ANALYSIS OF ROAD LOCATIONS IN WETLANDS AND MITIGATION BANK DEVELOPMENT

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ABSTRACT.—The problem posed is to create a spatial analysis tool that will allow transportation planners to minimize road impacts to wetlands while maximizing mitigation returns. Using a regional wetland rating system, we incorporated wildlife habitat, nonpoint source pollution reduction, and floodwater storage functions into a mixed integer formulation to determine an optimal combination of mitigation sites. These functions will be driven by a geographic information system. A lack of quantitative data and meeting regulatory requirements are the two issues of concern when developing wetland models.

INTRODUCTION

The purpose of our work is to find a way to improve the transportation planning process by including wetland functions in a spatial analysis tool. Wetlands are a part of the natural landscape that have been the subject of countless scientific and legislative debates. Evolving from these debates, federal and state policies require that impacts to or degradation of a wetland be mitigated for, meaning that wetland losses must be replaced. Transportation improvements and construction impact wetlands when projects intrude into low-lying, flat areas, making transportation agencies one of the largest destroyers of wetlands (Anonymous 1994). The process of mitigation can be *ad hoc*, in that there is no good tool for finding possible mitigation sites where the wetland replacement is based on functions instead of acreages. Wetland functions are the ecological processes that occur in these systems. For example, the ability of a wetland to provide nesting habitat for waterfowl is a function. Groundwater recharge, pollutant removal, and floodwater storage are other wetland functions. These functions should not be used as synonyms for wetland values, that is, the importance that society assigns to wetland functions. A wetland may play a large part in removing sediment and pollutants from a city's water supply, and therefore be valuable to the city. However, wetlands with the same functions but not directly affecting the water supply may not be as valuable to the city.

Wetlands were once pervasive in the coastal plain of North Carolina but draining and development have converted many sites to agricultural fields, pine plantations, road corridors, and urban areas. Because the societal and ecological values of wetlands have been emphasized in recent decades, there is a desire to better protect existing wetlands. Population growth, which requires larger transportation systems, heightens the impact of humans on the environment. Wetland restoration is the primary method by which road impacts are mitigated. Wetland restoration is simply taking an area that was once a wetland but has been developed and converting it back to a wetland. This may require restoring vegetation, hydrology, and some soil characteristics to pre-disturbance levels, if possible.

The North Carolina Department of Environmental Health and Natural Resources' Division of Coastal Management (DCM) has developed a wetland mapping and functional assessment initiative for the twenty coastal counties within their jurisdiction (Sutter and Wuenscher 1997). This assessment method, titled North Carolina Coastal Region Evaluation of Wetland Significance (NC-CREWS), is a procedure based on spatial data layers contained in a geographic information system (GIS). This paper looks at the development of wetland function models using NC-CREWS parameters, which will be linked to existing GIS databases developed by DCM. This tool will allow

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transportation planners to quickly analyze alternative road corridors, the accompanying impacts to wetlands, and possible sites to mitigate these impacts.

DESCRIPTION OF THE MODEL

NC-CREWS Functions

NC-CREWS looks at a variety of wetland functions, but only three will be considered in this first version of the model. Each function has a series of parameters that are combined to give each wetland unit in the GIS an overall rating for each function. The wetlands are rated High, Medium, or Low for the function being considered. The functions considered here are terrestrial wildlife habitat, nonpoint source pollution reduction, and floodwater storage.[2] The database developed by DCM contains these ratings for existing wetlands. Because the model looks at land units that could be converted to wetlands, these ratings must be calculated for each combination of land units chosen as alternatives satisfying the constraints.

Terrestrial Wildlife Habitat

This function is rated on the quality of habitat provided for terrestrial wildlife. The parameters considered are interior size, percent surrounding habitat that is natural vegetation, and the length of a wildlife corridor that links to other natural vegetation. To calculate interior habitat, a 100 meter buffer zone around the perimeter is subtracted from the total area (Sutter and Wuenscher 1997). The rating strategy for wildlife habitat parameters is shown in Table 1.

Table 1. —Ratings assigned to wildlife habitat parameters

Parameter	High Rating	Medium Rating	Low Rating
Interior Size	> 74 acres	0–74 acres	None
Surrounding Habitat	> 50% wetlands	< 50% wetlands	Isolated from other wetlands
Wildlife Corridor	> 600 feet	< 600 feet	Isolated from natural habitat

Nonpoint Source Pollution Reduction

Three parameters of the nonpoint source rating system were considered. First, the proximity to agriculture, developed land, pine plantation, and natural vegetation are considered using the percent of surrounding habitat as the criteria. Second, the distance from a water source is used. Third, the position of the wetland relative to stream orders is used. Table 2 summarizes the rating scheme.

[2] All functions and parameters are taken from the NC-CREWS manual by Sutter and Wuenscher, 1997.

Table 2. —Ratings assigned to nonpoint source pollution parameters

Parameter	High Rating	Medium Rating	Low Rating
Proximity to sources	> 50% perimeter agriculture + developed	> 50% perimeter agriculture + developed + pine plantation	> 50% perimeter natural vegetation
Distance to water source	Within 300 ft. of Permanent source	Within 300 ft. of intermittent stream	> 300 ft. from permanent or intermittent source
Wetland position	Intermittent or 1st order stream	2nd or 3rd order stream	Higher than 3rd order stream

Floodwater Storage

The position of the wetland in the landscape, the duration of flooding, and the width of the wetland perpendicular to the stream are the parameters considered for rating the floodwater storage capacity of a wetland. Table 3 summarizes floodwater storage rating criteria.

Table 3.—Ratings assigned to floodwater storage parameters

Parameter	High Rating	Medium Rating	Low Rating
Position in landscape	> 25% stream bordered by developed land	5–25% stream bordered by developed land	<5% stream bordered by developed land
Duration of flooding	Long to very long	Brief	Very Brief
Width of wetland perpendicular to stream	> 100 feet	50–100 feet	< 50 feet

Methods and Assumptions

To make the NC-CREWS rating method work in a model, values had to be assigned to the rankings of High, Medium, and Low. The rankings were treated as indices and were assigned integer values of 1, 2, and 3 (Low, Medium, and High). The acreage of the wetland is multiplied by the rating for each parameter in the three functions and combined to produce a cumulative, numerical ranking that represents functional units supplied by the wetland.

The generalized steps that the model employs are:

1. The total functional units existing in a watershed where a road is planned are calculated using the NC-CREWS GIS procedure.
2. The user indicates a transportation corridor by adding the link to an existing road network.
3. For links impacting wetlands, the functional units are recalculated to measure the number of units lost to the road addition.
4. The mixed integer model is run to find the optimal combination of land units to be converted to mitigation sites.

In order to make a workable model based on NC-CREWS that would be usable in a GIS environment, several key assumptions have been made:

1. All of the parameters and functions are equally weighted.
2. There is no requirement that specific parameter units removed by a corridor must be replaced by the same parameters in the mitigation sites. Only the total number of functional units must be replaced. For example, the number of habitat units destroyed must be replaced by habitat units, and likewise for nonpoint source and flood storage units.
3. Within the GIS layers, only entire sites may be considered for mitigation. No portion of a possible site may be used.

The Model

Following the above procedure and using the listed assumptions, the linear programming model has the form:

Maximize $A^TX(F_{Hab} \times R_{Hab} + F_{NPS} \times R_{NPS} + F_{FS} \times R_{FS} - c) - C_{Road} - (F_{Hab})(H_{Loss}) - (F_{NPS})(NPS_{Loss}) - (F_{FS})(FS_{Loss})$

Subject to
$R_{Hab}A^TX \geq H_{Loss}$
$R_{NPS}A^TX \geq NPS_{Loss}$
$R_{FS}A^TX \geq FS_{Loss}$
$C_{Road} + cA^TX \leq C_{Max}$

Where
A_i = acreage for land unit i for i = 1...n with n land units in study area
X_i = [0,1] decision variable to convert land unit i to wetland, i = 1 to n
F_{Hab} = scalar conversion factor of a habitat functional unit to dollars
F_{NPS} = scalar conversion factor of a nonpoint source functional unit to dollars
F_{FS} = scalar conversion factor of a floodwater storage functional unit to dollars
R_{Hab} = sum of ratings for habitat parameters, integer in [3..9]
R_{NPS} = sum of ratings for nonpoint source parameters, integer in [3..9]
R_{FS} = sum of ratings for floodwater storage parameters, integer in [3..9]
c = cost per acre of converting land to wetland
C_{Road} = cost of constructing road corridor
H_{Loss} = habitat functional units lost to road corridor
NPS_{Loss} = nonpoint source functional units lost to road corridor
FS_{Loss} = floodwater storage functional units lost to road corridor
C_{Max} = maximum dollar value available for road and mitigation project

The constraints for nonpoint source and floodwater storage are based only on the total area of the land units when calculating functional units. However, when calculating functional units for interior habitat, if adjacent land units are chosen, the amount of interior habitat will increase because portions of the 100 meter buffer will become interior space. For each iteration of the program, R_{Hab} must be recalculated. This will be done by the GIS database accompanying the NC-CREWS system.

The last four terms of the objective function are costs incurred from road construction and do not depend on the combination of possible mitigation sites. For a single road corridor alternative, these terms may be dropped from the objective function and the maximum mitigation return can be calculated. The terms have been included in the equation for clarity and to support the need for transportation planners to analyze alternative corridors.

An Example Using Habitat Functions

The following example uses only the habitat function to determine an optimal mitigation combination for a given road corridor. Visual display of nonpoint sources and floodwater storage models becomes difficult without a GIS since hydrology and land use data layers must be used together. Figure 1 shows the pre-road watershed and Table 4 contains the corresponding acreage information. After unavoidably placing part of a road through a wetland (Fig. 2) mitigation combinations must be calculated.

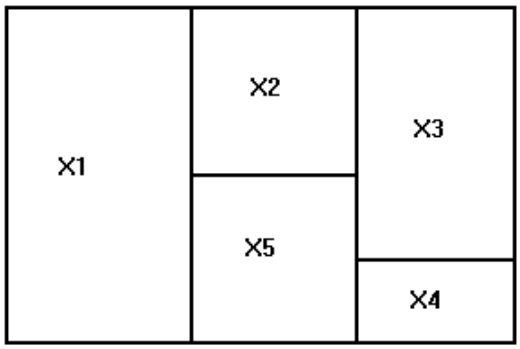

Figure 1. —Simplified arrangement of land units in a watershed where road impacts will require mitigation.

Table 4. —Characteristic of example watershed

Land Unit	Land Use/ Land Type	Total Acres	Interior Acres
X1	Wetland	150	80
X2	Pine Plantation	62.5	22.5
X3	Pine Plantation	70	25
X4	Pine Plantation	30	5
X5	Pine Plantation	62.5	22.5

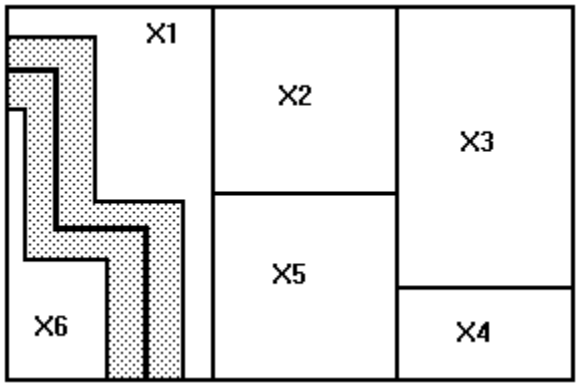

Figure 2. —Example watershed with added road that requires mitigation.

The road added to the watershed splits X1 into two new land units, creating X6. X6 has an area of 22.5 acres, with interior space occupying 10 acres. The shaded area represents the 100 meter buffer around the road where the impacts occur. The undisturbed watershed contained 750 functional units. Adding the road destroyed 390 units that must be mitigated for. Table 5 shows the user defined constants used in this example.

Table 5.—User defined constants for example

Constant	Value
	$
F_{Hab}	2
F_{NPS}	2
F_{FS}	2
c	20

When using the algorithm only with the habitat function, the optimum combination of land units to restore to wetlands is X2 and X5. Table 6 shows the functional units and mitigation returns possible from all combinations of X2, X3, X4, and X5. X6 remained wetland and obviously cannot be used for mitigation credit.

This example shows the optimum combination of mitigation sites in terms of financial outlay. Using the figures given in Table 5, meeting the constraints results in a financial loss. Depending on the choices of F_{Hab}, F_{NPS}, and F_{FS}, it is possible that the optimum objective function value could be positive.

Table 6.—Functional Units Gained from Possible Mitigation Site Combinations

Land Unit Combination	Total Area of Wetlands in Watershed	Watershed Functional Units	Units Gained from Mitigation Sites	Objective Function Value [a]
	acres			*dollars*
X2	130	610	250	NA
X3	70	565	205	NA
X4	30	405	45	NA
X5	130	610	250	NA
X2 + X3	200	1090	730	-400
X2 + X4	160	740	380	NA
X2 + X5	**192.5**	**1052.5**	**692.5**	**-385**
X3 + X4	167.5	760	400	-670
X3 + X5	200	890	530	-800
X4 + X5	160	730	370	NA
X2 + X3 + X4	230	1240	880	-460
X2 + X3 + X5	262.5	1402.5	1042.5	-525
X2 + X4 + X5	222.5	1202.5	842.5	-445
X3 + X4 + X5	230	1172.5	812.5	-595
X2 + X3 + X4 + X5	292.5	1552.5	1192.5	-585

[a] Does not include last four terms of the objective function which are constants. NA denotes infeasible solution.

DISCUSSION AND CONCLUSIONS

Because of the varying opinions of wetland functions and assessment methods, this project used only the NC-CREWS system to drive the models. This system was developed for a specific geographic region to which this model is currently limited. Because most wetland rating systems try to attach numbers to wetland functions, this model, because of its simplicity, could easily be modified to meet needs in regions other than the coastal plain of North Carolina.

The next step in this process is to attach the model to a GIS. Using macros and custom designed interfaces, the ideal tool would require the user to enter the watershed being impacted, the road corridor (through on-screen digitizing), costs associated with construction and mitigation, and values for F_{Hab}, F_{NPS}, and F_{FS}.. GIS procedures of buffering, overlay, and dissolving boundaries will be used to obtain the required values for each model iteration. Further work will focus on adding more functions and parameters to the model.

As with any complicated ecosystem, the model is only as good as the available input data. There is a wealth of quantitative data, but no one seems to know which numbers are correct and which are not, especially in light of current regulations and changing societal values. Because wetland mitigation is performed on an acre basis using policy defined ratios for restoration, this model is different in that it has no size requirements. The focus is purely on replacing functional units. As Kulkarni and others noted (1993), any time you use values that denote tradeoffs (F_{Hab}, F_{NPS}, and F_{FS}), some subjectivity is introduced. This subjectivity cannot be avoided since quantitative measures of wetland values do not exist. As wetlands become better understood and the driving forces behind functions are viewed within the context of the entire watershed the model will need to be revised.

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