Weller et al. (2007)
Wetland Condition Assessment Tools

This approach identifies relationships between HGM field assessments and landscape variables to calibrate statistical models that predict wetland condition (i.e., HGM score) based on landscape indicators. By relying on empirical data alone to drive its predictions of wetland condition, the Nanticoke model presents a contrast to typical landscape prioritization assessments that estimate wetland condition based on remotely sensed data and expert input. The underlying methods can be applied to prioritize wetland restoration or conservation for wetland types of any watershed for which a random sample of Rapid Assessment Method (RAM) scores can be obtained.

OVERVIEW

Lead developers: Donald Weller, Marcia Snyder, Dennis Whigham, and Thomas Jordan, Smithsonian Environmental Research Center; Amy Jacobs, The Nature Conservancy of Delaware.[1]

Year developed: 2007.[1]

Geographic area: The Nanticoke watershed (Fig. 1).[1]

Resource types: Wetland types specific to the Nanticoke watershed.[1]

Restoration/conservation: The tool can be used to find good sites for restoration (rehabilitation) because it can identify low condition wetlands (low HGM score). Conversely, because it identifies high quality wetlands (high HGM score), it can be used to find sites for preservation, protection, or acquisition.[1,2]

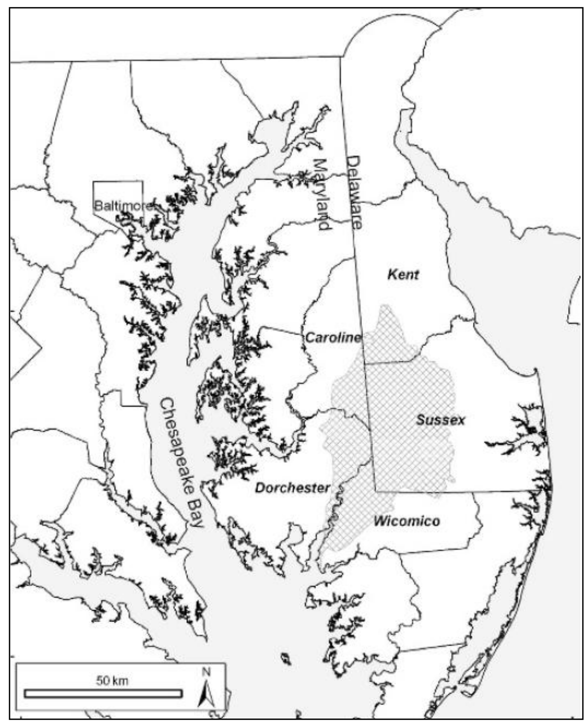

Figure 1. Researchers applied the Nanticoke approach to the Nanticoke watershed in Maryland and Delaware (shaded above). Map from Whigham et al. (2007), used with permission.

Current status: The tool has not yet been applied for restoration/conservation decisionmaking.[2]

PRIORITIZATION ANALYSIS

Determination of input factors/weightings: The process used to identify input factors/weightings for the model involved two phases. In the first phase, a systematic rapid assessment approach was used to obtain data for nine rapid assessment functions across wetlands throughout the watershed. For each of the nine wetland metrics (e.g., "hydrology," "biogeochemistry," "plant community," and "habitat" functions for flat and riparian wetlands, in addition to a "landscape" function for riparian wetlands), experts selected several variables that best resolved degraded from reference wetlands from an initial list of HGM variables.[3] The experts decided how each set of variables selected for each of the nine functions should be weighted against one another to develop equations describing how different field-measured variables related to specific wetland function. These equations, referred to as Functional Capacity Index (FCI) scores, were rapid assessment functions that provided the basis of functional assessments tailored specifically at the watershed level. FCI scores were obtained for wetlands selected randomly throughout the watershed by applying the Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP) sample design to select wetland sites to assess. Because they expected most sites to fall on privately-owned properties, the researchers drew an initial sample size 10 times larger than the target size. Researchers used FCI scores obtained for a final sample of 54 riverine and 89 flat wetlands as the basis for determining factors/weightings for the landscape prioritization models.[1]

The second phase involved the identification of 27 landscape indicators representing potentially important indicators of wetland condition that could be used to predict each of these rapid assessment scores. Example metrics included percentage deciduous forest, mean percentage impervious surfaces, and distance to nearest stream. Each of the nine datasets for FCI scores were correlated one-by-one with each of the 27 landscape indicators. Those landscape indicators for which the correlations were most significant for an FCI dataset were selected to form the basis of a multivariate model for that dataset, resulting in the selection of a set of landscape indicators for each of the nine FCI scores.

Landscape prioritization tool(s): The researchers found that these multivariate models produced a strong relationship between landscape variables and FCI scores, with even the poorest performing models explaining nearly 50% of the variability. Because all landscape prioritization regression models were significant they concluded that all could be used to predict the FCI scores.[1,4]

<u>Hydrology (flat wetlands) tool:</u> This landscape assessment predicted the hydrological condition FCI score for flat wetlands, which was calculated based on field data for presence of anthropogenic-derived sediment and percentage of assessment area affected by drainage. This tool predicted FCI scores by inputting 30m resolution spatial metrics for stream density, stream proximity, and composition of surrounding land cover (Table 1) into a GIS-based model.[1,5]

Prioritization objectives assessed:
- Aquatic resource condition
- Water quality
- Flood mitigation

Table 1. Factors and associated data sources used to prioritize for hydrology (flat wetlands).[1]

Factor used in analysis	Data source(s)
Total stream density within 100m (km/km^2)	NWI stream and ditch map[6]
Minimum distance to nearest stream based on available data (m)	NWI stream and ditch map[6]; 1:24,000 National Hydrography Dataset (NHD)[9]

Percentage wooded land cover within 1000m	2001 NLCD[7]
Percentage wetlands within 100m	Wetlands from NWI and states of MD and DE[8]
Stream density within 100m (km/km^2)	1:24,000 NHD[9]

NLCD = National Land Cover Dataset; NWI = National Wetlands Inventory

Biogeochemistry (flat wetlands): This landscape assessment predicted the biogeochemistry condition FCI score for flat wetlands, which was calculated based on field data for presence of microtopographic features, density of standing dead trees, basal area of trees, tree density, and hydrology (flat wetlands) FCI score. This tool predicted FCI scores by inputting 30m resolution spatial metrics for stream density, stream proximity, and surrounding land cover composition (Table 2) into a GIS-based model.[1,5]

Prioritization objectives assessed:

- Aquatic resource condition
- Water quality

Table 2. Factors and associated data sources used to prioritize for biogeochemistry (flat wetlands).[1]

Factor used in analysis	**Data source(s)**
Minimum distance to nearest stream based on available data (m)	NWI stream and ditch map[6]; 1:24,000 NHD[9]
Stream density (km/km^2)	1:24,000 NHD[9]
Percentage evergreen forest within 1000m	2001 NLCD[7]
Mean percentage tree cover per pixel within 100m	2001 NLCD[7]
Distance to nearest stream (m)	1:24,000 NHD[9]
Percentage forest within 100m	2001 NLCD[7]
Percentage evergreen forest within 100m	2001 NLCD[7]
Percentage wetland within 100m	2001 NLCD[7]

Plant community (flat wetlands) tool: This landscape assessment predicted the plant community condition FCI score for flat wetlands, which was calculated based on field data for tree species composition, species of herbs present, and presence of *Rubus* species. This tool predicted FCI scores by inputting 30m resolution spatial metrics for surrounding forest cover composition (Table 3) into a GIS-based model.[1,5]

Prioritization objectives assessed:

- Aquatic resource condition
- Habitat quality

Table 3. Factors and associated data sources used to prioritize for plant community (flat wetlands).[1]

Factor used in analysis	**Data source(s)**
Percentage deciduous forest within 100m	2001 NLCD[7]

Mean percentage tree cover per pixel within 100m	2001 NLCD[7]
Percentage of pixels with zero tree cover within 100m	2001 NLCD[7]
Percentage mixed forest within 100m	2001 NLCD[7]

Habitat (flat wetlands) tool: This landscape assessment predicted the habitat condition FCI score for flat wetlands, which was calculated based on field data for vegetation disturbance, basal area of trees, tree density, shrub density, and density of standing dead trees. This tool predicted FCI scores by inputting 30m resolution spatial metrics for stream density and surrounding land cover composition (Table 4) into a GIS-based model.[1,5]

Prioritization objectives assessed:

- Aquatic resource condition
- Habitat quality

Table 4. Factors and associated data sources used to prioritize for habitat (flat wetlands).[1]

Factor used in analysis	Data source(s)
Percentage forest within 100m	2001 NLCD[7]
Percentage deciduous forest within 100m	2001 NLCD[7]
Total stream density within 1000m (km/km^2)	NWI stream and ditch map[6]
Percentage mixed forest within 100m	2001 NLCD[7]
Percentage evergreen forest within 100m	2001 NLCD[7]

Hydrology (riverine wetlands) tool: This landscape assessment predicted the hydrological condition FCI score for riverine wetlands, which was calculated based on field data for stream conditions inside the assessment area, floodplain conditions, and stream condition outside the assessment area. This tool predicted FCI scores by inputting 30m resolution spatial metrics for stream density, stream proximity, nearest stream condition, and surrounding land cover composition (Table 5) into a GIS-based model.[1,5]

Prioritization objectives assessed:

- Aquatic resource condition
- Water quality
- Flood mitigation

Table 5. Factors and associated data sources used to prioritize for hydrology (riverine wetlands).[1]

Factor used in analysis	Data source(s)
Natural stream density (km/km^2)	NWI stream and ditch map[6]
Condition of nearest stream (0 = excavated, 1 = natural)	NWI stream and ditch map[6]
Distance to nearest stream (m)	1:24,000 NHD[9]
Percentage herbaceous wetland within 1000m	2001 NLCD[7]

Percentage evergreen forest within 100m	2001 NLCD[7]
Percentage cropland within 100m	2001 NLCD[7]
Percentage wooded wetland within 1000m	2001 NLCD[7]

Biogeochemistry (riverine wetlands) tool: This landscape assessment predicted the biogeochemistry condition FCI score for riverine wetlands, which was calculated based on field data for basal area of trees and the hydrology (riverine wetlands) FCI score. This tool predicted FCI scores by inputting 30m resolution spatial metrics for stream proximity, nearest stream condition, and surrounding land cover composition (Table 6) into a GIS-based model.[1,5]

Prioritization objectives assessed:

- Aquatic resource condition
- Water quality

Table 6. Factors and associated data sources used to prioritize for biogeochemistry (riverine wetlands).[1]

Factor used in analysis	Data source(s)
Condition of nearest stream (0 = excavated, 1 = natural)	NWI stream and ditch map[6]
Distance to nearest stream (m)	1:24,000 NHD[9]
Mean percentage tree cover per pixel within 100m	2001 NLCD[7]
Percentage deciduous forest within 100m	2001 NLCD[7]
Percentage wooded wetland within 1000m	2001 NLCD[7]

NHD = National Hydrography Dataset; NLCD = National Land Cover Dataset

Plant community (riverine wetlands) tool: This landscape assessment predicted the plant community condition FCI score for riverine wetlands, which was calculated based on field data for tree species composition, sapling species composition, and presence of invasive species. This tool predicted FCI scores by inputting 30m resolution spatial metrics for stream density and surrounding land cover composition (Table 7) into a GIS-based model.[1,5]

Prioritization objectives assessed:

- Aquatic resource condition
- Habitat quality

Table 7. Factors and associated data sources used to prioritize for plant community (riverine wetlands).[1]

Factor used in analysis	Data source(s)
Excavated stream density within 100m (km/km^2)	NWI stream and ditch map[6]
Percentage wetlands within 1000m	Wetlands from NWI and states of MD and DE[8]
Percentage cropland and grassland within 100m	2001 NLCD[7]
Percentage evergreen forest within 1000m	2001 NLCD[7]
Percentage grassland within 100m	2001 NLCD[7]
Percentage herbaceous wetland within 100m	2001 NLCD[7]

Percentage of pixels with zero tree cover within 100m	2001 NLCD[7]
Percentage herbaceous wetland within 1000m	2001 NLCD[7]

Habitat (riverine wetlands) tool: This landscape assessment predicted the habitat condition FCI score for riverine wetlands, which was calculated based on field data for basal area of trees, tree density, shrub density, vegetation disturbance, and stream condition inside the assessment area. This tool predicted FCI scores by inputting 30m resolution spatial metrics for stream density, stream proximity, nearest stream condition, and surrounding land cover composition (Table 8) into a GIS-based model.[1,5]

Prioritization objectives assessed:

- Aquatic resource condition
- Habitat quality

Table 8. Factors and associated data sources used to prioritize for habitat (riverine wetlands).[1]

Factor used in analysis	Data source(s)
Distance to nearest stream (m)	1:24,000 NHD[9]
Condition of nearest stream (0 = excavated, 1 = natural)	NWI stream and ditch map[6]
Percentage evergreen forest within 100m	2001 NLCD[7]
Percentage herbaceous wetland within 1000m	2001 NLCD[7]
Natural stream density within 100m (km/km^2)	NWI stream and ditch map[6]
Percentage wooded wetland within 1000m	2001 NLCD[7]
Percentage wetland within 1000m	2001 NLCD[7]
Strahler order of nearest stream	1:24,000 NHD[9]
Percentage cropland and grassland within 100m	2001 NLCD[7]

Landscape (riverine wetlands) tool: This landscape assessment predicted the habitat condition FCI score for riverine wetlands, which was calculated based on field data for condition of buffers 0-20m from wetland, condition of buffers 20-100m from wetland, and stream condition outside assessment area. This tool predicted FCI scores by inputting 30m resolution spatial metrics for stream proximity, road proximity, nearest stream condition, and surrounding land cover composition (Table 9) into a GIS-based model.[1,5]

Prioritization objectives assessed:

- Aquatic resource condition

Table 9. Factors and associated data sources used to prioritize for landscape (riverine wetlands).[1]

Factor used in analysis	Data source(s)
Condition of nearest stream (0 = excavated, 1 = natural)	NWI stream and ditch map[6]
Percentage cropland and grassland within 100m	2001 NWI[6]

Percentage developed land within 1000m	2001 NWI[6]
Percentage mixed forest within 1000m	2001 NWI[6]
Distance to nearest stream (m)	1:24,000 NHD[9]
Percentage pixels with zero impervious cover within 100m	2001 NLCD[7]
Distance to nearest road (m)	Census TIGER data[10]
Percentage wetland within 100m	Wetlands from NWI and states of MD and DE[8]
Percentage forest within 100m	2001 NLCD[7]
Percentage wooded wetland within 1000m	2001 NLCD[7]

Refinement of landscape priorities: Despite the strong predictive ability of the landscape prioritization models, the researchers stated that, because some uncertainty always exists, "landscape prioritization predictions alone should not be used to make management decisions."[1] They emphasize that practitioners should always verify predictions with field observations and state that "field visits to prioritize wetlands for preservation could be focused on wetlands that the landscape prioritization models predict to be in good condition. Conversely, the landscape prioritization models could identify wetlands likely to be degraded, helping to target field visits aimed at selecting restoration sites."[1] Although the model inputs were derived using FCI data, sites identified for restoration or conservation action must be observed on-the-ground before such actions are taken.[1,11]

Prioritization products: Through multivariate analysis the researchers generated nine landscape prioritization equations (four for flat wetlands and five for riverine) that predicted scores for each of the nine FCI models. The equations could be used to produce detailed maps predicting rapid assessment FCI scores throughout the Nanticoke watershed, but that step has not yet been taken. The researchers provided two sets of landscape prioritization equations: one specific to the Nanticoke watershed, incorporating locally-available stream condition data (Table 10) and the other more broadly applicable, incorporating only widely available landscape prioritization datasets (Table 11). Though both predict rapid assessment FCI scores based on landscape prioritization data, the former set of equations has a stronger predictive ability due to its use of local stream condition data.[1]

Table 10. Predicted rapid assessment scores for the nine FCI models can be calculated for a site based on landscape prioritization metrics. These models incorporate stream condition data, which are not widely available to other states.[1]

Rapid assessment FCI model	Equation for calculating rapid assessment FCI score based on landscape variables
Hydrology (flat wetlands)	1.04 – 0.0616 * (Total stream density within 100m) + 0.000251 * (Minimum distance to nearest stream based on available data) – 0.00626 * (Percentage wooded land cover within 1000m) – 0.00274 * (Percentage wetlands within 100m)
Biochemistry (flat	0.38 + 0.000588 * (Minimum distance to nearest stream based on available

wetlands)	data) – 0.0465 * (Stream density) – 0.00667 * (Percentage evergreen forest within 1000m0 + 0.00347 * (Mean percentage tree cover per pixel within 100m) – 0.000294 * (Distance to nearest stream)
Plant community (flat wetlands)	-1.04 + 0.00597 * (Percentage deciduous forest within 100m) + 0.0147 * (Mean percentage tree cover per pixel within 100m) + 0.0142 * (Percentage of pixels with zero tree cover within 100m) = 0.00998 * (Percentage mixed forest within 100m)
Habitat (flat wetlands)	0.28 + 0.00380 * (Percentage forest within 100m) + 0.00272 * (Percentage deciduous forest within 100m) – 0.0558 * (Total stream density within 1000m) + 0.00522 * (Percentage mixed forest within 100m)
Hydrology (riverine wetlands)	0.26 + 0.188 * (Natural stream density) + 0.328 * (Condition of nearest stream) + 0.000850 * (Percentage herbaceous wetland within 1000m) + 0.00500 * (Percentage evergreen forest within 100m) + 0.00366 * (Percentage cropland within 100m)
Biogeochemistry (riverine wetlands)	0.06 + 0.431 * (Condition of nearest stream) + 0.00107 * (Distance to nearest stream) + 0.00535 * (Mean percentage tree cover per pixel within 100m) – 0.00347 * (Percentage deciduous forest within 100m)
Plant community (riverine wetlands)	1.04 - 0.0270 * (Excavated stream density within 100m) – 0.00524 * (Percentage wetlands within 1000m) – 0.00397 * (Percentage cropland and grassland within 100m) + 0.00436 * (Percentage evergreen forest within 1000m)
Habitat (riverine wetlands)	0.27 + 0.00149 * (Distance to nearest stream) + 0.321 * (Condition of nearest stream) + 0.0101 * (Percentage evergreen forest within 100m) + 0.0169 * (Percentage herbaceous wetland within 1000m) + 0.0308 * (Natural stream density within 100m)
Landscape (riverine wetlands)	1.57 + 0.156 * (Condition of nearest stream) – 0.00512 * (Percentage cropland and grassland within 100m) – 0.00536 * (Percentage developed land within 1000m) + 0.0160 * (Percentage mixed forest within 1000m) + 0.000361 * (Distance to nearest stream) – 0.00925 * (Percentage pixels with zero impervious cover within 100m) + 0.000138 * (Distance to nearest road) – 0.000855 * (Percentage wetland within 100m)

Table 11. Predicted rapid assessment scores for the nine FCI models can be calculated for a site based on landscape prioritization metrics. These models incorporate only landscape prioritization data that are widely available to other states and are generally poorer predictors of rapid assessment scores than models incorporating locally-available stream condition data (e.g., in Table 10).[1]

Rapid assessment FCI model	Equation for calculating rapid assessment FCI score based on landscape variables
Hydrology (flat wetlands)	0.824 – 0.0742 * (Stream density within 100m)
Biochemistry (flat wetlands)	0.487 – 0.0570 * (Stream density within 100m) + 0.00438 * (Percentage of forest within 100m) – 0.00344 * (Percentage of evergreen forest within 100m) – 0.00238 * (Percentage of wetland within 100m)
Plant community (flat wetlands)	-1.039 + 0.00597 * (Percentage of deciduous forest within 100m) + 0.0147 * (Mean percentage of tree cover per pixel within 100m) + 0.0142 * (Percentage of pixels with zero tree cover within 100m) + 0.0100 * (Percentage of mixed forest within 100m)

Habitat (flat wetlands)	0.196 + 0.00605 * (Percentage forest within 100m) – 0.00284 + (Percentage evergreen forest within 100m)
Hydrology (riverine wetlands)	0.522 + 0.0283 * (Percentage wooded wetland within 1000m) – 0.0539 * (Percentage herbaceous wetland within 1000m)
Biogeochemistry (riverine wetlands)	0.337 + 0.00649 * (Percentage wooded wetland within 1000m) + 0.00124 * (Distance to nearest stream)
Plant community (riverine wetlands)	-2.796 - 0.00586 * (Percentage wetlands within 1000m) + 0.0394 * (Percentage forest within 1000m) – 0.00765 * (Percentage grassland within 100m) + 0.0224 * (Percentage herbaceous wetland within 100m) + 0.0373 * (Percentage pixels with zero tree cover within 100m) – 0.0205 * (Percentage herbaceous wetland within 1000m)
Habitat (riverine wetlands)	0.954 + 0.0441 * (Percentage wooded wetland within 1000m) – 0.101 * (Percentage wetland within 1000m) – 0.0663 * (Strahler order of nearest stream) – 0.0048 * (Percentage cropland and grassland within 100m)
Landscape (riverine wetlands)	0.299 + 0.0039 * (Percentage forest within 100m) + 0.0198 * (Percentage mixed forest within 1000m) + 0.0116 * (Percentage wooded wetland within 1000m) – 0.00144 * (Percentage wetland within 100m) + 0.000168 * (Distance to nearest road)

IMPLEMENTATION

Regulatory/non-regulatory programs:

- Section 404 compensatory mitigation: The landscape prioritization model may be used to inform a watershed approach to wetland mitigation site selection by providing a fairly precise estimate of average condition of wetlands within watersheds. These assessments of watershed condition can be used to evaluate how different watershed units might benefit from wetland restoration or conservation.[2]
- The tool was created for the purely academic purpose of developing landscape prioritization tools informed more by data and less by professional judgment.

Transferability:

- The tool's ability to extend field-based rapid assessment/intensive assessment programs into landscape prioritization tools that can be applied broadly throughout the landscape. If investment already exists in a Rapid Assessment Program, for instance, this investment can easily be extended by applying the Nanticoke method.[2]
- The tool can be applied wherever samples of field assessment data already exist. Weller et al. (2007) notes: "Our method could be applied wherever a large group of field assessments (say 50 or more) can be matched with appropriate digital geographic data."[1]
- In Weller et al. (2007), the researchers mention that because one of their best indicators, stream condition, is not widely available, the model is most predictive within the Nanticoke. However, they do provide less predictive models that use more broadly available landscape indicators that are applicable to "other areas on the Coastal Plain that have flat and riverine wetlands in settings like those in the Nanticoke River watershed.[1]

Data gaps:

- Better maps for stream condition (excavated or ditched) that cover a broader geographic region could really enhance the utility of the approach for wider application. These maps were available in the NWI data for the Nanticoke watershed but are not widely available.[2]

Barriers:

- A major barrier was the inability of field workers to complete HGM assessments at sites on privately-owned lands. Field workers were only able to access 95 of the 398 (24%) sites on these lands that they had identified in their sample.[5]

Future goals:

- Implement model results in a wetland project selection process.[2]

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[1] Weller DE, Snyder MN, Whigham DF, Jacobs AD, and Jordan TE. 2007. Landscape indicators of wetland condition in the Nanticoke River watershed, Maryland and Delaware, USA. Wetlands 27(3) 498-514.

[2] Interview on 9/29/2011 with Donald Weller, Senior Scientist, Smithsonian Environmental Research Center.

[3] http://www.wes.army.mil.el/wetlands/guidebooks.html

[4] The researchers noted that the regression equations become increasingly accurate at predicting wetland condition at broader scales, such as that of the watershed when used to calculate a mean condition score for many points across the landscape – e.g., within the same watershed. Because the confidence limits for mean scores are much narrower than those for individual point predictions, the researchers note that "the landscape prioritization models can provide fairly precise estimates of average condition within an area." Although they emphasized the importance of field verification, despite the increase in precision, they also stated that "one could reasonably use the landscape prioritization predictions alone to identify areas, perhaps watersheds, where restoration, preservation, or other management efforts should be focused."

[5] Whigham DF, Jacobs AD, Weller DE, Jordan TE, and Kentula ME. 2007. Combining HGM and EMAP procedures to assess wetlands at the watershed scale – status of flats and non-tidal riverine wetlands in the Nanticoke River watershed, Delaware and Maryland (USA). Wetlands 27(3) 462-478.

[6] http://wetlandsfws.er.usgs.gov/

[7] http://www.mrlc.gov

[8] http://dnrweb.dnr.state.md.us/gis/data/samples/doqqbase.html

[9] http://nhdgeo.usgs.gov/metadata/nhd_high.htm

[10] http://www.census.gov/geo/www/tiger/rd_2ktiger/tlrdmeta.txt

[11] However, in contrast to other landscape prioritization tools, the researchers noted that, because the Nanticoke Approach is statistically-based, their tool was capable of providing users with information on the quality of the model and the uncertainty of the predictions. In addition, because the Nanticoke Approach is based on FCI scores that are measured relative to undisturbed reference wetlands, its predictions have a high level of objectivity compared to other landscape prioritization tools that make only general estimates of wetland functions.[1]