 that private land conservation is increasing in all regions of the country, with the pace of conservation tripling in the past five years. Public incentives such as conservation easements, tax credits and incentives have spurred this growth in land conservation. Land trusts have also increased in numbers and have enhanced their professional standards. Potential land for acquisition is assessed for ecological and other benefits by these organizations, and public and private endowments are used to purchase the land.

Traditionally, land acquisition has proceeded through a rank based methodology. This entails ranking of the land parcels available for acquisition based on their conservation benefits. The land parcels are then purchased down the ranks until the available budget is exhausted.

Optimization methods, where the goal is to maximize (or minimize) an objective by allocating resources, while operating under constraints, has been shown recently to offer a more cost efficient route in the land acquisition process while maximizing conservation benefits.

The two methods described above were used to select land parcels for acquisition for a Conservation Fund project in Cecil County, MD. The project is a part of the green infrastructure plan4 that the Conservation Fund updated recently for Cecil County. Binary linear programming was the optimization method used in this study to maximize the conservation benefits, while operating under varying budget levels. 122 land parcels were considered in the study. 4

biophysical attributes were considered towards evaluating the conservations benefit values of the parcels (They are the GI Hub Rank, Water Quality Model Score, Reforestation Model Score and Ecological Services Score). The scores varied from 0 -100. The Budgets considered for the study were set at 10%, 25% and 50% of the total cost of all the 122 parcels in the study.

Binary Linear Programming Theory:

Binary linear programming (BLP) is a special case of Integer Linear Programming where the outcomes are restricted to the integers 0 and 1. In the context of this study, the outcomes would represent the purchasing of a land parcel for conservation or not.

Let i=1,…, 122 indicate an index representing the 122 parcels of land considered in this study. Further let j=1,…, 4 indicate an index representing the four biophysical attributes used in this study. The conservation benefit can then be represented as Cij (where i is the parcel index and j is the biophysical attribute).

All the four attributes in this study have been equally weighted. Thus the Conservation benefit value of the ith parcel is,

$$S_i = \sum_{j=1}^{4} C_{ij} \tag{1}$$

Let Xi represent the binary (1, 0) variable for the ith parcel, where a value of 1 would indicate selection of the parcel and a 0 would indicate rejection. The optimization problem can then be expressed as,

Maximize

$$S(x) = \sum_{i=1}^{122} \sum_{j=1}^{4} X_i C_{ij} \tag{2}$$

Subject to the constraint,

$$\sum_{i=1}^{122} D_i X_i \leq B \tag{3}$$

Where Di is the cost of the ith parcel and B is the total available budget.

The optimization as well as the Rank based selection was performed using a premium solver (Frontline System) based, MS Excel tool developed in house by Dr. Kent Messer.

Cecil County Green Infrastructure Plan:

The Conservation Fund has completed a green infrastructure plan for Cecil County, MD. Green infrastructure can be defined as "An interconnected network of natural areas (waterways, wetlands and forests), green space (parks, greenways and conservation lands), and working landscapes (farms, ranches and woodlands) that protect natural ecological processes, support wildlife and benefit people"5. The goal of the fund is to help Cecil County identify and protect its critical green infrastructure.

The green infrastructure consists of an interlinking series of hubs and corridors. In updating the green infrastructure network, the fund identified recent land use changes resulting in breakages and fragmentation of the older network. A new hub ranking scheme and new corridor connections (mainly north of the I-95 corridor) have been included to account and compensate for the changes resulting from development.

The fund has identified 122 parcels of land for acquisition into this network. The parcels have been assigned scores (0-100) for the following four biophysical attributes:

- GI Hub rank: Percentage of area of parcel that lies within the Green Infrastructure.
- Water Quality Model Score (WQMODEL): Represents the ability of the land parcel to provide clean water to the County.
- Reforestation Model Score (REFORMODEL): Represents protection and restoration opportunities in the land parcel.

- Ecosystem Services Score: Represents ability of the protected land parcel to provide ecosystem services to humans (especially large contiguous blocks of forests/wetlands).

The cost of the land parcels are based on the land value as well as an improvement value (for any structure that lies in the land parcel). The cost of each parcel is estimated to be twice that of the land value. The budgetary constraint was set at 10%, 25% and 50% of the total estimated value of the 122 parcels. ($5 million, $12.5 million and $25 million). Table 1 summarizes the Statistics of the 122 parcels.

Table 1 : Descriptive Statistics of the 122 land parcels

	ACRES	Land Value	GIHUBRANK	WQMODEL	REFORMODEL	ECO SERVE
Mean	609.11	411020	15.14	11.91	18.82	12.07
Standard Error	341.22	89866	1.86	1.11	0.81	0.91
Median	175.45	162330	0.00	7.00	20.00	10.00
Mode	109.44	246220	0.00	0.00	20.00	0.00
Standard Deviation	3768.86	992598	20.58	12.21	8.94	10.06
Kurtosis	111.50	45	-0.87	0.77	0.45	-0.65
Skewness	10.41	6	0.88	1.23	0.02	0.59
Range	40884.92	8820780	58.00	47.00	46.00	36.00
Minimum	100.08	32820	0.00	0.00	0.00	0.00
Maximum	40985.00	8853600	58.00	47.00	46.00	36.00
Count	122.00	122	122.00	122.00	122.00	122.00

It is noted that the parcel area as well as its land value are highly positively skewed (10.4 and 6 respectively). While parcels below 100 acres were not included in the data, it can be seen that the largest parcel is 40,985 acres, while the mean area is 609 acres and the smallest parcel is just over 100 acres. The average parcel land value is $411,020 with a minimum land value of $32,820 and a maximum land value of $8,820,780. The coefficients of variation for the parcel area and land value are high at 6.2 and 2.4 respectively. The biophysical attributes are normally distributed with very little skew. The maximum value for the GI Hub rank (% area within green infrastructure) is 58 while the minimum is 0. More than half of the land parcels have a GI Hub rank of 0 (median is zero).

Table 2 shows the correlation matrix of the land value and the biophysical attributes. Land value is positively correlated to GI hub rank (0.05), WQ model score (0.29) and Ecoservices score (0.24). It is negatively correlated to Reforestation model score. GI hub rank, WQ model score and Ecoservices score are positively correlated to one another with WQ model score and Ecoservices score being highly correlated (0.83). The Reforestation model score is negatively correlated with the other scores.

Table 2: Correlation matrix of land value and biophysical attributes

	LAND VALUE	GIHUBRANK	WQMODEL	REFORMODEL	ECOSERVE
LAND VALUE	1.00				
GIHUBRANK	0.05	1.00			
WQMODEL	0.29	0.42	1.00		
REFORMODEL	-0.17	-0.36	-0.74	1.00	
ECOSERVE	0.24	0.48	0.83	-0.62	1.00

Results:

The data described in the earlier section was used to run the rank based model as well as the binary linear programming based optimization model. The biophysical attributes were equally weighted. The attributes were also normalized by using a scheme shown below.

$$Z_{ij} = \frac{R_{ij} - R_j^{\min imum}}{R_j^{\max imum} - R_j^{\min imum}} \quad (4)$$

Where Zij represents the normalized value of the jth attribute (Rj) for the ith parcel .The budgets were set at 10%, 25% and 50% of the total value of the 122 parcels. ($5 million, $12.5 million and $25 million respectively out of a total value of approximately $50 million). The results are summarized in table 3 overleaf.

Table 3 : Land parcel selection - Rank based vs. BLP Optimization

Budget	Rank Based	Optimization	Rank Based	Optimization	Rank Based	Optimization
	Parcels	Parcels	Conservation Value	Conservation Value	Acres	Acres
$ 5,000,000	6 (5%)	50 (41%)	14.48 (9%)	82.4(54%)	2358(3%)	57601 (78%)
$ 12,500,000	26 (21%)	88 (72%)	56.13 (37%)	116.84 (76%)	7311 (10%)	66763 (90%)
$ 25,000,000	47(39%)	114 (93%)	92.59 (60%)	140.65 (92%)	10788 (15%)	72782 (98%)

It is clearly evident that the BLP based optimization model performs much better than the rank based model in terms of the conservation benefit values, area selected and number of parcels selected. At a $5 million budget, the Rank based method has a conservation value of only 14.48 (or 9% of total conservation value available) while the BLP optimization model yields a significantly higher conservation value of 82.4 (54%). In terms of acres protected, it is again evident that the BLP optimization model scores considerably higher (78% of available area is protected) as compared the rank based model (3% of available area protected).

The staggering difference in the two models at this budget level can be attributed to the selection of a single land parcel (parcel Id 97 in the dataset) by the rank based model. This parcel offers a high conservation value (the second highest value among the 122 parcels), but costs $4 million. This is consistent with the positive correlation observed earlier between the land value and the conservation benefit scores. The optimization model, however, has rejected this parcel and instead used the $4 million in selecting a lot more parcels (45 more) with a significantly higher aggregate conservation value and concomitantly protecting a larger area. This example clearly illustrates the efficiency of the BLP optimization method over the rank based model in maximizing conservation value at a comparable budget level.

Table 4 compares the ratio of BLP model over the rank based model for the number of parcels selected, conservation benefit value and the acreage protected.

Table 4 : BLP Optimization model over rank based model

Budget	BLP (times greater than) Rank based model		
	Parcels	Conservation Value	Acreage
$ 5,000,000	8.3	5.7	24.4
$ 12,500,000	3.4	2.1	9.1
$ 25,000,000	2.4	1.5	6.7

The BLP scores significantly over the rank based model at all the three budget levels compared. The greatest differences, however, is at the lowest budget level. The two models were then run for budget levels ranging from 5% to 100 % and the percentage of the conservation benefit values and the acres protected were calculated. The results are shown in fig.1, also known as the Lorenz curve. The curve clearly the shows the magnitude of the difference between the two models, especially at the lower budget levels.

The curve also reveals a wavy pattern for the rank based model. This illustrates the sub-optimality of the rank based methodology. This methodology is based on greedy style heuristics which solves one sub-problem after another iteratively while never reconsidering its choices. Thus, when more budgets become available, the model would choose a single expensive, albeit valuable land parcel, over the choices made at a lower budget level. The BLP model, on the other hand constantly strives to maximize the conservation value at an aggregate level while balancing between the budget levels at which it is constrained to operate and the conservation values of the parcels. The compromise of the BLP model works better overall than the greed of the rank based model.

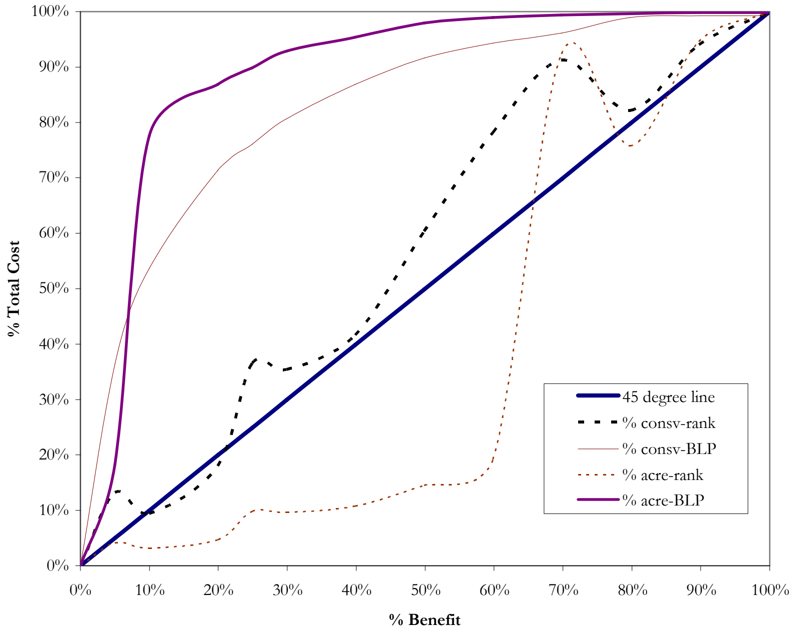


Figure 1 : Lorenz curve - rank based model vs. model

An alternative way of looking at the results is to calculate the minimum budget required for the BLP model that could provide the same aggregate level of conservation benefit values as compared to the rank based model at one of the earlier specified budget levels. This is easily done by setting the BLP model to be constrained by an aggregate conservation benefit value at a level greater than or equal to the value from the rank based model. The model is then run to minimize the budget that could achieve the desired conservation benefit value. The results are shown in table 5. The BLP model shows an impressive savings of $4.6 million over the rank based model at the same conservation benefit value of 14.48. Similar savings can be observed at higher budget levels.

Table 5 : Savings from BLP model at a given conservation benefit value

Rank based Model		BLP Model	
Budget	Conservation Value	Minimum Budget	Savings
$ 5,000,000	14.48	$ 395,520	$ 4,604,480
$ 12,500,000	56.13	$ 2,502,920	$ 9,997,080
$ 25,000,000	92.59	$ 6,293,280	$ 18,706,720

Conclusion:

It has been clearly demonstrated in the preceding section that the BLP optimization model efficiently and significantly maximizes the aggregate conservation benefits that the land parcels in Cecil County have to offer at varying budget levels. The conservation fund has created an implementation quilt that would enable it to match funding resources to the needs of the green infrastructure network in the County. In this context, especially at lower level of budgets as compared to the total available land value, the BLP model provides the best recommendation of land parcels to be purchased while ensuring a high level of conservation value. A sample recommendation of parcels to be purchased at a $2.5 million dollar level can be found in the appendix.

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Appendix

PARCELID	BLP-Selection	Conservation Value	Land Value	ACRES
1	0	0.0	0.0	0.0
2	0	0.0	0.0	0.0
3	0	0.0	0.0	0.0
4	1	2.2	72,780.0	135.4
5	1	1.4	32,820.0	109.4
6	0	0.0	0.0	0.0
7	1	2.1	61,260.0	181.5
8	0	0.0	0.0	0.0
9	0	0.0	0.0	0.0
10	0	0.0	0.0	0.0
11	0	0.0	0.0	0.0
12	1	2.1	50,900.0	104.4
13	1	1.7	113,240.0	151.0
14	0	0.0	0.0	0.0
15	0	0.0	0.0	0.0
16	0	0.0	0.0	0.0
17	0	0.0	0.0	0.0
18	0	0.0	0.0	0.0
19	0	0.0	0.0	0.0
20	0	0.0	0.0	0.0
21	0	0.0	0.0	0.0
22	0	0.0	0.0	0.0

23	0	0.0	0.0	0.0
24	0	0.0	0.0	0.0
25	0	0.0	0.0	0.0
26	0	0.0	0.0	0.0
27	0	0.0	0.0	0.0
28	0	0.0	0.0	0.0
29	0	0.0	0.0	0.0
30	0	0.0	0.0	0.0
31	1	2.0	110,020.0	176.1
32	0	0.0	0.0	0.0
33	0	0.0	0.0	0.0
34	1	2.1	80,940.0	113.6
35	0	0.0	0.0	0.0
36	0	0.0	0.0	0.0
37	0	0.0	0.0	0.0
38	0	0.0	0.0	0.0
39	0	0.0	0.0	0.0
40	0	0.0	0.0	0.0
41	1	2.4	112,500.0	250.0
42	0	0.0	0.0	0.0
43	0	0.0	0.0	0.0
44	0	0.0	0.0	0.0
45	0	0.0	0.0	0.0
46	0	0.0	0.0	0.0
47	0	0.0	0.0	0.0
48	0	0.0	0.0	0.0
49	0	0.0	0.0	0.0
50	0	0.0	0.0	0.0
51	0	0.0	0.0	0.0
52	0	0.0	0.0	0.0
53	0	0.0	0.0	0.0
54	0	0.0	0.0	0.0
55	0	0.0	0.0	0.0
56	1	2.2	88,200.0	235.2
57	1	1.8	96,260.0	132.8
58	0	0.0	0.0	0.0
59	0	0.0	0.0	0.0
60	0	0.0	0.0	0.0
61	1	2.4	105,560.0	105.6
62	0	0.0	0.0	0.0

63	1	1.9	85,900.0	180.9
64	0	0.0	0.0	0.0
65	0	0.0	0.0	0.0
66	1	2.1	53,020.0	101.0
67	1	2.0	122,400.0	306.0
68	1	2.3	147,800.0	193.9
69	0	0.0	0.0	0.0
70	0	0.0	0.0	0.0
71	0	0.0	0.0	0.0
73	0	0.0	0.0	0.0
74	0	0.0	0.0	0.0
75	0	0.0	0.0	0.0
76	0	0.0	0.0	0.0
77	0	0.0	0.0	0.0
78	1	1.4	88,100.0	113.7
79	0	0.0	0.0	0.0
80	0	0.0	0.0	0.0
81	0	0.0	0.0	0.0
82	0	0.0	0.0	0.0
83	0	0.0	0.0	0.0
84	0	0.0	0.0	0.0
85	0	0.0	0.0	0.0
86	1	1.2	79,440.0	122.2
87	1	1.6	87,880.0	146.5
88	0	0.0	0.0	0.0
89	0	0.0	0.0	0.0
90	1	1.1	59,620.0	106.0
91	0	0.0	0.0	0.0
92	0	0.0	0.0	0.0
93	0	0.0	0.0	0.0
94	0	0.0	0.0	0.0
95	1	1.9	67,400.0	158.6
96	0	0.0	0.0	0.0
97	0	0.0	0.0	0.0
98	0	0.0	0.0	0.0
99	0	0.0	0.0	0.0
100	1	0.8	60,000.0	8,712.0
101	1	2.3	91,060.0	364.3
102	0	0.0	0.0	0.0
103	0	0.0	0.0	0.0

104	0	0.0	0.0	0.0
105	0	0.0	0.0	0.0
106	1	2.0	85,500.0	342.0
107	1	1.1	36,680.0	104.9
108	1	1.6	101,060.0	175.8
109	0	0.0	0.0	0.0
110	0	0.0	0.0	0.0
111	0	0.0	0.0	0.0
112	0	0.0	0.0	0.0
113	1	1.1	78,300.0	104.4
114	0	0.0	0.0	0.0
115	1	1.5	51,280.0	100.1
116	1	1.8	47,360.0	108.3
117	0	0.0	0.0	0.0
118	1	1.5	94,980.0	185.4
119	0	0.0	0.0	0.0
120	1	1.4	38,800.0	100.1
121	1	1.7	38,580.0	102.9
122	0	0.0	0.0	0.0
123	1	1.2	54,800.0	104.4

Improving the Efficiency and Effectiveness of the U.S. Forest Legacy Program

Stela Stefanova

Introduction

The U.S. Forest Legacy Program (FLP) is a federal voluntary program that is designed to support States in their effort to protect environmentally sensitive, privately owned forests by acquiring partial ownership of the forest land. The goal of FLP is to maximize the public benefits of resource conservation. This is study is an effort to evaluate and improve the efficiency of FLP. Operation research techniques are used to maximize the benefits of conservation for the least possible costs. The results are then compared to the rank-based approach of project selection, which is the most commonly used selection method by conservation organizations.

The conservation values of parcels are defined as the average value of the scores provided by a panel of 10 experts with the highest and lowest scores dropped to alleviate potential biases resulting from the use of averages. State representatives are not allowed to rate their own projects, however, if state representatives rates consistently low or consistently high they will skew the scores for the projects they ranked relatively to their own project for which they do provide values.

To evaluate the role of using “cost share” as a means for obtaining greater efficiency of the Program, two cases with different definitions for the project costs are compared. In the analysis of the first case the variable “total project costs” measures the costs. In the second case the variable “funding request” is used, which is calculated as the difference between total project costs and the cost share.

The analysis in this study is based on a budget of $53 million.

Project Selection Algorithms

Traditional rank based selection algorithm

This selection approach ranks the parcels according to their benefits. The parcel that yields the highest benefit ranks first. The parcel that yields the lowest benefit ranks last. The Agent selects the parcels with the highest ranks as long as the parcels' costs are within the remaining budget. The selection ends with the budget's exhaustion. This is the method used by FLP.

Column 2 and 3 in Tables 1 below present the projects recommended for finding using the traditional rank-based selection method. Column 2 contains the parcels recommended for conservation if all project costs are paid by FLP. That is, total project costs are used as a measure for costs assuming that "cost share" is not an option. Column 3 lists the parcels recommended if owners make a "cost share" commitment. In this case the cost considered in the selection mechanism is the funding request by the owners rather than the full project cost. As evidenced by the recommended projects' statistics, presented in Table 2, the use of "cost share" helps the Forest legacy program obtain higher efficiency for its monies.

As expected, the commitment to "cost share" by the owners of the land helps FLP achieve higher aggregate conservation benefits – 25.1% of the total benefits compared to 11.7% when the Agency pays the whole cost. The "cost share" program leads to contracting more parcels (19 compared to 9), conserving more acres (218,833 compared to 154,673) and having more states with funded projects with New Hampshire receiving funding for more than one project. If the Agency shares the costs of conservation, it can obtain more benefits per dollar spent as indicated by the higher benefit to cost ratio (22.7 compared to 13.95).

To evaluate the effect of the definition of the benefits, project ratings were scaled to the size of the parcel. That is, the ratings were redefined to be on a "per acre" basis instead of a "per project basis". Column 4 and Column 5 in Table 1 show the recommended parcels after the scaling of the rankings with and without the “cost share” option. There is a significant change in the funding recommendations after the size of the parcel is taken into account.

Table 3 summarizes some characteristics of the selected parcels from Column 4 and 5. There is not a big change in the number of parcels selected when benefits are scaled per acre compared to the number of parcels selected on the basis of benefits per project. However, the scaled benefits approach achieves a higher number of acres protected and a higher benefit to cost ratio regardless of the funding options.

Binary Linear Programming Algorithm

Using the same cost and benefit definitions as with the traditional rank based algorithm, an optimization algorithm is used to select projects for funding from the FLP. The binary linear programming algorithm for project selection takes into account the costs of potential parcel purchases. It identifies the parcels that would contribute to achieving the maximum total benefit with the allocated budget. In contrast to this optimization method, the traditional rank-based approach selects the parcels with the largest individual benefits and does not guarantee the maximum total benefit for the same cost. Column 6 and 7 in Table 1 present the recommended parcels with and without the option for cost share when the benefits ratings are considered “per project”.

Table 4 shows the summary statistics of the selected parcels using the binary linear programming algorithm when the benefits are per project using the $53 million budget for all parcels. The optimization routine yields higher benefits, higher number of parcels funded and less states without a funded project when compared to the traditional method used by FLP. Column 8 and 9 in Table 1 below present the recommended parcels with and without the option for cost share when the benefits ratings are scaled for the size of the parcel and defied “per acre”.

Table 5 shows the summary statistics of the selected parcels using the binary linear programming algorithm when the benefits are per acre using the $53 million budget for all parcels. The optimization algorithm with scaled benefits yields the highest values for total benefits, protected acreage, and states with a funded project among all algorithms and specifications in this study.

Conclusion

Based on the analysis presented above, I recommend using the binary linear programming method to determine selected projects. The binary linear programming takes into account both the benefits and the costs of a parcel and selects the parcels that would yield the highest aggregate "average score" or conservation value within the specified budget of $53,000,000. Using this algorithm and "cost share" the FLP can achieve 3,024 in aggregate "average benefits". This is the highest value aggregate benefit values obtained in the study.

Table 1: Recommended parcels using different strategies

	Total Project Cost	Funding Request	Total Project Costs with Benefits Scaled per Acre	Using funding Request with Benefits Scaled per Acre	Total Costs with Benefits per Project Using BLP (Binary Linear Programming)	Funding Request with Benefits per Project Using BLP	Total Project Costs with Benefits per Acre Using BLP	Funding Request with Benefits per acre Using BLP
AK-1				X				
AL-1					X	X		
AR-1						X		
AS-1	X	X			X	X		
AZ-1			X		X	X		
CA-1	X	X		X				X
CA-2								
CO-1		X						
CT-1					X	X		

CT-2								
CT-3					X	X		
DE-1								
FL-1						X		
FL-2						X		
GA-1		X		X				X
GA-2						X		
HI-1					X	X		
IA-1					X	X		X
ID-1					X	X		
IL-1					X	X		
IL-2								
IN-1					X	X		
IN-2					X	X		
IN-3					X	X		
KY-1								
LA-1								
MA-1	X	X						
MA-2					X	X		
MA-3					X	X		
ME-1	X	X	X	X			X	X
ME-2			X	X			X	X
MI-1		X	X	X		X	X	X
MN-1	X	X	X	X			X	X
MN-2								
MN-3					X			
MO-1								
MO-2								
MS-1								
MT-1				X				X
MT-2								
MT-3		X			X	X		
NC-1								
NC-2					X	X		
NC-3					X	X		
NE-1		X	X	X	X	X	X	
NH-1		X				X		
NH-2		X		X				X
NH-3				X	X	X		X
NJ-1								
NM-1								
NM-2				X				
NY-1					X	X		
NY-2								
OH-1								

OH-2	X	X			X	X	X	
OR-1						X		
OR-2				X		X		X
PA-1								
PA-2					X	X		
PA-3	X	X						
PR-1					X	X		
RI-1					X	X		
SC-1								
TN-1								
TN-2					X	X		
TN-3				X		X		X
TX-1	X	X			X	X	X	X
USVI-1					X	X		
UT-1		X						
UT-2								
VA-1	X	X			X	X		
VA-2					X	X		
VA-3								X
VT-1			X	X	X	X	X	X
VT-2					X	X		X
VT-3					X	X		
WA-1								
WA-2								
WA-3					X	X		
WI-1			X	X			X	X
WI-2			X	X		X	X	X
WI-3		X		X	X	X		X
WV-1		X						
WV-2					X	X		
WV-3								

Table 2: Summary of recommended parcels.

	Total cost		With "cost share"	
	Value	**% of total**	**Value**	**% of total**
Parcels	9	10.8%	19	22.9%
Aggregate "Average score"	670	11.7%	1435	25.1%
Acres Protected	154,673	40.2%	218,833	56.9%
Mean "Average score"	74.5		75.5	
Number of states w/o funded projects	35		26	
Number of states w multiple projects	0		1	
Benefit/Cost ratio	13.95		22.7	
Cost to Agency	$52,886,060		$52,966,070	

Table 3: Summary of selected parcels using total project cost and funding request with benefits scaled "per acre"

	Total Cost		With "Cost Share"	
	Value	**% of total**	**Value**	**% of total**
Parcels	9	10.8%	18	21.7%
Aggregate "Average Score"	664	11.6%	1317	23.0%
Acres Protected	224,812	58.4%	299,413	77.8%
Mean "Average Score"	73.8		73.2	
Number of states w/o funded projects	37	84.1%	30	68.2%
Number of states w multiple projects	2	4.5%	14	31.8%
Mean Scaled Benefit/Cost ratio	47.19		37.43	
Cost to Agency	$52,984,975		$52,912,892	

Table 4: Summary of selected parcels using total project cost and funding request with per project benefits using binary linear programming

	Total Cost		With "Cost Share"	
	Value	**% of total**	**Value**	**% of total**
Parcels	36	43.4%	45	54.2%
Aggregate "Average score"	2386	41.7%	3024	52.8%
Acres Protected	31,521	8.2%	100,975	26.3%
Mean "Average score"	66.3		67.2	
Number of states w/o funded projects	16		12	
Number of states w multiple projects	6		11	
Cost to Agency	$52,592,151		$52,898,650	

Table 5: Summary of selected parcels using total project cost and funding request with per acre benefits using binary linear programming

	Total Cost		With "Cost Share"	
	Value	**% of total**	**Value**	**% of total**
Parcels	10	12.0%	20	24.1%
Aggregate "Average score"	714	12.5%	1436	25.1%
Acres Protected	224,932	58.5%	300,781	78.2%
Mean "Average score"	71.4		71.8	
Number of states w/o funded projects	36	81.8%	29	65.9%
Number of states w multiple projects	2	4.5%	4	9.1%
Cost to Agency	$52,928,958		$52,996,136	