A COMPUTERIZED METHODOLOGY FOR ESTIMATING THE IMPACT OF WATER RESOURCE PROJECTS ON THE TERRESTRIAL ECOSYSTEM

by

RICHARD H. McCUEN

Associate Professor, Department of Civil Engineering
University of Maryland, College Park, Maryland 20742

GENE A. WHITAKER

Biologist, Soil Conservation Service
4321 Hartwick Road, College Park, Maryland 20740

ABSTRACT

Measurement of the quality of wildlife habitat is a necessity in planning and analyzing water resource projects. A methodology that provides a measure of habitat quality must consider the following factors: 1) the quantity of land uses, 2) the degree of interspersion of land uses, and 3) the condition of land management. A computerized methodology that considers each of these factors is provided for estimating habitat quality and evaluating the impact of proposed water resource development alternatives. A computerized methodology is desirable because it reduces the computational effort, the likelihood of computational error, and the time required to evaluate a large number of proposed alternatives. The computer output includes the information required to assess the degree of mitigation required.

INTRODUCTION

In the past, wildlife habitat assessment often has been limited to annual population estimates. Variation in such estimates often resulted from differences in the observer's opinion or changes in natural conditions such as climatological and seasonal variations. It is now recognized that land use changes affecting the quality of the habitat are the primary cause of variation in wildlife populations. Recently several attempts have been made at developing methodologies for assessing the quality of wildlife habitat and the effect of land use changes on the quality of habitat (Hamor, 1970; Daniel and Lamaire, 1974; Whitaker and McCuen, 1975).

There are many characteristics that can be used to evaluate the effectiveness of a methodology that assesses the quality of wildlife habitat. First, a methodology must be relatively consistent and, therefore, formulated in such a manner so that simultaneous evaluations of a habitat by more than one group will lead to similar decisions; a methodology lacking evaluation stability would not be a reliable tool for decision-making. Second, a methodology must provide for variation in those characteristics and factors considered important in affecting variation in habitat quality; values for these characteristics must be available for watershed conditions both before and after the land use changes resulting from water resource development has occurred. Third, a methodology must provide a means of weighting the variables according to their relative importance; a methodology will not provide an accurate indication of the quality of a habitat if the relative importance of the model components does not directly indicate the relative importance of the corresponding components of the terrestrial ecosystem. Thus, a means of weighting is desirable and necessary. Fourth, variables that can be identified in the field and assigned values with a minimum of effort and with a reasonable degree of accuracy should be selected for use in the model; if the accuracy of an estimated value of a model variable is low then the resulting index may be an unreliable indicator of habitat quality. Fifth, the cost of using a model on a particular site should be considered in selecting a methodology for assessing the quality of wildlife habitat.

The widespread availability of computer systems has simplified computational procedures. Thus, a methodology that is readily adaptable to computer usage also will be of value to public agencies and private firms involved in environmental impact assessment. The wildlife habitat assessment methodology proposed by Whitaker and McCuen (1975) is easily adapted to computer use. The development and application of a computerized version of the methodology proposed by Whitaker and McCuen (1975) is provided herein. Such computer adaptation reduces both the man-hour (i.e., cost) effort required for evaluation and the likelihood of computational errors. *Acknowledgments*. The authors appreciate the use of computer facilities provided by the Computer Science Center, University of Maryland, College Park, Maryland. The data were collected by the personnel of the Denton field office of the USDA, Soil Conservation Service.

MODEL FORMULATION

In developing a methodology for assessing the quality of wildlife one must select characteristics that reflect the sensitivity of habitat quality to changes in land use. Three broad categories affecting the quality of wildlife habitat were considered significant in the methodology proposed by Whitaker and McCuen (1975). First, the quantity of specific land uses was considered important because wildlife require elements of various land uses for food, shelter and propagation. Second, the degree of interspersion of the various land uses also affects the adaptability of wildlife to a specific location and thus is considered in the proposed methodology. And finally, the evaluation of management conditions and the type of vegetation were considered important and were included in the model. These three characteristics, i.e., quantity of land uses, interspersion of land uses, and management conditions, were characterized by the following three variables, respectively: percentage of the total area in a land use, mean distances between land uses, and the type of vegetation and quality of management provided.

A weighted geometric mean of the above three variables was used to provide interaction between model variables that adequately reflected the relative importance and degree of interaction between the corresponding elements of the terrestrial ecosystem. The weighted geometric mean has the general form:

$$O = F\left[\prod_{i=1}^{\eta} C_i^{w_i}\right]^{1/\sum_{i=1}^{\eta} w_i}$$

where O is the system output, F is the output control factor, C_i is the i^{th} component of the model, w_i is the weight applied to the i^{th} component and the symbol Π indicates multiplication of the η components. The ratio O/F is referred to herein as the mean weighted factor and represents a standardized estimate of the habitat quality.

If the relative importance of the model components is to be similar to that of the corresponding processes in the terrestrial ecosystem, the variation associated with each measurable characteristic of the system must be properly scaled in the model. One method of scaling the model components is to transform the measurable characteristics of each process to a value that varies between some specified bounds, say 0 to 1. The distribution of the transformation function can then be used to control the variation of the quality index with respect to change in measurable characteristics of the system. For example, the transformation curve that represents the quantity of a land use related the percentage of the land use to a transformation factor (i.e., C_i in equation 1). Thus, the quality index (i.e., 0 in equation 1) represents the habitat-acre value of a watershed. Changes in the habitat-acre value due to changes in the land use indicate the degree to which alternative habitat acreage must be provided so that a proposed water resource development does not reduce the ability of an area to maintain a wildlife population.

COMPUTERIZED SOLUTION

A computer program representing the above methodology was written in Fortran and is presented in Appendix 1. The program should be adaptable to any computer system that accepts Fortran programs. Computer storage requirements are small. A generalized flowchart of the program execution sequence is given in Figure 1 and a description of the required input is given in Table 1. The main program must be accompanied by three FUNCTION subprograms; these subprograms represent the transformation curves for quantity, interspersion, and management and are watershed dependent. Examples of these subprograms, which were developed for use with the watershed discussed in the next section, are given in Appendices 2, 3, and 4.

The methodology described requires estimates of the percentage of land devoted to each specific land use, mean distances between selected land uses, and management or vegetative conditions of each land use. The computer program developed herein provides two means of transmitting this information into core storage. First, if average values for the above three characteristics already exist, these values can be input directly; this option might be used when actual quantity values are available or average values have been forecasted for future watershed conditions. Second, the input may consist of a matrix of sample land use descriptions; the required averages can then be computed directly from the sample data. The methodology and accuracy of this technique was discussed by Whitaker and McCuen (1975).

Figure 1. Generalized Flowchart of Computer Program

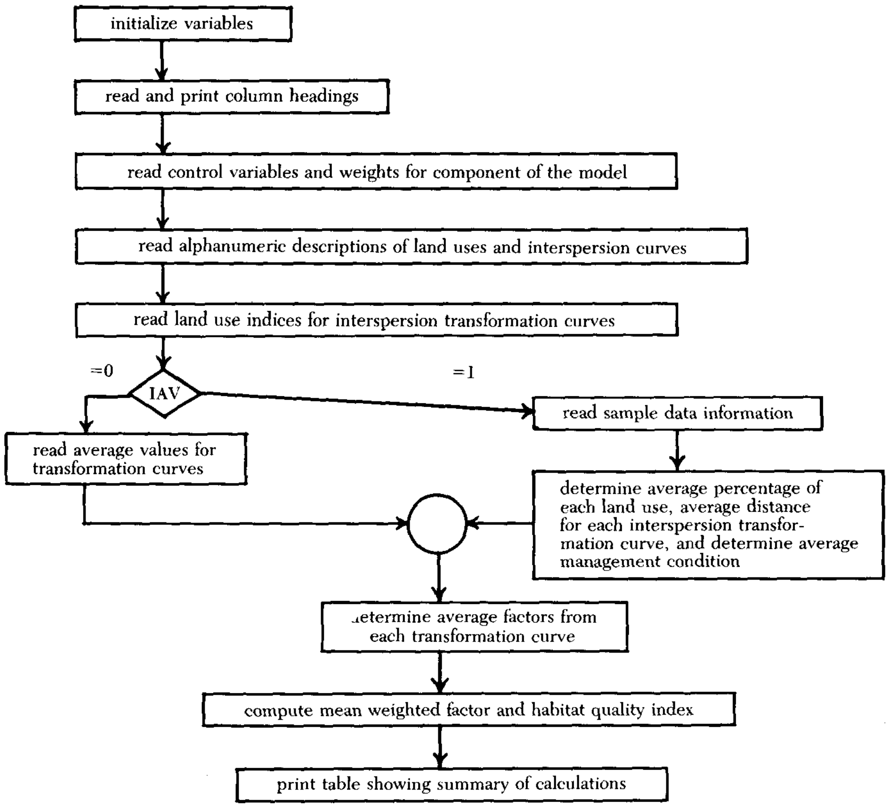


Table 1. Program input

Item	*Condition*	*Format*	*Variables*	*Comments*
1.		29Ar	ALPH(I),I=1,40	Two information cards containing alphanumeric information that are used as headings on the computer output
2.		5I3,F10.3, 2A4	NLU,NTCI,MIM,IAV, IPR,AREA, (UNITSA(I),I=1,2)	NLU=number of land uses (maximum of 10) NTCI=number of interspersion transformation curves (maximum of 10) MIM=management index method =0 if code number is input =1 if value of transformation factor is input IAV=index for indicating average values =0 if input consists of average land use densities, distances and management conditions. =1 if input consists of sampling point data IPR=print option =1 if sample point data is to be printed =0 otherwise AREA=area of watershed UNITSA=alphanumeric data specifying the units in which AREA is given.
3.		10F5.3	WQ(I),I=1, NLU	weights used for each quantity of land use factor
4.		10F5.3	WI(I),I=1, NTCI	weights used for each interspersion factor
5.		10F5.3	WM(I),I=1,NLU	weights used for each management factor
6.		5A4	((AQ(I,J),J=1,5),I=1,NLU)	alphanumeric description of each land use (20 columns for each land use; 1 card per land use)
7.		5A4	((AI(I,J),J=1,5),I=1,NTCI)	alphanumeric description of each interspersion transformation curve (20 columns for each transformation curve)
8.		20I2	((II,(I,J),J=1,2),I=1,NTCI)	integer values indicating that the I^{th} interspersion transformation curve is between land use II(I,1) and II(I,2).
9.	if IAV=0	8F10.4	AVQ(I),I=1,NLU	average percentage of the I^{th} land use
10.	if IAV=0	8F10.4	AVI(I),I=1,NTCI	average interspersion distance for I^{th} transformation curve
11.	if IAV=0	8F10.4	AVM(I),I=1,NLU	average factor representing the management condition of land use I
12.	if IAV=1	11F5.0	(U(I),I=1,NLU),CM	U(I)=distance measurement for I^{th} land use for a sample point CM=indicator for management condition

When the input consists of sample data points, the input data consists of the minimum distance from each sample point to each of the other land uses. The management condition must also be specified on the data card; the input for the management condition is the numerical indicator for the management condition table.

APPLICATION OF COMPUTERIZED METHODOLOGY

Description of Study Area

The Marshyhope Creek Watershed was chosen to test the computerized version of the methodology proposed by Whitaker and McCuen (1975). The watershed encompasses 100,600 acres in west central Delaware and in the center of Maryland's Eastern Shore. Most of the area is between 50 and 70 feet above mean sea level. As is true of much of the Delmarva peninsula, the natural drainageways in most of the watershed were ill defined when the area was settled over 200 years ago. To clear and farm the area, ditches had to be dug and maintained. Since the 1940's many of the ditch systems have not been adequately maintained and agricultural production is now seriously limited by inadequate drainage and periodic flooding because of insufficient capacity of the outlet ditches.

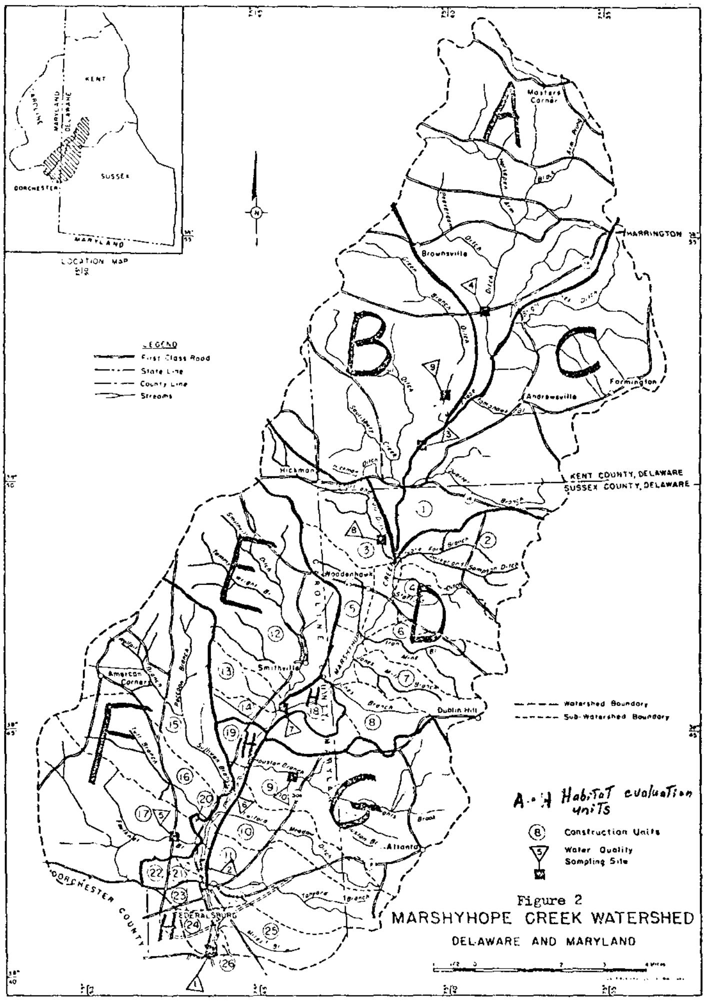


Figure 2
MARSHYHOPE CREEK WATERSHED
DELAWARE AND MARYLAND

The Marshyhope Creek Watershed is nearly half woodland with the woodland fairly evenly distributed over the area. The farm fields are relatively small being divided by hedgerows in and along the ditches. The woods, hedgerows and the abundant food, which consists primarily of corn and soybean residues, provides good habitat for a large variety of wildlife species.

The watershed work plan (SCS, 1964), which was approved for federal assistance under Public Law 566 by the U. S. Congress in 1964, proposed reconstruction of 458 miles of multiple-purpose channels in agricultural areas. Approximately 38 percent of the work has been completed. The USDA Soil Conservation Service is now preparing an environmental impact statement as required by the National Environmental Policy Act. The results reported herein are part of the environmental assessment procedure.

For the purpose of the environmental assessment of the Marshyhope watershed, wildlife in the study area were lumped into two groups: openland and woodland wildlife. Their habitats will be evaluated separately. However, to demonstrate the development and use of the computer program only openland wildlife is addressed in this paper. Openland wildlife includes those species that normally frequent cropland, meadows, lawns, and areas of non-forested land that are overgrown with grasses, herbs, and shrubby growth. This includes those species dependent on edge but deriving most of their substance from openland. Examples are bobwhite quail *(Colinus virgininus)*, rabbits *(Sylvilagus sp.)*, meadowlarks *(Sturnella magna)*, sparrows *(Fringillidac, sp.)*, robins *(Turdus migratorius)*, skunks *(Mephitis, mephitis)*, and meadow mice *(Microtus sp.)*.

Measurement of Land Use Descriptions

To obtain sample data useful in describing the characteristics of the study area, a composite aerial photograph at a scale of 1 inch = 1,320 feet was prepared. A grid was placed over the photo and 1,012 random points were selected using a table of random numbers. These sites were analyzed according to the procedure developed by Whitaker and McCuen (1975), and estimates of the three variables were obtained from this data for each land use and each interspersion characteristic.

Project Evaluation

The model of equation 1 can be used to quantify the quality of the habitat under existing land use and management conditions and for expected conditions with planned project alternatives. Transformation curves used to represent the components of the model of equation 1 are given in Appendices 5, 6, and 7. These correspond to the subprograms of Appendices 2, 3, and 4, respec-

Table 2. Marshyhope Watershed Total

Variable	*Weight*	*Unit*	*Factor*
Quantity of Land Use		Percentage	
Cropland	1.00	43.2	.65
Herbaceous Cover	1.00	6.1	.61
Woodland	.80	47.2	.28
Residential	.20	3.7	.71
Interspersion		Distance (feet)	
Cropland-Woodland	4.00	410.	.44
Cropland-Herbaceous	2.00	306.	.52
Herbaceous-Woodland	1.20	267.	.75
Woodland-Openland	.50	551.	.07
Management		Category	
Cropland	2.00	—	.53
Herbaceous Cover	1.00	—	.39
Woodland	1.00	—	.71
Residential	.10	—	1.00
Total of Weights	14.80		
Mean Weighted Factor			.4818
Total Area			100600.000 Acres
Weighted Habitat Value Area			48473.298 Acres

tively. A "before - after" comparison of mean weighted factors can be used to assess the expected effects on the quality of wildlife habitat of proposed alternatives.

Using the factors and weights of Table 2, a mean weighted value of 0.4818 was computed for openland wildlife habitat in the Marshyhope Creek Watershed under present land use and management conditions.

The quality of the watershed study area projected to 1990 was evaluated for three alternative states: 1) without the proposed project, 2) with the proposed project, and 3) with the proposed project and with hedgerows preserved. The effects of these alternatives on land use and management were evaluated by a group familiar with the project area including biologists, agronomists, soil scientists, engineers, and general soil and water conservationists. The group concluded that without the proposed project deteriorating drainage conditions would cause the quantity of cropland to decrease while herbaceous and woodland percentages would increase as shown in Table 3. Neither the mean distances, which represent the interspersion of land uses, nor the management factors were expected to change significantly by 1990 without the project. Therefore, if the project is not completed, by 1990 there will be a 1.9 percent gain in the quality of the habitat for openland wildlife.

Completion of the watershed project as planned will improve drainage so that some herbaceous land will return to crop use. The maintenance ditch right-of-ways will be in good herbaceous cover. The assessment group concluded that by 1990 the quantity of land uses would be as shown in Table 4. The most significant impact will be on the degree of interspersion of land uses. Elimination of the hedgerows in and along the existing ditches will increase the mean distance to woodland cover from both cropland and herbaceous areas. The average management condition for cropland and woodland is not expected to change significantly in the next 15 years. The herbaceous strip along the ditches will be maintained in an ideal condition. Therefore, if the project is completed as planned, by 1990 there will be an 11.6 percent loss in the quality of the openland wildlife habitat.

Completion of the project with modifications to preserve or replace most of the hedgerows, the third alternative examined, would result in no significant change in mean distances from cropland and herbaceous cover to woodland. By 1990, this would result in only 1.4 percent loss in the quality of the openland wildlife habitat (Table 5).

Table 5 also shows the weighted habitat value area which is the mean weighted value times the total area of the watershed and represents the area of ideal habitat needed to support an equivalent wildlife population.

Table 3. Marshyhope Watershed 1990 Without Project

Variable	*Weight*	*Unit*	*Factor*
Quantity of Land Use		Percentage	
Cropland	1.00	41.0	.82
Herbaceous Cover	1.00	9.4	.94
Woodland	.80	43.8	.30
Residential	.20	5.9	.34
Interspersion		Distance (feet)	
Cropland-Woodland	4.00	410.	.44
Cropland-Herbaceous	2.00	306.	.52
Herbaceous-Woodland	1.20	267.	.75
Woodland-Openland	.50	551.	.07
Management		Category	
Cropland	2.00	—	.53
Herbaceous Cover	1.00	—	.38
Woodland	1.00	—	.71
Residential	.10	—	1.00
Total of Weights	14.80		
Mean Weighted Factor			.4911
Total Area			100800.000 Acres
Weighted Habitat Value Area			49401.624 Acres

Table 4. Marshyhope Watershed with Project as Planned

Variable	Weight	Unit	Factor
Quantity of Land Use		Percentage	
Cropland	1.00	45.7	.69
Herbaceous Cover	1.00	5.1	.51
Woodland	.80	42.1	.32
Residential	.20	7.1	.15
Interspersion		Distance (feet)	
Cropland-Woodland	4.00	523.	.29
Cropland-Herbaceous	2.00	306.	.52
Herbaceous-Woodland	1.20	337.	.66
Woodland-Openland	.50	532.	.08
Management		Category	
Cropland	2.00	—	.53
Herbaceous Cover	1.00	—	.54
Woodland	1.00	—	.71
Residential	.10	—	1.00
Total of Weights	14.80		
Mean Weighted Factor			.4260
Total Area			100600.000 Acres
Weighted Habitat Value Area			42860.567 Acres

Table 5. Marshyhope Watershed with Project as Planned with Hedgerows Preserved

Variable	Weight	Unit	Factor
Quantity of Land Use		Percentage	
Cropland	1.00	45.7	.69
Herbaceous Cover	1.00	4.2	.42
Woodland	.80	43.1	.30
Residential	.20	7.1	.15
Interspersion		Distance (feet)	
Cropland-Woodland	4.00	410.	.44
Cropland-Herbaceous	2.00	306.	.52
Herbaceous-Woodland	1.20	267.	.75
Woodland-Openland	.50	532.	.08
Management		Category	
Cropland	2.00	—	.53
Herbaceous Cover	1.00	—	.54
Woodland	1.00	—	.71
Residential	.10	—	1.00
Total of Weights	14.80		
Mean Weighted Factor			.4752
Total Weight			100600.000 Acres
Weighted Habitat Value Area			47801.615 Acres

Computerized evaluation of habitat quality permits a much more detailed analysis of project effects than would otherwise be feasible. The study watershed was divided into eight habitat evaluation units. A comparison of the mean weighted factors for groups of these habitat evaluation units can be used to assess the spatial variation of factors such as construction work, soil characteristics, and farming practices. Table 6 shows the mean weighted factors for two groupings of habitat evaluation units: B and D, and F and G. These groupings are in different states and are subject to different construction permit procedures. Also the group of F and G has 20 percent more cropland than the B-D group and is subject to more intensive farming operations. These facts are reflected in the difference in the mean weighted factors of Table 6 for existing watershed conditions. Because hedgerows will be removed with improved farming conditions by 1990, if the project is adopted, the two areas will be of very similar habitat quality, as reflected in the mean weighted factors of 0.4497 for B-D and 0.4489 for F-G. The quality of the habitat will not change significantly if the project is not completed as planned or the hedgerows are preserved and the project completed.

Table 6. Comparison of Mean Weighted Factors for Habitat Evaluation Units

Units	*Factor for Existing Conditions*	*1990 without project*		*1990 with project*		*1990 with project (hedgerows preserved)*	
		Factor	*% Change*	*Factor*	*% Change*	*Factor*	*% Change*
B-D	.5013	.5102	1.8	.4497	−10.3	.4994	−0.3
F-G	.4876	.5021	3.0	.4489	− 7.9	.4997	2.5
A thru H	.4818	.4911	1.9	.4260	−11.6	.4752	−1.4

DISCUSSION

Computerization of this methodology as presented herein does much more than simply make calculations easier and less subject to error; it allows the biologist to obtain full benefits from the methodology in a workable time frame without large expenditures of time and money. This is of particular value in calibrating the methodology to new areas. It permits the biologist to make changes in the system and observe the results. It also allows environmental assessment groups and eventually the decision makers to rapidly consider a wide variety and combinations of alternative construction techniques or project activities.

The land use information can also be easily stored for later use or reevaluation at any stage in the planning process as new information becomes available or conditions change. The computerized data base will also provide future investigators with the solid foundation needed to study the actual effect of completed water resource projects.

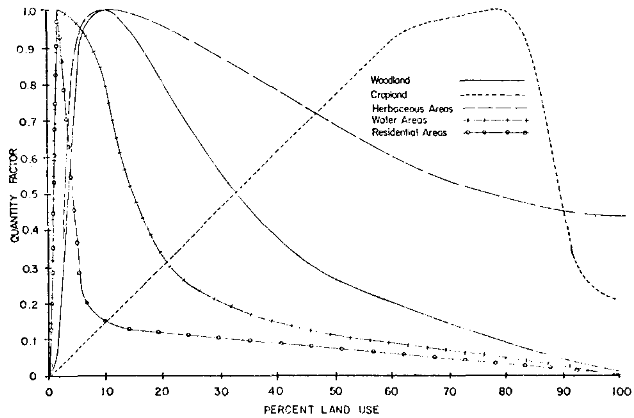
Our analysis does not represent a final report on the Marshyhope Creek Watershed on which an environmental assessment is being made by the Maryland and Delaware offices of the USDA Soil Conservation Service in cooperation with several state and other federal agencies. The final report must take into consideration the fact that some of the planned work will not be completed, all of the potential channel work on individual properties will not be completed by the landowners, and some landowners will install measures to benefit openland wildlife. Analysis of the effects on woodland wildlife and several individual wildlife species are also being conducted. This methodology is currently being used on several additional watershed projects in Maryland and Delaware, even through it has not been approved as a standard system for nationwide use by the Soil Conservation Service. We hope that it not only provides insight to quantitative effects of project activities on wildlife habitat, but, more importantly, that it elicits responses, data, and more structured insights from biologists. Decision making is difficult enough with the best of data; it can only be more capricious when observations, intuitions, and emotions are allowed free rein.

LITERATURE CITED

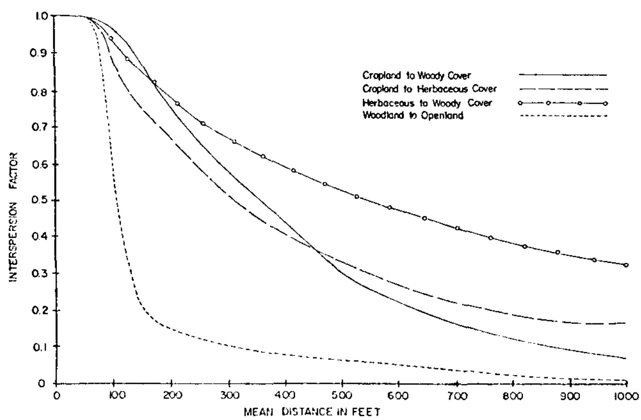
Daniel, C., and R. Lamaire, 1974. Evaluating effects of water resource developments on wildlife habitat, Wildlife Society Bulletin, 2(3):114-118.

Hamor, W. H., 1970. Guide for evaluating the impact of water and related land resource development projects on fish and wildlife habitat, USDA, Soil Conservation Service, Lincoln, Nebraska, 25 pp., 1970.
Soil Conservation Service, USDA, 1964. College Park, Maryland. 58 pp. Watershed work plan: Marshyhope Creek Watershed.
Whitaker, G. A., and R. H. McCuen, 1975. A methodology for assessing the quality of wildlife habitat, Technical Report, Department of Civil Engineering, University of Maryland, College Park.

Appendices 1, 2, 3 and 4 are computer programs in the Fortran language and are available from the Authors.



Appendix 5. Transformation curves for openland wildlife for the Marshyhope Creek Watershed to convert the percentage of the major land uses to the quantity of land use factor.



Appendix 6. Transformation curves for openland wildlife for the Marshyhope Creek Watershed to convert the mean distances between major land uses to the degree of interspersion factors.

Appendix 7. Transformation tables for land use management conditions used for the Marshyhope Creek Watershed.

Cropland	*Wildlife value factor Openland*
Corn—grain harvested, no tillage	1.0
Corn—grain harvested and stubble grazed, mowed, or lightly tilled	0.8
Corn—minimum tillage with cover crop	0.9
Soybeans—harvested only	0.6
Soybeans—harvested and lightly tilled or grazed	0.5
Soybeans—minimum tillage with cover crop	0.7
Cover crop—previous crop not of obvious value or corn cut for silage	0.4
Tilled and essentially bare ground	0.1
Grain stubble not planted to another crop after harvest, may have been tilled, annual weeds predominate	1.0
Permanent herbaceous land	
Wide variety of perennial grasses and forbs—over 20% woody less than 2" diameter	1.0
Wide variety of perennial grasses and forbs—5 to 20% woody less than 2" diameter	0.9
One or two species dominant and over 10% woody	0.7
Wide variety of perennial grasses and forbs, over 8" high	0.8
One or two species dominant, over 8" high	0.5
Grass and forbs 4" to 8" high—hayed land with a little regrowth or idle land mowed midsummer	0.3
Grass and forbs less than 4" high—mowed in fall	0.1
Pasture—moderately or lightly grazed—most grass 4" to 8" high	0.3
Pasture—heavily grazed—most grass less than 4" high	0.1
Woodland	
Saw timber[a], mixed hardwoods[b], heavy understory	1.0
Saw timber, maple-gum[c], heavy understory	0.8
Saw timber, mixed hardwoods, medium understory	0.8
Saw timber, maple-gum, medium understory	0.6
Saw timber, mixed hardwoods, low understory	0.5
Saw timber, maple-gum, low understory	0.3
Post and pole[d], heavy understory	0.7
Post and pole, medium understory	0.5
Post and pole, light underwood	0.2
Sapling[e], heavy understory	0.8
Sapling, medium understory	0.3
Sapling, light understory	0.2

[a] Saw timber: The dominant canopy trees are over 15" DBH.

[b] Mixed hardwoods: several species of trees, including some oaks and up to 10% pine, are dominant.

[c] Maple-gum: maples and/or gums are completely dominant with less than 10% oaks.

[d] Post and pole: most trees are 6" to 12" DBH.

[e] Sapling: most trees are 2" to 6" DBH.