FINAL PROJECT REPORT

Combining a Pairwise Comparison Approach and Statistical Analysis to Guide Land Conservation in the Northern Neck, Virginia

Prepared for the project ending December 31, 2006

Submitted by:

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Executive Summary

The goal of this study was to aid the National Park Service Chesapeake Bay Watershed Assistance Program in land conservation activities for the Northern Neck of Virginia. The work focused on helping to develop information for a conservation strategy to protect the unique natural and historical heritage of the Northern Neck. This included identifying the most important landscape features for conservation and to integrate local stakeholders and their preferences for the features they want to protect. A form of pairwise comparison – the analytical hierarchy process was integrated into a survey to evaluate preferences for conservation objectives and criteria. The Watershed Assistance Program administered this survey to key personnel and decision makers. Results indicated that the most important objectives for land conservation in the Northern Neck were to protect Ecological Lands (.438), followed by Agricultural Lands (.341), and Areas with Unique Historical Sites and Communities (.222). A second part of the survey was used to characterize criteria for these objectives on the landscape. The criteria and their associated importance for land conservation included; Waterfront Lands (.168), Water Quality (.166), Non-tidal and Tidal Wetlands (.151), Century Farms (.127), Working Farmlands (.090), Rural Lands (.080), Prime Farmland Soils (.078), Scenic Resources (.073), and Upland Terrestrial (.068). Statistical tests for consistency (Saaty, 1980) were performed on each survey to give credence to the weights. The preference weights can now be used by the Watershed Assistance Program with spatial data layers within a geographic information system (GIS) to find areas most suitable to target for conservation activities.

The following sections in this final report detail the deliverables for each of the project tasks.

Task # 1 Develop a Pairwise Comparison Survey

The purpose of the pairwise comparison survey was to allow participants to easily compare and provide preferences for the conservation objectives and criteria. To derive preference weights for the objectives and criteria, I used the Analytical Hierarchy Process (AHP) as the solicitation technique in this study. The choice of AHP was based on the following reasons:

- The AHP method allows for many criteria to be simplified to individual comparison choices.
- The time constraints required each participant to take the test (i.e. perform comparisons) at the same time. AHP could be administered as an individual test.
- AHP has one of the strongest theoretical foundations and the ability to easily incorporate the normalized weights into a GIS ranking model.
- The availability of AHP software made calculations easy and provided many display tools to quickly view results.
- Group and individual comparisons could be made to identify trends and potential trade offs.

As in Duke and Aull-Hyde (2003), this study extended the use of AHP from a single decision maker to a group of N people. Because of this, the geometric mean is used in place of individual ratings. Obviously it was not possible to sample all residents interested in land conservation in the Northern Neck. Therefore the issue is not whether there are enough samples to use AHP but whether there are enough samples to accurately represent the area's residents.

The following AHP conceptual model is adopted in form and notation from Duke and Aull-Hyde (2003), Kangas (1994), and Triantaphyllou and Mann (1989). The hierarchy used in this study consisted of three main land conservation objectives. From the objectives, criteria were defined and assembled as one matrix for participants to perform pairwise comparisons. The matrix can take the following form:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix}$$

where a_{mn} is the pairwise comparison rating for criterion m and criterion n. For the pairwise comparisons, Duke and Aull-Hyde (2003) and Saaty (1987) note the axioms of theoretical validity of the comparison matrix A:

- Reciprocal comparison: If $a_{mn} = x$, then $a_{nm} = 1/x$ where $x \neq 0$.
- Homogeneity: If characteristics m and n are judged to be of equal relative importance then, $a_{mn} = a_{nm} = 1$ for all m.
- Independence: When expressing preferences under each criterion, each criterion is assumed to be independent of the properties of the decision alternatives.
- Expectations: When proposing a hierarchal structure for a decision problem, the structure is assumed to be complete.

The a_{mn} values represent the relative degree of importance of criterion m over criterion n. To combine the responses, the geometric mean has been proven to be an effective method to calculate an overall rating (Benjamin et. al, 1992; Schmoldt et al. 1994). With a survey of p respondents, a composite judgment of their a_{mn} values, is the geometric mean of the a_{mn} values which is defined as

$$a^*_{mn} = \sqrt[p]{\prod_{k=1}^{p} a^k_{mn}}$$

With the geometric averaged a*mn values, a set of numerical weights w1, w2, … wi may be computed to represent the relative degree of importance assigned to each criterion. The numerical weights sum to 1, a useful outcome when combining the spatial data layers in a GIS (Eastman, 1995).

Using the complete list of criteria, a survey was administered to each individual. In order to minimize problems with path dependency (Saaty, 1987), the criteria were presented to participants in a randomly ordered format. All possible pairings of the criteria are presented to the participant. Consistency ratios, as measures of consistent (transitive) preferences, are used to verify that each participant did not randomly enter information.

A relative importance scale for measuring intensity of preferences was used in this survey. However, we employed a reduced form of the traditional nine nominal values to reduce the cognitive burden of participants. I used a crosswalk of the nine traditional values to the four intensity of preference nominal values used in the survey, including “equal, “somewhat prefer”, “prefer”, and “strongly prefer”. Figure 1 below shows an example of the abbreviated pairwise survey used in this study.

Figure 1. Traditionally pairwise intensities and simplified choices used in this study:

Traditional pairwise intensities	Simplified choices [1]
Equal	Equal
Barely prefer	
Weakly prefer	Somewhat prefer
Moderately prefer	
Definitely prefer	
Strongly prefer	Prefer
Very strongly prefer	
Critically prefer	
Absolutely prefer	Strongly prefer

[1]The simplified choices were used in this study based on the difficulty test respondents experienced in distinguishing between intensities with the nine point traditional scale. The four point scaling system was adopted to reduce the cognitive burden.

The participants in this study were treated as the decision makers. Their aggregated individual weights would serve as the criteria weights for the analysis. Traditionally, AHP is applied on a single decision maker or a small decision making group. The participants in this study represent a small, but not random, sample of stakeholders.

The administered survey for the objectives and criteria are shown in Figures 2 and 3.

Figure 2. Survey for Land Conservation Objectives

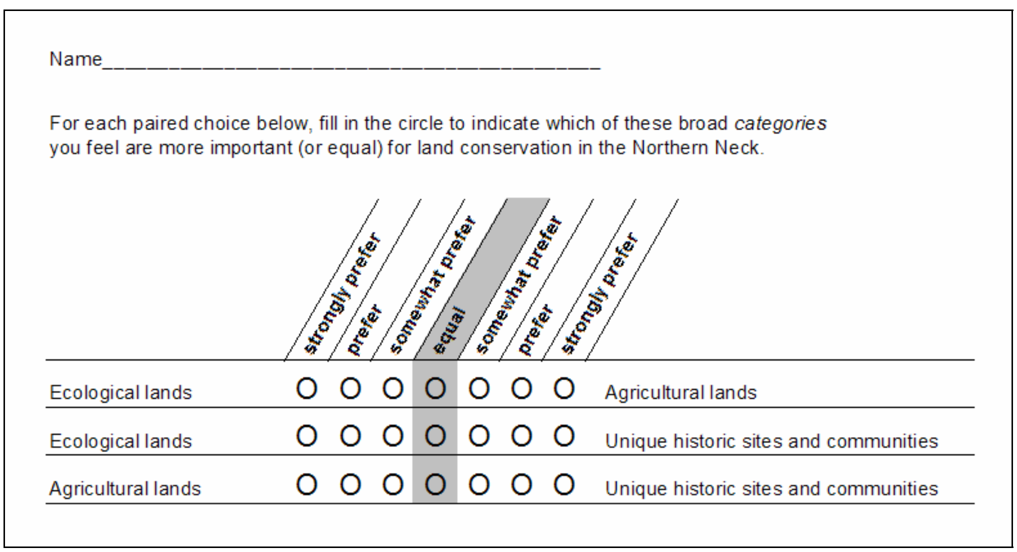

Figure 3. Survey for Land Conservation Criteria

Name____

For each paired choice below, fill in the circle to indicate which of these *criteria* you feel are more important (or equal) for land conservation in the Northern Neck.

	strongly prefer	prefer	somewhat prefer	equal	somewhat prefer	prefer	strongly prefer	
Working farmlands	O	O	O	O	O	O	O	Prime farmland soils
Working farmlands	O	O	O	O	O	O	O	Upland terrestrial
Working farmlands	O	O	O	O	O	O	O	Non-tidal and tidal wetlands
Working farmlands	O	O	O	O	O	O	O	Century farms
Working farmlands	O	O	O	O	O	O	O	Water quality
Working farmlands	O	O	O	O	O	O	O	Waterfront lands
Working farmlands	O	O	O	O	O	O	O	Scenic resources
Working farmlands	O	O	O	O	O	O	O	Rural lands
Prime farmland soils	O	O	O	O	O	O	O	Upland terrestrial
Prime farmland soils	O	O	O	O	O	O	O	Non-tidal and tidal wetlands
Prime farmland soils	O	O	O	O	O	O	O	Century farms
Prime farmland soils	O	O	O	O	O	O	O	Water quality
Prime farmland soils	O	O	O	O	O	O	O	Waterfront lands
Prime farmland soils	O	O	O	O	O	O	O	Scenic resources
Prime farmland soils	O	O	O	O	O	O	O	Rural lands
Upland terrestrial	O	O	O	O	O	O	O	Non-tidal and tidal wetlands
Upland terrestrial	O	O	O	O	O	O	O	Century farms
Upland terrestrial	O	O	O	O	O	O	O	Water quality
Upland terrestrial	O	O	O	O	O	O	O	Waterfront lands
Upland terrestrial	O	O	O	O	O	O	O	Scenic resources
Upland terrestrial	O	O	O	O	O	O	O	Century farms
Upland terrestrial	O	O	O	O	O	O	O	Water quality
Upland terrestrial	O	O	O	O	O	O	O	Waterfront lands
Upland terrestrial	O	O	O	O	O	O	O	Scenic resources
Upland terrestrial	O	O	O	O	O	O	O	Rural lands
Non-tidal and tidal wetlands	O	O	O	O	O	O	O	Century farms
Non-tidal and tidal wetlands	O	O	O	O	O	O	O	Water quality
Non-tidal and tidal wetlands	O	O	O	O	O	O	O	Waterfront lands

Non-tidal and tidal wetlands	O	O	O	O	O	O	O	Scenic resources
Non-tidal and tidal wetlands	O	O	O	O	O	O	O	Rural lands
Century farms	O	O	O	O	O	O	O	Water quality
Century farms	O	O	O	O	O	O	O	Waterfront lands
Century farms	O	O	O	O	O	O	O	Scenic resources
Century farms	O	O	O	O	O	O	O	Rural lands
Water quality	O	O	O	O	O	O	O	Waterfront lands
Water quality	O	O	O	O	O	O	O	Scenic resources
Water quality	O	O	O	O	O	O	O	Rural lands
Waterfront lands	O	O	O	O	O	O	O	Scenic resources
Waterfront lands	O	O	O	O	O	O	O	Rural lands
Scenic resources	O	O	O	O	O	O	O	Rural lands

Task #2 Collect Data from Surveys and Enter into Appropriate Analysis Software

Criterium Decision Plus (Info Harvest, 2000) software was used to summarize the pairwise comparisons from each participant. Criterium Decision Plus provided a complete ranking of criteria with preference weights. The software also allowed for tests of consistency. A consistency vector is computed and a consistency index using the notation below.

λ = the average of the consistency vector
N = number of criteria

Consistency Index (CI) = $(\lambda - N) / (N - 1)$

With the consistency index (CI) we can now use the random index (RI) (Figure 4) to compute the consistency ratio (CR) (Saaty, 1987, p 186).

Figure 4. Random Index Table from Saaty (1987)

Number of criteria	RI
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32

8	1.41
9	1.45
10	1.49
11	1.51
12	1.48
13	1.56
14	1.57
15	1.59

The constancy ratio (CR) is found by

CR = CI/RI

The consistency ratio can be interpreted as if CR < 0.100 then there is consistency in responses. Otherwise, there is too much variance in the pairwise responses to use in the geometric mean calculation and they should be omitted.

Task #3 Intra Group Comparisons Using the Geometric Mean

The weights from the AHP test were analyzed to determine if the individuals could be grouped based on their affiliations, and if so, whether the groups' preferences were substantially different from each other and on which criteria they differed. If the variation in individual responses is too great within a group, the median value should not be used to represent the group (Bantayan and Bishop, 1998).

We defined the groups based on participants' affiliation. Friedman's Q statistic (a nonparametric, two-way analysis of variance by ranks statistic) (Seigel, 1954) is used to test for statistical differences of preference weights. Bantayan and Bishop (1998) applied this statistic to test for intra-group differences among their decision makers. The null hypothesis for the intra-group comparisons states that the preferences of members *i* in a group (*y*) represent a population (P_y). The alternative hypothesis states that intra-group members are not from the same population (i.e., preferences significantly differ across the group members). Formally, this hypothesis test may be written as:

$H_0: y_i = P_y \qquad \forall\ i \in P_y$

$H_1: y_i \neq P_y \qquad \forall\ i \in P_y$

The inter-group comparisons test whether the preferences comprising a group (P_y or P_z) are from the same population P. Formally, this hypothesis test can be written as:

H_0: $P_y = P_z$ $y_i \in P_y$; $z_i \in P_z$; $y \neq z$

H_1: $P_y \neq P_z$ $y_i \in P_y$; $z_i \in P_z$; $y \neq z$.

The inter-group comparisons are restricted to the pairs of residents. Membership in a group is mutually exclusive within the inter-group comparisons.

Friedman's Q statistic is:

$$Q = 12/[Nk(k+1)] * \sum_{i=1}^{k} R_i^2 - 3N(k+1)$$

where N is the number of individuals, k is the number of criteria and R_i^2 is the square of the rank sum associated with the kth criterion (Seigel, 1954). Friedman's Q statistic is distributed as a Chi-squared with k-1 degrees of freedom. The data for the equation are extracted from the ranks of the criteria among the participants. The ranks were adjusted for ties by performing the RANK function option in EXCEL (Microsoft, 2002).

Friedman's Q statistics provide information on whether group members comprise a homogeneous unit or group and whether the groups differ from each other. However, the statistic does not provide information on which criteria the group members' preferences may differ. Therefore, the nonparametric Mann-Whitney U test is used to test for statistical differences of preference weights for each criterion across groups (Kachigan, 1986; Seigel, 1954). The null hypothesis of states that the aggregated preference weight for individuals i in group y are equal to the aggregated preference weight for individuals i in group z for criterion k. The alternative hypothesis states they are not equal.

H_0: $w^k_{iy} = w^k_{iz}$ $\forall\ i \in (y,z)$; $y \neq z$

H_1: $w^k_{iy} \neq w^k_{iz}$ $\forall\ i \in (y,z)$; $y \neq z$.

The Analyse-IT (General and Clinical Labs, 1997) software for Microsoft Excel aided computation of the Mann-Whitney U statistics.

Task #4 Results of Pairwise Comparison Survey

The results of this study were surprisingly different than that found by Duke and Aull-Hyde (2003) and Strager and Rosenberger (2006). Unlike the other studies, the variation of individual responses was not statistically different across criteria and the geometric mean could be used to summarize the group response using all the individuals. One reason for this result could be attributed to a smaller more homogenous group of survey participants who shared interests and needs for conservation. Another reason could be that the participants were directly aware of the reason why the objectives and criteria were included in the study because they helped to define them from the beginning. A third reason may be the presentation by the Chesapeake Bay Watershed Assistance

Program which described and outlined the reasons for including each objective and criteria (see powerpoint presentation accompanying this report).

Results indicated that the most important objectives for land conservation in the Northern Neck were to protect Ecological Lands (.438), followed by Agricultural Lands (.341), and Areas with Unique Historical Sites and Communities (.222). A second part of the survey was used to characterize criteria for these objectives on the landscape. The criteria and their associated importance for land conservation included; Waterfront Lands (.168), Water Quality (.166), Non-tidal and Tidal Wetlands (.151), Century Farms (.127), Working Farmlands (.090), Rural Lands (.080), Prime Farmland Soils (.078), Scenic Resources (.073), and Upland Terrestrial (.068). The information is summarized in the table below for easier viewing.

Land Conservation Objective	Preference Weight
Ecological Lands	.438
Agricultural Lands	.341
Areas with Unique Historical Sites and Communities	.222
	=====
	1.000
Land Conservation Criteria	**Preference Weight**
Waterfront Lands	.168
Water Quality	.166
Non-tidal and Tidal Wetlands	.151
Century Farms	.127
Working Farmlands	.090
Rural Lands	.080
Prime Farmland Soils	.078
Scenic Resources	.073
Upland Terrestrial	.068
	======
	1.000

The full utility of these preference weights will be realized when the Chesapeake Bay Watershed Assistance Program combines them with spatial data layers in a GIS for identifying and prioritizing areas for conservation opportunities. Some recommendations offered at this time include the following:

1. When combining the data, consider a compromise programming framework as compared to a simple linear weighted function.
2. Focus on lands with a high degree of multifunctional characteristics. For example, a highly rated landscape area because of a few highly rated criteria may be scored the same as another landscape area with many low weighted criteria. In this case it may be worthwhile to reward areas that have many multifunctional characteristics that would appease more people.
3. Try to accurately capture size and function of the landscape areas depending on their intended use. For example, the size of tidal wetland areas may be much

smaller than the area that occupies a working farmland. Area weighted prioritization is difficult by could be used as a proxy.

4. Try to identify spatial features as objectively as possible. What is a scenic resource to one person may be entirely different to another.
5. Try to aggregate criteria when necessary to help simplify the data collection process.
6. Be careful of the maximum number of combined spatial datasets and the impacts on mapping accuracy. See Chrisman (1987) and Huevelink et al. (1987) for additional information.
7. Above all remember that this is a process and should be used to learn more about the spatial features and how they compare to help guide conservation. One approach may be to determine how conservation area priorities change if weights are adjusted. The spatial sensitivity of conservation areas can also be used to find priority areas that have the most consensus.

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