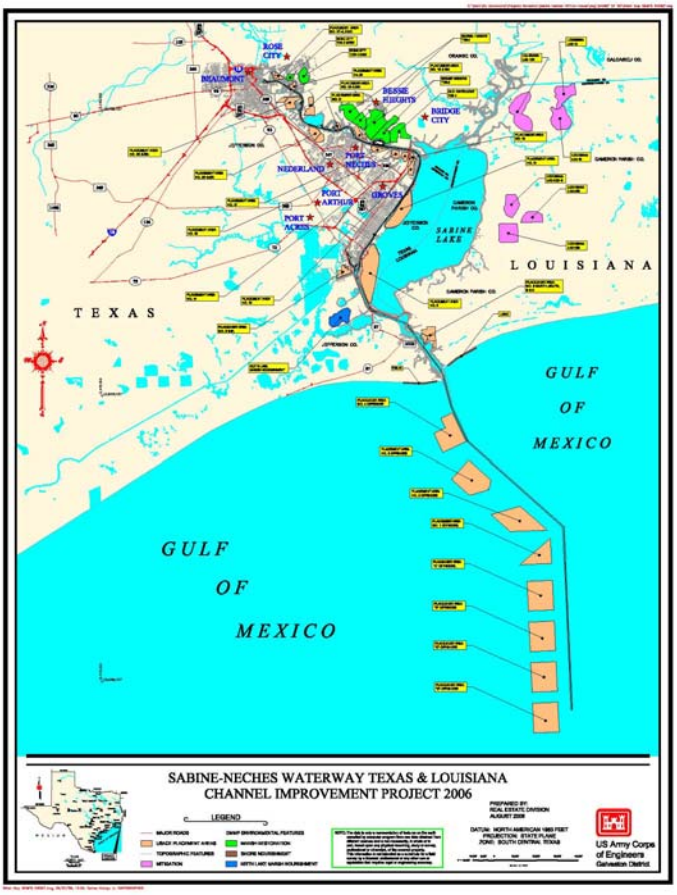
Wetland Value Assessment Model
Application in
the Sabine-Neches Waterway Channel Improvement Project
Model Assessment Report



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Executive Summary

Summary of task:

The Louis Berger team conducted a model assessment of the application of the Wetland Value Assessment (WVA) Models in the Sabine-Neches Waterway Channel Improvement Project (SNWW CIP). The WVA methodology is a quantitative habitat-based assessment methodology developed for use in determining wetland benefits of project proposals submitted for funding under the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA). The WVA quantifies changes in fish and wildlife habitat quality and quantity that are expected to result from a proposed wetland restoration project. The results of the WVA, measured in Average Annual Habitat Units (AAHUs), can be combined with cost data to provide a measure of the effectiveness of a proposed project in terms of annualized cost per AAHU gained.

The WVA is a modification of the Habitat Evaluation Procedures (HEP) developed by the U.S. Fish and Wildlife Service. A notable difference exists between the two methodologies, however, in that HEP generally uses a species-oriented approach, whereas the WVA utilizes a community approach. The WVA has been developed for application to several habitat types of coastal Louisiana and community models have been developed for fresh marsh, intermediate marsh, brackish marsh, saline marsh, fresh swamp, barrier islands, and barrier headlands. Two other habitat assessment models for bottomland hardwoods and coastal chenier/ridge habitat have also been developed.

As a part of the SNWW CIP, ecological modeling was conducted to evaluate impacts and benefits of proposed navigation features. WVA was the tool selected to conduct this ecological modeling. In the SNWW CIP, the Emergent Marsh Community Model (EMCM), the Swamp Community Model (SCM), and the Bottomland Hardwood Community Model (BHCM) were used:

- The EMCM can be applied to four marsh communities within the coastal zone: saline marshes (average water salinity of 16 ppt), brackish marshes (average water salinity of 8 ppt), intermediate marshes (average water salinity of 3-4 ppt), and freshwater marshes (average water salinity of 0.5 to 1 ppt). The EMCM was initially developed in the early 1990s by the Environmental Work Group (EnvWG) of the Planning and Evaluation Subcommittee of Louisiana's CWPPRA Technical Committee (USFWS, 2006).

- The SCM is applicable to forested wetlands where the woody canopy cover is at least 33 percent of the surface area, and at least 60 percent of the canopy consists of any combination of bald cypress (*Taxodium distichum*), tupelo gum (*Nyssa aquatica*), red maple (*Acer rubrum*), buttonbush (*Cephalanthus occidentalis*), and/or planer tree (*Planera aquatica*) (LDNR, 1994; USFWS, 2002). The SCM was developed in 2001 by the EnvWG to evaluate the impacts of proposed restoration projects within Louisiana CWPPRA program by determining

the suitability of swamp habitat in providing resting, foraging, and nesting habitat for a wide variety of wildlife.

- The BHCM applies to forested wetlands that can support a canopy of woody vegetation of which more than 40 percent consist of wetland tree species other than those of swamp habitat. The BHCM was developed by the Louisiana Department of Natural Resources (LDNR) for use in quantifying impacts and mitigation for permitted activities in Louisiana's coastal zone (LDNR, 1994).

All models consist of: 1) variables considered important to each habitat type; 2) a Suitability Index (SI) graph for each variable; and 3) mathematical formulae that combine the SIs for each variable into a single value for habitat quality (Habitat Suitability Index or HSI). HSIs are then established for the baseline (existing) condition, for future without-project (FWOP) conditions, future with-project (FWP) conditions, and for the mitigated future with-project (MFWP) condition for selected target years (TY) throughout the life of the project.

The intent of this assessment is to ensure that the application of these models is technically sound, theoretically sound, computationally accurate, and can be used to calculate impacts and benefits over the life of the project and perform sensitivity analysis. The assessment criteria of a model are based on its: **1) technical quality, 2) system quality, and 3) usability**.

The model assessment was conducted by the Louis Berger Team using procedures described in Protocols for Certification of Planning Models in accordance with requirements specified under Engineering Circular 1105-2-407, entitled *Planning Models Improvement Program: Model Certification.* Models, such as WVA, that are developed by other agencies are subject to approval for use rather than certification *per se* based on an assessment of the documentation provided by the proponents that demonstrate the model satisfies the certification criteria.

Specifically, the objective of this assessment was to evaluate the application of the EMCM, the SCM, and the BHCM in the Sabine-Neches Waterway (SNWW) Feasibility Study. In assessing the application of these three WVA models in the SNWW we focused on the following guidelines.

In accordance with U.S. Army Corps of Engineers (USACE) guidance (ER 1105-2-100)[1], mitigation includes:

- Avoiding the impact altogether by not taking a certain action or part of an action;
- Minimizing impacts by limiting the degree or magnitude of the action and its implementation;
- Rectifying the impact by repairing, rehabilitating, or restoring the affected environment;

[1] This regulation provides the overall direction by which Corps of Engineers Civil Works projects are formulated, evaluated and selected for implementation.

- Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action;
- Compensating for the impact by replacing or providing substitute resources or environments. "Replacing" means the replacement of fish and wildlife resources in-kind. "Substitute" means the replacement of fish and wildlife resources out-of-kind. Substitute resources, on balance, shall be at least equal in value and significance as the resources lost (USACE, 2000).

We also considered the following mitigation planning objectives that were established by the Interagency Coordination Team (ICT) for the SNWW study:

- Minimize salinity impacts to the SNWW affected area
- Maximize the use of dredged material in marsh restoration measures
- Meet the goal of no net loss of wetlands
- Replace Average Annualized Habitat Units (AAHUs) on a one-to-one basis
- Replace AAHUs in-kind to the extent practicable
- Mitigate losses in the state in which they occur
- Share dredged material from Sabine Pass equally between Louisiana and Texas

SNWW CIP Specific Results Summary:

Keeping in mind the general USACE mitigation guidelines and the SNWW CIP specific guidelines we evaluated the application of the WVA models in the context of those guidelines. Conclusions that apply to the three models assessed (i.e. EMCM, SCM, and BHCM) are listed below.

Theory: The theoretical approach behind the use of the models is valid within the context of USACE guidelines.

System Description: The variables used in the models provide a reasonable description of emergent marsh, swamp and bottomland hardwood system habitats.

Analytical Requirements: The models identify habitat structural components and assess habitat-related ecological functional processes that may be affected by the project. All models assess damages or losses that may result from the project using habitat units.

Variable Assumptions: Assumptions of variables specific to the models are appropriate. An in depth look at each assumption for each model is contained in this report.

Risk and Uncertainty:

- None of the models include a direct way to perform a sensitivity analysis. A sensitivity analysis was performed on each model using data tables. Results of those analyses are contained in the report.
- All models allow a quantitative evaluation of losses that are specific to the SNWW CIP.

- All models evaluate compensatory mitigation with a habitat unit that allows quantification of suitable habitat quantity and quality for fish and wildlife over the period of analysis.
- Based on the assumption that no net loss of habitat equals no net loss of function, the use of the models in the SNWW CIP meet the goal of "no net loss" to wetlands.

System Quality:

- All models are Microsoft Excel® -based simple models which includes data entry or input in tables within a worksheet.
- Formulae in Microsoft Excel® spreadsheets are appropriate and accurate.
- There is no computer programming associated with the models; however, all Microsoft Excel® formulae, logical arguments and linkages are accurate.
- Test datasets where results were known allowed comparing results.
- Model outputs are consistent with variable/data input as described in the accompanying documentation.
- Input data and results can be easily imported into similar software programs; model inputs and results can be easily made available to other users.

Usability:

- All models require ecological data. Data on baseline conditions can be easily obtained through field assessments. Future conditions are assessed using an external component (i.e. Hydrodynamic-Salinity Model), scientific literature, professional judgment, and personal knowledge of assessors of the project area.
- Model outputs are clear and understandable and can easily be exported to other documents.
- Model outputs provide useful information in the form of AAHUs that allows comparing alternatives and the assessment of benefits or impacts during the life of the project.
- Training in basic ecological concepts of coastal wetlands and coastal fish and wildlife habitat, as well as in the use of spreadsheets, should be sufficient for models' use.
- Models are considered to be transparent in terms of allowing for a relatively easy verification of calculations and outputs. However, the following issue is identified as a source of user confusion: Poor integration between models protocols and spreadsheet.

Conclusion and Recommendations Specific to the SNWW CIP

1. The BHCM provides a reasonable description of the system being represented. In addition to information that describes tree community structure and hydrological conditions, salinity effects on bottomland hardwood habitat are incorporated into the model through the effect that it might have on tree growth. Additionally, the model includes information on landscape context; an important factor for assessing wetland mitigation needs.
2. A standard quality control mechanism for all models is recommended to secure integrity of the formulae/calculations. Cells in Excel® spreadsheet containing formulae and logical arguments should be locked to prevent unintentional modification by users.
3. It is recommended that if models are going to be made available to users in an electronic format, links be established between the model protocols and spreadsheets to improve its user friendliness.

General Comments on the WVA Methodology:

1. The WVA is susceptible to temporal or spatial variability; the use of community models that follow the WVA methodology outside the project area is not recommended without model recalibration. In addition to the recalibration of existing model variables the following is also recommended:

   a) Consideration should be given to include information on overall plant community composition in all models. This might be particularly important where invasive species are a concern.
   b) Consideration should be given to include a variable that provides information on landscape context to the SCM. Disturbances inside the site and outside may be equally important in affecting the condition of wetlands.
   c) Weighting factors for variables need to be reviewed. Additionally, project specific hydrology should be considered as a tool to evaluate wetlands' structure and processes when applying the model to different systems.
   d) For the BHCM, redundancy among variables that describe landscape context needs to be tested. Variables that are providing similar information should be considered for elimination.

2. The WVA methodology operates under the underlying assumption that in general, the ability of a wetland to provide suitable fish and wildlife habitat is sufficient to characterize overall wetland ecological function. The use of surrogates to assess ecosystems has been applied and accepted in some instances as a valid approach, and this approach does satisfy current USACE guidelines, it is recommended that in assessing compensatory mitigation an effort is made to account for other ecological processes and functions in order to provide a more robust measure of wetland function.

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ACRONYMS

AAHU	Average Annual Habitat Unit
CWPPRA	Coastal Wetlands Planning, Protection and Restoration Act
BHCM	Bottomland Hardwood Community Model
CWA	Clean Water Act
EMCM	Emergent Marsh Community Model
EnvWG	Environmental Work Group
FWP	Future with-project
FWOP	Future without-project
HEP	Habitat Evaluation Procedure
H-S	Hydrodynamic-Salinity Model
HSI	Habitat Suitability Index
ICT	Interagency Coordination Team
SNND	Sabine Neches Navigation District
LDNR	Louisiana Department of Natural Resources
Ppt	parts per thousand
SAV	Submerged aquatic vegetation
SCM	Swamp Community Model
SI	Suitability Index
SNWW	Sabine-Neches Waterway
SNWW CIP	Sabine-Neches Waterway Channel Improvement Project
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
WVA	Wetland Value Assessment

1 INTRODUCTION

The Wetland Value Assessment (WVA) methodology is a quantitative habitat-based assessment methodology developed for use in determining wetland benefits of project proposals submitted for funding under the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA). The WVA quantifies changes in fish and wildlife habitat quality and quantity that are expected to result from a proposed wetland restoration project. The results of the WVA, measured in Average Annual Habitat Units (AAHUs), can be combined with cost data to provide a measure of the effectiveness of a proposed project in terms of annualized cost per AAHU gained.

As a part of the Sabine-Neches Waterway Channel Improvement Project (SNWW CIP) ecological modeling was conducted to evaluate impacts and benefits of proposed navigation features. WVA was the tool selected to conduct this ecological modeling. In the SNWW CIP, the Emergent Marsh Community Model (EMCM), the Swamp Community Model (SCM), and Bottomland Hardwood Community Model (BHCM) were used. The intent of this assessment is to ensure that the application is technically sound, theoretically sound, computationally accurate, and can be used to calculate benefits over the life of the project and perform sensitivity analysis. The assessment criteria of a model are based on its: **1) technical quality, 2) system quality, and 3) usability**.

A model that meets the **technical quality** criterion is one that is based on well-established contemporary science and/or theory, and is a realistic representation of the actual system. Additionally, the model needs to clearly address the defined analytical requirements, which must be supported by valid model assumptions. Technical quality is also ensured when formulae used in the model are accurate and done correctly, and reflect the relationships among variables as specified in the system description. Finally, assumptions, data requirements and model outputs must be fully documented.

System quality refers to the quality of the entire system regarding model development, use and support. The quality of the system is ensured by system level functional testing of hardware and software components, including the assessment of the suitability of the software or programming language. It includes model testing and validation using test datasets, the availability of hardware and software to model users, and the third party interoperability.

Usability refers to the ability to access model programs or files, the skills required for model use, data requirements and ease of availability, model's user friendliness, and usefulness of the model outputs to support project analysis. Additional components of this criterion are the availability of model documentation and technical support, and the ease for verification of model calculations and outputs.

1.2 Model Purpose

The WVA was developed by the Environmental Work Group (EnvWG) assembled under the Planning and Evaluation Subcommittee of the CWPPRA Technical Committee; the EnvWG includes members from each agency represented on the CWPPRA Task Force and members

of the Academic Assistance Subcommittee. The WVA was designed to be applied, to the greatest extent possible, using only existing or readily obtainable data.

The WVA has been developed strictly for use in determining the wetland benefits of proposed CWPPRA projects; it is not intended to provide a detailed, comprehensive methodology for establishing baseline conditions within a project area. Some aspects of the WVA have been defined by policy and/or functional considerations of the CWPPRA; therefore, user-specific modifications may be necessary if the WVA is used for other purposes.

The WVA is a modification of the Habitat Evaluation Procedures (HEP) developed by the U.S. Fish and Wildlife Service (U.S. Fish and Wildlife Service, 1980). HEP is widely used by the Fish and Wildlife Service and other Federal and State agencies in evaluating the impacts of development projects on fish and wildlife resources. A notable difference exists between the two methodologies, however, in that HEP generally uses a species-oriented approach, whereas the WVA utilizes a community approach.

The WVA has been developed for application to several habitat types along the Louisiana coast and community models have been developed for fresh marsh, intermediate marsh, brackish marsh, saline marsh, fresh swamp, bottomland hardwoods, barrier islands, and barrier headlands. A WVA Procedural Manual has also been prepared by the EnvWG to provide guidance to project planners in the use of the various community models. Habitat assessment models for bottomland hardwoods, coastal chenier/ridge, and swamp community habitats were developed outside of the CWPPRA arena and are periodically used by the EnvWG.

1.3 Model Assessment

The model assessment was conducted by the Louis Berger Team using procedures described in Protocols for Certification of Planning Models in accordance with requirements specified under Engineering Circular 1105-2-407, entitled *Planning Models Improvement Program: Model Certification.* Models, such as WVA, that are developed by other agencies are subject to approval for use rather than certification *per se* based on an assessment of the documentation provided by the proponents that demonstrate how the model satisfies the certification criteria.

Specifically, the goals and objectives of this assessment were to evaluate the application of the EMCM, the SCM, and the BHCM in the Sabine-Neches Waterway (SNWW) Feasibility Study.

In assessing the application of the three models in the SNWW we focused on the following guidelines.

In accordance with U.S. Army Corps of Engineers (USACE) guidance (ER 1105-2-100)[2], mitigation includes:

- Avoiding the impact altogether by not taking a certain action or part of an action;
- Minimizing impacts by limiting the degree or magnitude of the action and its implementation;
- Rectifying the impact by repairing, rehabilitating, or restoring the affected environment;
- Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action;
- Compensating for the impact by replacing or providing substitute resources or environments. "Replacing" means the replacement of fish and wildlife resources in-kind. "Substitute" means the replacement of fish and wildlife resources out-of-kind. Substitute resources, on balance, shall be at least equal in value and significance as the resources lost (USACE, 2000).

We also considered the following mitigation planning objectives that were established by the Interagency Coordination Team (ICT) for the SNWW study.

- Minimize salinity impacts to the SNWW affected area
- Maximize the use of dredged material in marsh restoration measures
- Meet the goal of no net loss of wetlands
- Replace Average Annualized Habitat Units (AAHUs) on a one-to-one basis
- Replace AAHUs in-kind to the extent practicable
- Mitigate losses in the state in which they occur
- Share dredged material from Sabine Pass equally between Louisiana and Texas

1.4 Contribution to Planning Effort

The USACE Galveston District and the Sabine Neches Navigation District (SNNW) conducted a feasibility study and environmental impact assessment of navigation improvements to the Sabine-Neches Waterway (Texas and Louisiana, SNWW CIP). As part of this study ecological modeling was conducted to evaluate impacts and benefits of navigation features and mitigation measures. WVA was used to assess impacts of the Recommended Plan and evaluate the effectiveness of avoidance and mitigation measures in average annual habitat units.

The WVA was chosen as the most appropriate ecological model for the SNWW project based on a number of factors. It is a quantitative, habitat-based assessment methodology developed to prioritize Louisiana coastal restoration projects submitted for funding under CWPPRA. Although WVA was developed specifically to apply to habitat types present along the Louisiana coast, the same types of coastal habitat (chenier plain, emergent coastal marsh, bottomland hardwoods, and cypress-tupelo swamp) are present throughout the Sabine-Neches coastal watershed in both Texas and Louisiana. In addition, the areas contain the same fish and wildlife communities, similar soils and topography, and the

[2] This regulation provides the overall direction by which Corps of Engineers Civil Works projects are formulated, evaluated and selected for implementation.

Sabine-Calcasieu basins share an interconnected hydrology. Furthermore, the types of variables measured by the WVA community models are sensitive to the types of changes that have been identified as the highest concerns by resource agencies and the general public for the SNWW project. Specifically, these are potential changes in salinity, stress and death of marsh vegetation, and further loss or degradation of already stressed coastal marshes. The variables measured by WVA are also recognized scientifically and technically as important in characterizing overall habitat quality. Variables utilized in the WVA were selected from existing, widely accepted HEP models. A final factor is that variables were established such that data were easily estimated or collected from existing data sources. This was especially important because the study area is exceptionally large, and therefore extensive field data collection efforts were not practical.

The study area was defined by the ICT so as to include all areas that could be affected by potential project impacts in Texas and Louisiana. Navigation improvements are being proposed for the existing 65-mile long deep draft channel from the Gulf of Mexico through a jettied channel at Sabine Pass, the Port Arthur Canal, the Sabine-Neches Canal, and the Neches River Channel to the Port of Beaumont. No improvements are proposed for the Channel to Orange portion of the Sabine-Neches Waterway. Environmental affects have been analyzed for adjacent coastal wetlands in a large surrounding area which includes Sabine Lake and adjacent marshes in Texas and Louisiana, the Neches River channel up to the new Neches River Saltwater Barrier, the Sabine River channel to the Sabine Island Wildlife Management Area, the GIWW west to Star Bayou, the GIWW east to Gum Cove Ridge, the Gulf shoreline extending to 10 miles either side of Sabine Pass, and offshore in the Gulf of Mexico to 13 miles beyond the end of the current channel.

1.5 Report Organization

The report is organized as follows: Section 2 is a review of the EMCM. Section 3 is a review of the SCM and Section 4 is a review of the BHCM. Each of these sections includes an assessment of technical quality, system quality, and usability specific to each model. Model assessment Conclusions and Summary, for specific models and in general terms, are presented in Section 5. References are presented after Section 5. A detailed listing of model components and formulae are presented in Appendix A.

2 COASTAL MARSH COMMUNITY MODELS

2.1 Model Description

2.1.1 Model Applicability

The EMCM is applied to all marsh and open water habitats within the coastal zone. Model application should correspond to the marsh type(s) found within the project area according to the habitat classification data obtained from USGS. However, field investigations or other data may more accurately indicate the marsh type within the project area.

In some instances, a project area may shift from one marsh type to another under FWOP and/or FWP conditions. Salinities may be expected to increase under without-project conditions and cause a shift from intermediate to brackish, or a freshwater diversion may cause a shift to fresher conditions. In those cases, two models are required for the evaluation with a model switch at an intermediate target year. (WVA procedure manual 3-7-06)

EMCMs can be applied to four marsh communities. The marsh communities are characterized as follows:

Saline marshes are located along the Gulf shoreline, and they are subjected to regular tidal inundation with salinity typically averages 16 parts per thousand (ppt). Indicator species in the project area are *Spartina alterniflora, Juncus roemerianus, Spartina patens, Distichlis spicata,* and *Salicornia spp.*

Brackish marshes are located inland of saline marshes with average salinities of 8 ppt. Indicator species in the project area are *Scirpus robustus, Vigna luteola, Amaranthus tamariscinus,* and *Eleocharis parvula.*

Intermediate marshes are located inland of brackish marshes with average salinities of 3-4 ppt. Indicator species in the project area are *Paspalum vaginatum, Scirpus americanus, Scirpus californicus, Phragmites australis,* and *Sagittaria lancifolia.*

Freshwater marshes average salinity is 0.5 to 1 ppt. Salinity in freshwater marshes rarely increases above 2 ppt. Indicator species in the project area are *Panicum hemitomem, Zizaniopsis milacea, Eleocharis quadrangulata,* and *Lemma spp.*

2.1.2 Model Summary

Each EMCM consists of: 1) variables considered important to each habitat type; 2) a Suitability Index (SI) graph for each variable; and 3) mathematical formulae that combine the SIs for each variable into a single value for habitat quality (Habitat Suitability Index or HSI). HSIs are then established for the baseline (existing) condition, for future without-project (FWOP), future with-project (FWP) conditions, and for the mitigated future with-project (MFWP) condition for selected target years (TY) throughout the life of the project.

Habitat units are calculated by multiplying these HSIs by the affected acreage at each target year. The habitat units for the FWOP, FWP, and MFWP conditions are annualized over the project life to determine AAHUs. The impacts or benefits of the project are then quantified by comparing AAHUs between FWP and FWOP, and between MFWP and FWOP conditions.

2.1.3 Model Components

The EMCM is represented by six variables:

V_1 Percent of the wetland covered by emergent vegetation
V_2 Percent of the open water covered by submerged aquatic vegetation
V_3 Marsh edge and interspersion
V_4 Percent of open water areas less than or equal to 1.5 ft deep
V_5 Salinity
V_6 Aquatic organism access

A detailed discussion of these variables and the mathematical formulae that represent and calculate marsh habitat quality in the models can be found in Appendix A.

Habitat Suitability Index Formulae

All of the variable suitability indices (SI) for a specific marsh type (i.e. fresh/intermediate, brackish, or saline) are combined in a mathematical formula, the HSI, which represents the composite habitat quality of the wetland being evaluated. Within each HSI formula, specific variables can be weighted to increase the relative importance of that variable over others in the formula. The HSI formulae were the same as those used by the CWPPRA EnvWG. These formulae can be found in Appendix A.

2.2 Model Evaluation

2.2.1 Assessment Criteria

The EMCM was developed by a Federal Agency other than the USACE; therefore it is subject to approval for use rather than certification (Almodovar et al., 2007). The assessment criteria of a model are based on its: **1) technical quality, 2) system quality, and 3) usability**. An evaluation of the applicable components of the EMCM with respect to the assessment criteria is presented later in this section.

A model that meets the **technical quality** criterion is one that is based on well-established contemporary science and/or theory, and is a realistic representation of the actual system. Additionally, the model needs to clearly address the defined analytical requirements, which must be supported by valid model assumptions. Technical quality is also ensured when formulae used in the model are accurate and done correctly, and reflect the relationships

among variables as specified in the system description. Finally, assumptions, data requirements and model outputs must be fully documented.

System quality refers to the quality of the entire system regarding model development, use and support. The quality of the system is ensured by system level functional testing of hardware and software components, including the assessment of the suitability of the software or programming language. It includes model testing and validation using test datasets, the availability of hardware and software to model users, and the third party interoperability.

Usability refers to the ability to access model programs or files, the skills required for model use, data requirements and ease of availability, model's user friendliness, and usefulness of the model outputs to support project analysis. Additional components of this criterion are the availability of model documentation and technical support, and the ease for verification of model calculations and outputs.

2.2.2 Approach to Model Testing

Technical quality assessment of the EMCM was performed to **determine if the model satisfies general USACE guidelines for mitigation and specific mitigation objectives for the SNWW CIP.** Review of model calculations and formulae, as well as a system quality and usability evaluation were based on direct observations that resulted from the general use and operation of the model. Telephone meetings were held with members of the modeling team from USACE and U.S. Fish and Wildlife Service (USFWS) to present partial model evaluation results and to discuss specifics of the model that allowed the evaluation team to gain valuable insight into the development and application of the EMCM.

The version of the EMCM templates used for review and testing was provided via electronic transfer by the USACE in March of 2008. In addition to the model template, examples of model applications which included data inputs and outputs for the SNWW project area were provided by USACE and used for model testing and validation. Model applications for Texas and Louisiana hydrologic units[3] were used for testing and validation. For saline marshes the model spreadsheets for Sabine Lake Ridges, Johnson's Bayou Ridge, and Texas Point were evaluated. For brackish marshes, model spreadsheets for Black Bayou, Texas Point, and West Johnson's Bayou were evaluated. For intermediate marshes models spreadsheets for Bessie Heights, Black Bayou, and Southeast Sabine were evaluated. For freshwater marshes, model spreadsheets for Southwest Gum Cove, Perry Ridge and North Neches River were evaluated.

[3] Hydrologic units (hydro-units) are planning units with specific topographic and hydrologic characteristics used to facilitate impact evaluation (USACE, 2007).

2.2.3 Technical Quality Assessment

2.2.3.1 Review of Theory and External Model Components

USACE guidance ER 1105-2-100 requires that the Nation's wetlands be restored, enhanced, replaced and/or preserved when these are affected or lost during the implementation of water and related land resources projects. The ecological benefits of mitigation should compensate for the functional loss resulting from the allowed wetland impact. Furthermore, this USACE guidance document defines compensation for an impact to a wetland as "compensating for the impact by replacing or providing substitute resources or environments. 'Replacing' means the replacement of fish and wildlife resources in-kind. 'Substitute' means the replacement of fish and wildlife resources out-of-kind." The guidance clearly states "this regulation provides the overall direction by which Corps of Engineers Civil Works projects are formulated, evaluated and selected for implementation." Within the context of these guidelines, the EMCM is theoretically sound in that it measures the suitability of coastal marsh habitat for fish and wildlife communities.

In the evaluation mitigation measures, a reference or a baseline wetland condition allows comparing impacts among proposed alternatives; it allows assessing if proposed mitigation would effectively compensate for the impact, and determining if, once implemented, mitigation actions have actually compensated for impacts or losses (Brinson and Rheinhardt, 1996). By comparing FWOP and FWP conditions for selected target years throughout the life of the mitigation initiative, the EMCM satisfies project needs for comparing alternative scenarios.

The EMCM was initially developed for the assessment of proposed restoration projects in the Louisiana coastal zone, thus the application of the model is restricted to areas with the same type of marshes as those present in coastal Louisiana. Since the ecosystems in the SNWW project area belong to the same ecological regions as those in western coastal Louisiana according to Griffith et al. (2004) and Daigle et al. (2006), the application the EMCM in the SNWW project area has no perceptible ecological restrictions.

The model incorporates regionally appropriate protocols for quantifying habitat suitability. The model was defined based on previously tested models (i.e. HEP/USFWS; WVA/CWPRRA), and was used by regional and federal agencies for assessing wetland function. Theoretical supports of these models come from ecological theories related to habitat selection, niche partitioning, and limiting factors (Barry et al., 2006). These models have been used extensively in characterizing ecosystems (Williams 1988, VanHorne and Wiens 1991, Brooks 1997, Brown et al. 2000, Store and Jokimaki 2003, Shifley et al. 2006, Van der Lee et al. 2006). However, the validity of these assumptions has been questioned in some instances (e.g. Van Horne and Wiens, 1991; Roloff and Kernohan, 1999; Barry et al., 2006). SI graph construction is based on these models as well as on professional and research consultation outside the SNWW Habitat Group. Monitoring data, scientific literature, professional judgment and knowledge of the assessors of the project area is used to predict changes to baseline conditions, yielding quantifications of marsh habitat suitability with and without project scenarios.

The EMCM relies on the Hydrodynamic-Salinity Model (H-S) to compute hydrodynamics and salinity transport in the SNWW study. The H-S model takes into account forcing due to tides, freshwater inflows, wind, coriolis, and density gradients due to salinity variation, and accounts for precipitation and evaporation. The H-S model was calibrated and verified using field observations collected by the Engineer Research and Development Center (ERDC) during and long-term data collection effort at 16 locations (stations) in the study area from May 16, 2001 through January 10, 2002 (Fagerburg 2003). In addition to the long term effort additional velocity and salinity data were collected during a short-term, intensive data collection effort at 10 transects over a 25-hour period during a spring tide event.

Land loss projections were used in the preparation of baseline data. Limitations and uncertainties are associated with any prediction of land loss. The limitations and uncertainties associated with the SNWW project are listed below.

- Since the rates reflect observed changes over specific time periods, they include effects of actual hurricanes, tropical storms and droughts that occurred during the period of observation, rather than the average probability of these events.

- Effects of relative sea level rise are reflected in the historical analysis, and are assumed to continue at the same rate as in the past. No attempt is made to predict potential changes in relative sea level rise associated with climate change or changes in subsidence rates.

- Changes in land loss rates predicted for CWPPRA projects are assumed to be 100 percent effective, since all are too early in their project lives to assess actual performance.

- All of the rates are based on time periods after heaviest oil/gas extraction, and after canal/levee construction. They capture the lingering effects of these activities, but not the localized high subsidence rates that occurred earlier.

- The direct, linear relationship between productivity decreases and land loss rate increases is based upon the assumption that abrupt salinity increases stress marsh vegetation, which leads to the death of a small percentage of that vegetation, the subsequent erosion of marsh soils, and the creation of open water.

2.2.3.2 Review of Representation of the System

The regulation used by the USACE for issuing dredge and fill permits under Section 404 of the Clean Water Act (CWA), defines wetlands as "those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas" (33 CFR 328.3(b)). Under this definition, the EMCM represents the actual system through the variables that are included that make reference to presence of a specific type of vegetation (i.e. V_1 and V_2) that is subjected to periodic inundations. Additionally, the

model includes information regarding the condition of the inundating and/or saturating waters (V_4 and V_5).

Variables in the model assess the quality of the system as fish and wildlife habitat. The models make little reference to functional characteristics of marsh plant communities or other system components (e.g. underground biomass accumulation, nutrient cycling, and biological diversity). However, model variables and habitat suitability are assumed to be surrogates for wetland components and processes not considered directly by the models. The model incorporate key variables that describe habitat suitability and includes habitat units that allow determining net losses based on multiple scenarios.

2.2.3.3 Review of Analytical Requirement

Analytical requirements associated with the EMCM include its ability to identify and assess the ecological functions of marsh ecosystems that may be affected by the improvement of SNWW navigation conditions. Additionally, analytical requirements include the ability of the model to assess compensation for damages or losses that may result from the SNWW navigation improvements. Marsh ecological function and compensation assessment is determined based on field and secondary data, as well as professional judgment, in accordance with established USACE protocol. The model includes variables sensitive to changes in marsh ecological condition that are summarized as habitat suitability indices. These indices determine the ability of emergent marshes to provide habitat for fish and wildlife. When the suitability index is expressed in terms of the extent of the potentially affected marsh area during the life of the project, it allows assessing compensatory mitigation requirements.

2.2.3.4 Review of Model Assumptions

The basic assumptions that guide the WVA assessment methodology and that apply to the EMCM are:

- Optimal conditions for fish and wildlife can be characterized within a given coastal wetland habitat type;
- Existing or predicted conditions can be compared to a desired condition to provide an index of habitat quality;
- The resulting HSI of a model has a linear relationship with the suitability of a coastal wetland system in providing fish and wildlife habitat;
- Coastal wetland functions and values (e.g. storm-surge protection, flood water storage, water quality, and nutrient import/export) are positively correlated with fish and wildlife habitat quality.

All the above assumptions operate under an the underlying assumption that in general, the ability of a wetland to provide suitable fish and wildlife habitat is sufficient to characterize

overall wetland ecological functions, a limitation that has been noted previously. However, as also previously noted, this assumption of fish and wildlife habitat as a proxy for overall wetland ecological function does meet the requirements of USACE mitigation guidelines.

Assumptions specific to the EMCM are as follows:

Parameter	Description	Assumptions	Assessment
V_1	Percent of wetland covered by emergent vegetation	An area that is 100 percent shallow water is assumed to have minimal habitat suitability (SI = 0.1). For all marsh types, optimal vegetative coverage is assumed to be 100 percent (SI = 1.0).	These assumptions appropriately reflect the importance of emergent vegetation as habitat. No mention is made of plant community composition or the presence or absence of invasive species.
V_2	Percent of Open Water Covered by Submerged Aquatic Vegetation	Open water with no aquatics within fresh, intermediate, and brackish marshes is assumed to have low suitability (SI = 0.1). Optimal conditions within fresh, intermediate, and brackish marshes are assumed when 100 percent of the open water is dominated by aquatic vegetation (SI = 1.0). A saline marsh with no aquatic vegetation is assigned an SI of 0.3. Optimal coverage by aquatic plants in a saline marsh is assumed to be 100 percent (SI = 1.0)	The assumptions reflect the importance of aquatic plants as food and cover for fish and wildlife. In saline marshes the SI is appropriately adjusted to reflect the importance of saline open waters to marine organisms. No mention is made of plant community composition or presence of non-native species.
V_3	Marsh Edge and Interspersion	Optimal conditions (SI = 1.0) are assumed if the entire area is solid marsh or marsh with natural stream courses and tidal channels. Open water is assumed to have low suitability (SI = 0.1).	These assumptions appropriately reflect the importance of the marsh/open water edge as habitat for fish and shellfish. Similarly, a low suitability index reflects marsh degradation.
V_4	Percent of Open Water Areas Less Than or Equal to 1.5 ft Deep	Optimal shallow water conditions in fresh/intermediate marshes are assumed when 80-90 percent of the open water is equal to or less than 1.5 ft deep (SI = 1.0). Optimal shallow water conditions	Assumptions take into account the biological productivity of shallow water in relation to deeper water. That is appropriate. The assumptions also appropriately reflect the importance of shallow water

Parameter	Description	Assumptions	Assessment
		in brackish and saline marshes are assumed when 70-80 percent of the open water is equal to or less than 1.5 ft deep (SI = 1.0). The SI for 100 percent shallow water is slightly less in saline marshes than in brackish marshes. This reflects the importance of deeper tidal channels for estuarine organism access into saline marshes.	as bottom habitat for water fowl, better foraging habitat for wading birds, and more favorable conditions for the growth of aquatic vegetation. The adjustment of the SI to reflect the importance of deeper tidal channels to allow estuarine organisms access into saline marshes is appropriate.
V_5	Salinity	Optimum salinity ranges assumed by the model for the various habitat types are as follows: Fresh marsh ≤ 2 ppt, intermediate marsh ≤ 4 ppt, brackish marsh ≤ 10 ppt, and saline marsh ≥ 9 and ≤ 21 ppt.	These assumptions appropriately reflect typical salinities of the four marsh types.
V_6	Aquatic Organism Access	A high degree of surface hydrologic connectivity with adjacent systems provides high organism access, as well as, greater nutrient exchange. Optimal conditions are assumed when the entire wetland area is accessible and access points are unobstructed. Brackish and saline marshes are assumed to be more important than fresh/ intermediate marshes as habitat for estuarine-dependent fish and shellfish.	The assumptions appropriately reflect the importance of organism access to the marsh. It is appropriate to assume, based on proximity that brackish and saline marshes are more important than fresh/ intermediate marshes as habitat for estuarine-dependent fish and shellfish.

2.2.3.5 Review Ability to Evaluate Risk and Uncertainty

The model does not include a direct way to perform sensitivity analysis. However, to assess how project initial conditions vary, the value of each variable was varied 10, 20, and 30% while holding the others constant. This is a simple way to perform model sensitivity analysis (Hamby, 1994; Jackson et al., 2000). If changing the value of a particular variable by 10% results in more than 10% change in model output, the model is considered to be sensitive to that particular variable (Jackson et al., 2000). Following this rule for the fresh/intermediate component of the EMCM, the model is most sensitive to changes in V1 (percent emergent vegetation) with the model output varying 6.77 % with a 30% change in

V_1 (Figure 1). Since model output does not react significantly to changes in any of the input values, precision estimates of model variables are not considered to be critical and the uncertainty in model behavior is considered to be low. Model outputs responded as expected to changes in model input.

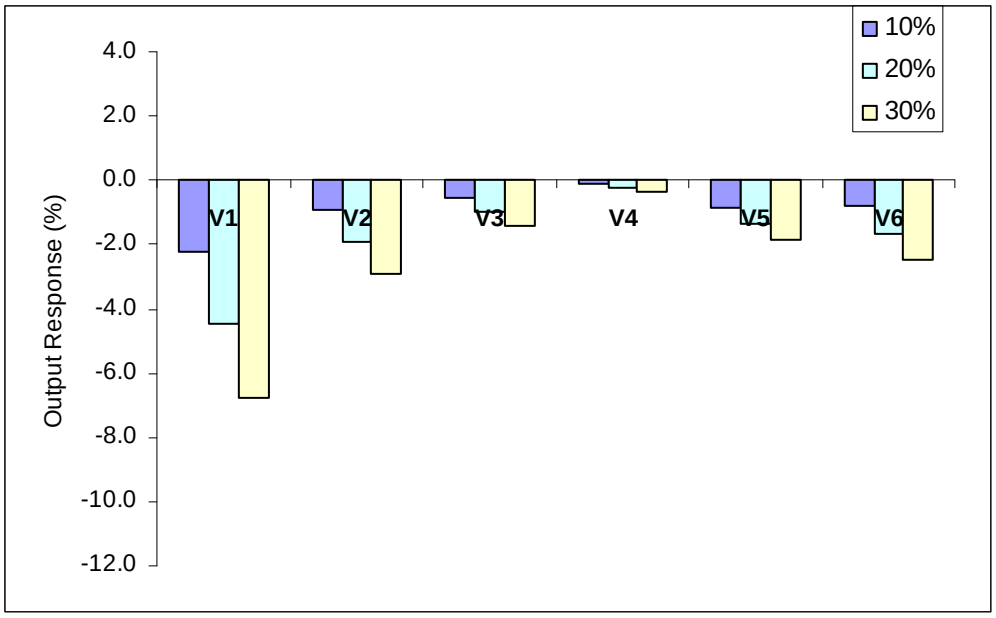

Figure 1. Changes in fresh/intermediate component of the EMCM output with changes in input data. Variables SI values were decreased repeatedly while holding the others constant.

2.2.3.6 Review Ability to Calculate Benefits for Total Project Life

The EMCM calculates habitat units for FWOP, FWP, and MFWP conditions. These units are annualized over the life of the project to determine AAHUs. The impacts or benefits of the project are then quantified by comparing AAHUs between FWP and FWOP, and between MFWP and FWOP conditions. This procedure fulfills the USACE requirement that compensation be evaluated using a unit of comparison that measures quality and quantity of habitat over time.

2.2.3.7 Review of Model Calculations/Formulae

The model is deterministic since for the same initial conditions and time period projected, they always give the same result. Formulae internal to the model were verified relative to the formulae presented in the WVA procedure manual. The accuracy of external calculations to the model was not verified. The following internal formulae of the EMCM were verified:

- Suitability Index (SI) Formula for each variable

- Habitat Suitability Index (HSI) Formulae
- Habitat Units (HUs) Formula

  HU = HSI x Area of available habitat

- Average Annual Habitat Units (AAHUs) Formula

$$\text{AAHUs} = \frac{\text{Sum of HUs across all years in the period of analysis}}{\text{Number of years in the life of the project}}$$

Suitability Index calculations are based on external estimates (i.e. suitability index graphs). These external components were not verified; however, these were assumed to be correct as they are based on established protocols of the HEP and WVA methodologies. The review of internal formulae and calculations found no errors in the models internal formula calculations or function statements.

2.2.4 System Quality

2.2.4.1 Review of Supporting Software

The EMCM is a Microsoft Excel® computer-based model which includes data entry or input in tables within a worksheet. Formulae within the analysis tables for FWOP and FWP conditions follow the protocols defined in the model components section of this report and are linked to the data entry for specific variables. Model calculations are performed based on the input values to yield the model output (AAHUs) that allow assessing project benefit/impact.

2.2.4.2 Review of Programming Accuracy

There is no computer programming associated with the EMCM. The model consists of formulae defined within an Excel spreadsheet linked to the various data entries for specific model variables. These formulae/linkages were reviewed and verified for accuracy.

Since the EMCM is Microsoft Excel® supported, the data and results can be easily imported into similar software programs. Both model inputs and results can be easily made available to other users; therefore, interoperability is not a limitation. Since Excel is a spreadsheet program that can perform numerical calculations such as those required by the model, it is appropriate software for model development.

2.2.4.3 Review of Model Testing and Validation

Model testing and validation were performed by running the model using three different test datasets form each marsh community type provided by USACE and comparing the results. Models/test datasets used were:

- Saline marshes: Sabine Lake Ridges, Johnson's Bayou Ridge, and Texas Point.
- Brackish marshes: Black Bayou, Texas Point, and West Johnson's Bayou.
- Intermediate marshes: Bessie Heights, Black Bayou, and Southeast Sabine.
- Freshwater marshes: Southwest Gum Cove, Perry Ridge and North Neches River.

Results are presented below:

Marsh Type	Hydrologic Unit	Emergent Marsh Net AAHUs	Open Water Net AAHUs	Net Change in AHHUS due to Project
Saline	Sabine Lake Ridges	-10.32	3.23	-7.31
Saline	Johnson's Bayou Ridge	-6.80	0.89	-5.09
Saline	Texas Point	-34.34	18.32	-22.64
Brackish	Black Bayou	-2.55	-4.23	-3.02
Brackish	Texas Point	-47.49	-7.88	-36.49
Brackish	West Johnson's Bayou	-2.90	-0.92	-2.35
Intermediate	Bessie Heights	-22.25	-35.55	-26.54
Intermediate	Black Bayou	-622.70	-622.78	-622.72
Intermediate	Southeast Sabine	0.49	-11.70	-3.44
Fresh	Southwest Gum Cove	-22.70	-26.11	-23.80
Fresh	Perry Ridge	-20.54	-362.44	-130.83
Fresh	North Neches River	34.47	37.38	-2.92

Model outputs were consistent with variable/data input as described in the accompanying documentation (USFWS, 2002). In the above examples net changes in wetlands AAHUs were predicted due to project implementation suggesting that model is able to discriminate between different scenarios as conditions change. Future conditions were determined based on scientifically-based projections, and professional judgment and knowledge of the area by the SNWW model assessment team.

2.2.5 Usability

2.2.5.1 Review of Data Availability

Model variable inputs were determined by the SNWW ICT's Habitat Workgroup based on USFWS Excel worksheets for each of the habitat models which automatically calculated SI and HSI values, habitat units, and AAHUs. Baseline and future values were developed by

the Habitat Work Group using land loss projections, monitoring data, scientific literature, professional judgment, and personal knowledge of the project area. The ICT established a Modeling Workgroup to advise and assist in development of the H-S model for the SNWW study.

2.2.5.2 Review of Results

The EMCM's output provides useful information in the form of AAHUs that allows the user to support project analysis and easily export the results into project management documentation. The model quantifies the impacts the proposed project will have on the marshes in the SNWW project area by a providing an estimate of then number of HUs that will be available for fish and wildlife every year during the life of the project versus the number of HUs that will be available if the proposed action is not implemented. To obtain an estimate of compensation for losses in area units, the model can be run adding acreages in FWP conditions until the target number of AAHU's lost with the project are replaced.

2.2.5.3 Review of Model Documentation

It would be useful from the point of view of the model user to have all the related documents (i.e. introduction to WVA methodology, procedural manual, and EMCM) as one updated file with a link to the model spreadsheet (if made available electronically). Although the EMCM is considered to be transparent in terms of allowing for a relatively easy verification of calculations and outputs, the lack of integration between documents and spreadsheet makes the community model difficult to navigate when it comes to following protocols and instructions to model usage.

2.3 Model Assessment Summary

A summary of the technical assessment of the EMCM as described in *Protocols of Certification of Planning Models* (Almodovar et al., 2007) in accordance with requirements specified by USACE (2005) are presented in Section 5.

3 SWAMP COMMUNITY MODEL

3.1 Model Description

3.1.1 Model Applicability

The SCM was developed in 2001 by the EnvWG of the Planning and Evaluation Subcommittee of Louisiana's CWPPRA Technical Committee by modifying a habitat assessment model for freshwater swamps originally developed by the Louisiana Department of Natural Resources (LDNR) (USFWS, 2002). The SCM is a WVA tool and was developed to evaluate the impacts of proposed restoration projects by determining the suitability of swamp habitat in providing resting, foraging, and nesting habitat for a wide variety of wildlife. For its application in the study area, the SNWW ICT established a Habitat Workgroup represented by state (Texas and Louisiana) and federal agencies.

The SCM is applicable for sites where the woody canopy cover is at least 33 percent of the surface area, and at least 60 percent of the canopy consists of any combination of bald cypress (*Taxodium distichum*), tupelo gum (*Nyssa aquatica*), red maple (*Acer rubrum*), buttonbush (*Cephalanthus occidentalis*), and/or planer tree (*Planera aquatica*) (LDNR, 1994; USFWS, 2002). The 33 percent canopy cover criterion is considered a general "rule of thumb" for model application, since in some cases sites with less than 33% canopy cover can still provide functions and values associated with a swamp ecosystem (USFWS, 2002). When more than 40 percent of the woody vegetation canopy consists of species such as oaks (*Quercus* spp.), hickories (*Carya* spp.), American elm (*Ulmus Americana*), green ash (*Fraxinus pennsylvanica*), sweetgum (*Liquidambar styraciflua*), sugarberry (*Celtis laevigata*), boxelder (*Acer negundo*), common persimmon (*Diospyros* spp.), honeylocust (*Gleditsia triacanthos*), red mulberry (*Morus rubra*), eastern cottonwood (*Populus deltoids*), American sycamore (*Platanus occidentalis*), among other woody species, the SCM should not be used; a bottomland hardwood community model (BHCM) should be applied instead (LDNR, 1994; USFWS, 2002).

3.1.2 Model Summary

The SCM is a deterministic model that consists of: 1) four variables that allow determination of swamp habitat suitability for fish and wildlife communities; 2) a SI graph or matrix for each variable; and 3) a mathematical formula that combines the SI for each variable into a single value for habitat suitability - HSI. The HSIs are established for FWOP and FWP conditions for selected target years throughout the life of the project. By multiplying HSIs by the project area acreage at each target year, HUs are calculated. The HUs for the FWOP and FWP conditions are annualized over the project life to determine AAHUs. The difference in AAHUs between FWOP and FWP conditions represents the net benefits or impacts of a project in terms of habitat quantity and quality (USFWS, 2006).

The original swamp model developed by LDNR resulted from a modification of USFWS' HEP, which consisted of a set of variables considered important for determining the suitability of a site to support a variety of fish, forest birds, and small mammal species (LDNR, 1994).

The LDNR swamp model consisted of six variables (stand structure, stand maturity, hydrology, size of contiguous forested area, suitability and traversability of surrounding land use, and disturbance). Because the LDNR model was developed for regulatory purposes, it was modified so that it would be more sensitive to the impacts of proposed restoration projects within the CWPPRA program. As a result the SCM was modified by the EnvWg (USFWS, 2002); the variables size of the contiguous forested area, suitability and traversability of surrounding land uses, and disturbance were eliminated from the model and a salinity variable was included. Thus, the final SCM includes four variables: 1) stand structure, 2) stand maturity, 3) water regime, and 4) mean high salinity during the growing season.

3.1.3 Model Components

The four variables that represent and calculate swamp habitat quality in the model are:

V_1 Stand Structure
V_2 Stand Maturity
V_3 Water Regime
V_4 Mean High Salinity during the Growing Season

More detail about these variables and the mathematical formula that represent and calculate swamp habitat quality in the model can be found in Appendix A.2.

Habitat Suitability Index Formula

All of the variable suitability indices are combined in a mathematical formula to calculate the HSI, which represents the composite habitat quality. The HSI formula can be found in Appendix A.2.

3.2 Model Evaluation

3.2.1 Assessment Criteria

The SCM is a regional/local model developed by a Federal Agency different than the USACE; therefore it is subject to approval for use rather than certification (Almodovar et al., 2007). The assessment criteria of a model are based on its: **1) technical quality, 2) system quality, and 3) usability**. An evaluation of the applicable components of the SCM with respect to the assessment criteria is presented in Sections 3.2.3, 3.2.4, and 3.2.5.

A model that meets the **technical quality** criterion in one that is based on well-established contemporary science and/or theory, and is a realistic representation of the actual system. Additionally, the model needs to clearly address the analytical requirements defined, which must be supported by valid model assumptions. Technical quality is also ensured when formula used in the model are accurate, and reflect the relationships among variables as specified in the system description. Finally, assumptions, data requirements and model outputs must be fully documented.

System quality refers to the quality of the entire system regarding model development, use and support. The quality of the system is ensured by system level functional testing of hardware and software components, including the assessment of the suitability of the software or programming language. It includes model testing and validation using test datasets, the availability of hardware and software to model users, and third party interoperability.

Usability refers to the ability to access model programs or files, the skills required for model use, data requirements and ease of availability, model's user friendliness, and usefulness of the model outputs to support project analysis. Additional components of this criterion are the availability of model documentation and technical support, and the ease for verification of model calculations and outputs.

3.2.2 Approach to Model Testing

The technical quality assessment was performed considering if the SCM satisfies general USACE guidelines for mitigation and specific mitigation objectives for the SNWW navigation expansion project. An analysis of wetland functioning description and system representation was done to assess how the SCM integrates indicators of wetland processes for determining compensation mitigation. Review of model calculations and formulae, as well as system quality and usability evaluation, were based on direct observations that resulted from the general use and operation of the model. Telephone meetings were held with members of the modeling team from USACE and USFWS to present partial model evaluation results and to discuss specifics of the model that allowed the evaluation team to gain valuable insights into the development and application of the SCM.

The version of the SCM template used for review and testing was provided via electronic transfer by Kevin J. Roy of the USFWS in March, 2008. In addition to the model template, examples of model applications which included data inputs and outputs for the SNWW project area were provided by USACE and used for model testing and validation. Model applications for Texas and Louisiana hydrologic units[4] (i.e. TX1 – North Neches River, TX2 - Neches Lake Bayou, and LA/TX1- Sabine Island) were used for testing and validation.

3.2.3 Technical Quality Assessment

The technical quality evaluation considered the theoretical basis of the SCM, the degree to which the model represents the actual system, the validity of the assumptions used in creating the model, the ability of the model to estimate project benefits and impacts, and the suitability of the internal and external model components and accuracy of formulae and calculations.

[4] Hydrologic units (hydro-units) are planning units with specific topographic and hydrologic characteristics used to facilitate impact evaluation (USACE, 2007).

3.2.3.1 Review of Theory and External Model Components

USACE guidance ER 1105-2-100 requires that the Nations wetlands be restored, enhanced, replaced and/or preserved when these are affected or lost during the implementation of water and related land resources projects. The ecological benefits of mitigation should compensate for the functional loss resulting from the allowed wetland impact. Furthermore, this USACE guidance document defines compensation for an impact to a wetland as "compensating for the impact by replacing or providing substitute resources or environments. 'Replacing' means the replacement of fish and wildlife resources in-kind. 'Substitute' means the replacement of fish and wildlife resources out-of-kind." The guidance clearly states "this regulation provides the overall direction by which Corps of Engineers Civil Works projects are formulated, evaluated and selected for implementation." Within the context of these guidelines, the SCM is theoretically sound in that it measures the suitability of swamp habitat for fish and wildlife communities.

In the evaluation mitigation measures, a reference or a baseline wetland condition allows comparison of impacts among proposed alternatives; it allows assessment if proposed mitigation would effectively compensate for the impact, and determining if, once implemented, mitigation actions have actually compensated for impacts or losses (Brinson and Rheinhardt, 1996). By comparing FWOP and FWP conditions for selected target years throughout the life of the mitigation initiative, the SCM satisfies project needs for comparing alternative scenarios.

It has been mentioned that the SCM was initially developed for the assessment of proposed restoration projects in the Louisiana coastal zone, thus the application of the model is restricted to areas with the same type of swamps as those present in coastal Louisiana. Since the swamp ecosystems in the SNWW project area belong to the same ecological regions as those in western coastal Louisiana according to Griffith et al. (2004) and Daigle et al. (2006), the application the SCM in the SNWW project area has no perceptible ecological restrictions.

The model incorporates regionally appropriate protocols for quantifying habitat suitability. The model was defined based on previously tested models (i.e. HEP/USFWS; HAM/LDNR; WVA/CWPRRA), used by regional and federal agencies for wetland's assessment functions. Theoretical supports of these models come from ecological theories related to habitat selection, niche partitioning, and limiting factors (Barry et al., 2006). These models have been used extensively in characterizing ecosystems (Williams 1988, VanHorne and Wiens 1991, Brooks 1997, Brown et al. 2000, Store and Jokimaki 2003, Shifley et al. 2006, Van der Lee et al. 2006). However, the validity of these assumptions has been questioned in some instances (e.g. Van Horne and Wiens, 1991; Roloff and Kernohan, 1999; Barry et al., 2006). Suitability Index (SI) graphs are based on these models as well as on professional and research consultation outside the SNWW Habitat Group. Monitoring data, scientific literature, professional judgment and knowledge of the assessors of the project area is used to predict changes to baseline conditions, yielding quantifications of swamp habitat suitability without and with project scenarios. Additionally, the SCM relies on an external salinity model to establish baseline salinity conditions and future salinity impact on wetland habitat condition.

3.2.3.2 Review of Representation of the System

The regulation used by the USACE for issuing dredge and fill permits under Section 404 of the CWA, defines wetlands as "those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas" (33 CFR 328.3(b)). The model represents the actual swamp system through the variables that are included that make reference to the presence of a specific type of vegetation (i.e. V_1 and V_2) that is subjected to periodic inundations. Additionally, the model includes information regarding the condition of the inundating and/or saturation waters (V_3). Although the model does not include specific information on saturated soil conditions, variables V_1, V_2, and V_3 are appropriate surrogates to describe this component of swamp ecosystems.

Variables in the model assess the quality of the system as fish and wildlife habitat. The model makes little or no reference to the functional characteristics of swamp plant communities or other system components (e.g. underground biomass accumulation, nutrient cycling, and biological diversity). However, model variables and habitat suitability are assumed to be surrogates for wetland components and processes not considered by the model and an assessment approach that includes the goals set for mitigation for the SNWW project area. The SCM incorporates key variables that describe habitat suitability and includes habitat units that allow determination of net losses based on multiple scenarios.

3.2.3.3 Review of Analytical Requirement

Analytical requirements associated with SCM include its ability to identify and assess the ecological functions of swamp ecosystems that may be affected by the improvement of SNWW navigability. Additionally, analytical requirements include the ability of the model to assess compensation for damages or losses that may result from the SNWW CIP. Swamp ecological function and compensation assessment is determined based on field and secondary data, as well as professional judgment, in accordance with an established protocol as listed in Appendix A-2. The model includes variables sensitive to changes in swamp ecological condition that are summarized as a habitat suitability index that allows determination of the ability of swamps to provide required habitat for fish and wildlife activities. When the suitability index is expressed in terms of the extent of the potentially affected swamp area during the life of the project, it allows assessment of compensatory mitigation requirements.

3.2.3.4 Review of Model Assumptions

The basic assumptions that guide the WVA methodology and that apply to the SCM are:

- Optimal conditions for fish and wildlife can be characterized within a given coastal wetland habitat type;

- Existing or predicted conditions can be compared to a desired condition to provide an index of habitat quality;

- The resulting HSI of a model has a linear relationship with the suitability of a coastal wetland system in providing fish and wildlife habitat;

- Coastal wetland functions and values (e.g. storm-surge protection, flood water storage, water quality, and nutrient import/export) are positively correlated with fish and wildlife habitat quality.

All the above assumptions operate under an the underlying assumption that in general, the ability of a wetland to provide suitable fish and wildlife habitat is sufficient to characterize overall wetland ecological functions, a limitation that has been noted previously.

Assumptions specific to the SCM are:

Parameter	Description	Assumptions	Assessment
V_1	Stand Structure	Variable defined based on food availability to wildlife (soft mast, other edible seeds, invertebrates, and vegetation) and ability for a swamp to provide resting, foraging, breeding, nesting, and nursery habitat; Variable is calculated using six possible combinations of the relative coverage of structure components (i.e. herbaceous vegetation, scrub-shrub/midstory cover, overstory canopy); Tree species composition is not considered a limiting factor.	Assumptions related to the importance of stand structure for providing food and other activities to fish and wildlife are appropriate. No mention is made of the percentage of dead or dying trees or shrubs, or the presence of undesirable overstory/understory plant species.
V_2	Stand Maturity Stand age/stand density are combined to score this variable - calculated separately for bald cypress and tupelo gum	Stand maturity - it is assumed that swamps with mature, sizeable trees provide important habitat for wildlife and invertebrates and as the older/weaker trees die additional habitat is provided. Stand density (measured in terms of basal area) - allows evaluation of mature swamps	Assumptions are appropriate for providing habitat for fish and wildlife. However, under natural conditions swamp ecosystems present a wide range of age and size distribution that includes mature and younger trees and different age/size combinations of bald cypress and tupelo gum (Conner and

Parameter	Description	Assumptions	Assessment
		that present an overstory with a few widely-scattered, mature bald cypress but that fail to provide important habitat components of a mature swamp.	Buford, 1998).
V_3	Water Regime	Variable considers the duration and amount of water flow/exchange and is assigned according to the various combinations of the flow/exchange and flooding duration; The optimal water regime is assumed to be seasonal flooding with abundant and consistent riverine/tidal input and water flow-through; Seasonal flooding with periodic drying cycles is assumed to contribute to increased nutrients, increased vertical structure complexity, and increased recruitment of dominant overstory trees; Optimal water flow-through maximizes fish and wildlife habitat use; Temporary flooding is also assumed to be desirable.	Assumptions are appropriate; water regime (hydrology) is probably the most important variable in defining wetland process and structure (Zedler, 1996; Mitsch and Gosselink, 2000).
V_4	Mean High Salinity during the Growing Season	Optimal habitat suitability is assumed to occur at mean high salinities less than 1.0 ppt, and to decrease rapidly at mean high salinities above 1.0 ppt. Bald cypress may tolerate some degree of salinity; however other swamp species such as tupelo gum and many herbaceous species are salinity-sensitive.	Assumptions are appropriate; the effect of salinity on swamp ecosystems is well documented (e.g. McLeod et al., 1996; Conner et al., 1997; Conner and Inabinette, 2003). Additionally, the assessment of salinity impacts are an important aspect of the SNWW mitigation objectives.

3.2.3.5 Review Ability to Evaluate Risk and Uncertainty

The SCM allows a quantitative evaluation of losses that are specific to swamp habitat that might be affected by the SNWW navigation improvement project. Similarly, the model evaluates compensatory mitigation with a habitat unit that allows quantification of the value of habitat quantity and quality for fish and wildlife over the period of analysis.

The model does not include a direct way to perform sensitivity analysis. However, to assess how project initial conditions vary, the value of each variable was varied repeatedly while holding the other constant until a 10% change in model output was observed. This is a simple way to perform model sensitivity analysis (Hamby, 1994; Jackson et al., 2000). If changing the value of a particular variable by 10% results in more than 10% change in model output, the model is considered to be sensitive to that particular variable (Jackson et al., 2000). Following this rule, the model is most sensitive to changes in V_1 and V_3 with the model output (AAHUs) varying 10% with a 30% change in SI value for each variable (Figure 2). A 10% change in model output was observed when these two variables were varied simultaneously by 16%. Since model output does not react significantly to changes in any of the input values, precision estimates of model variables are not considered to be critical and the uncertainty in model behavior is considered to be low. Model outputs responded as expected to changes in model input.

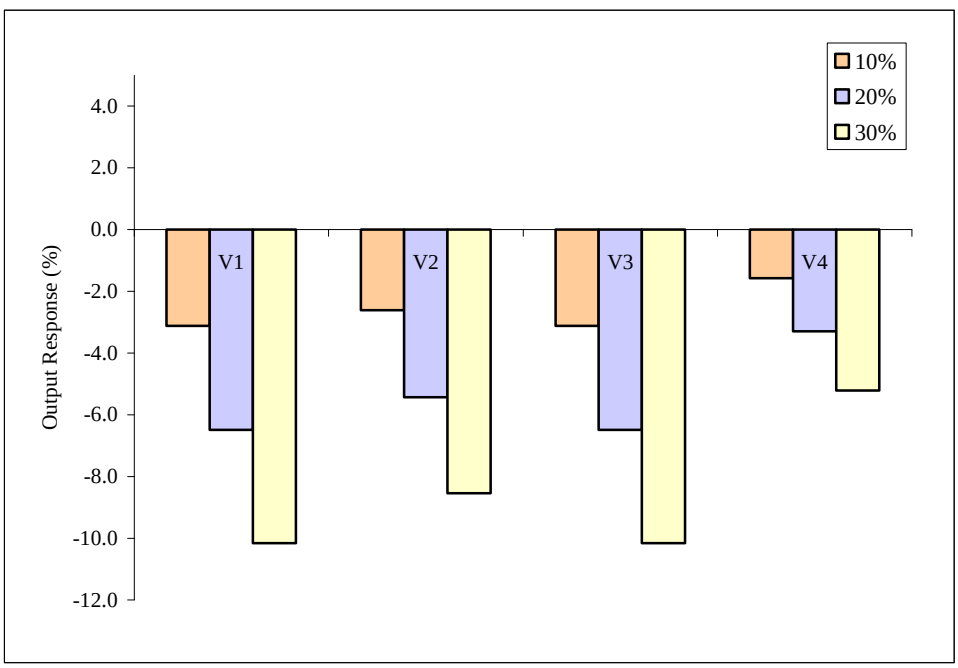

Figure 2. Changes in SCM output with changes in input data. Variables SI value were decreased repeatedly while holding the other constant until a 10% change in output value was observed.

3.2.3.6 Review Ability to Calculate Benefits for Total Project Life

The SCM calculates habitat units for FWOP and FWP conditions. These units are annualized over the life of the project to determine AAHUs. The impacts or benefits of the project are then quantified by comparing AAHUs between FWP and FWOP. This procedure fulfills the USACE requirement that compensation be evaluated using a unit of comparison that measures quality and quantity of habitat over time.

3.2.3.7 Review of Model Calculations/Formulae

The model is deterministic since for the same initial conditions and time period projected, it always gives the same result. Formulae internal to the model were verified following the SCM protocols as defined in Appendix A-2. The accuracy of external calculations to the model was not verified. The following internal formulae of the SCM were verified:

- Suitability Index (SI) Formula for each variable
- Habitat Suitability Index (HSI) Formula
- HSI = ((SI Stand structure)^{3} x (SI Stand maturity)$^{2.5}$ x (SI Water regime)^{3} x (SI Mean high salinity)$^{1.5}$)$^{1/10}$
- Habitat Units (HUs) Formula
- HU = HSI x Area of available habitat
- Average Annual Habitat Units (AAHUs) Formula
- AAHUs = $\frac{\text{Sum of HUs across all years in the period of analysis}}{\text{Number of years in the life of the project}}$

Suitability Index calculations are based on external estimates (i.e. suitability index graphs). These external components were not verified; however, these were assumed to be correct as they are based on established protocols of the HEP and WVA methodologies. The review of internal formulae and calculations is summarized as follows:

- The internal model formulae for determining stand maturity (V_2) show an error on the logical argument; however, this does not affect the final result and can be ignored. This error can be attributed to the fact that multiple levels of functions are nested with the main function statement;
- Also, for V_2 differences exist between the sustainability index line formulae for bald cypress as defined in the supporting documentation for the SCM (USFWS, 2002) and the formulae defined in the model (spreadsheet). Specifically, the y-intercepts for logical statements 3, 4, and 8 do not match for any of the time periods considered (TY 0, TY 1, and TY *N*) for the FWOP and FWP scenarios. Information provided by the USFWS during the course of this assessment confirmed that the formulae

included in the model spreadsheet were correct and the formulae provided in the model documentation need to be revised to match those of the spreadsheet. Despite these differences, the significance of the error is very low and inconsequential to model output.

- No additional errors were found in the remaining formula calculations or function statements.

3.2.4 System Quality

3.2.4.1 Review of Supporting Software

The SCM is a Microsoft Excel® -based simple model which includes data entry or input in tables within a worksheet. Formulae within the analysis tables for FWOP and FWP conditions follow the protocols defined in Appendix A-2 and are linked to the data entry for specific variables. Model calculations are performed based on the input values to yield the model output (AAHUs) that allow assessing project benefit/impact.

3.2.4.2 Review of Programming Accuracy

There is no computer programming associated with the SCM. The model consists of formulae defined within an Excel spreadsheet linked to the various data entries for specific model variables. These formulae/linkages were reviewed and verified for accuracy.

Since the SCM is Microsoft Excel® supported, the data and results can be easily imported into similar software programs. Both model inputs and results can be easily made available to other users; therefore, interoperability is not a limitation. Since Excel is a spreadsheet program that can perform numerical calculations such as those required by the model, it is appropriate software for model development.

3.2.4.3 Review of Model Testing and Validation

Model testing and validation was performed by running the model using three different test datasets provided by USACE and comparing the results. Models/test datasets used were: TX1 – North Neches River, TX2 – Neches Lake Bayou (Texas Hydro Unit), and LA/TX1 Sabine Island. Summary of results for FWOP and FWP for each unit is presented on the next page.

HU #	Hydrologic Unit	FWOP Net Change # Acres	FWP Net Change # Acres	Net Change in AAHUS due to Project
TX1	North Neches River	0	0	-133.27
TX2	Neches Lake Bayou	0	0	-374.65
LA/TX 1	Sabine Island	0	0	-36.76

Model outputs were consistent with variable/data input as described in the accompanying documentation (USFWS, 2002). In the above examples net changes in wetlands AAHUs were predicted due to project implementation suggesting that model is able to discriminate between different scenarios as conditions change. Future conditions were determined based on scientifically-based projections, and professional judgment and knowledge of the area by the SNWW model assessment team.

3.2.5 Usability

The SCM combines several biological and environmental protocols derived from recognized wetlands functional assessment methods (see USFWS, 1980; Bartoldus, 1999; NRC, 2001). Users that have training/experience in basic ecological concepts of coastal wetlands and coastal fish and wildlife habitat should find the SCM easy and readily usable.

3.2.5.1 Review of Data Availability

Model inputs of baseline wetland data (V_1, V_2, and V_3) are based on field investigations and previous observations by Workgroup members in the hydro-units of the project area. Baseline and salinity projections for conditions within swamp habitats (V_4) are obtained from a numerical model (H-S model) for assessing potential salinity impacts due to the proposed navigation improvements to the SNWW. The H-S model is an external component to the SCM. Future projections for other variables are based on monitoring data, scientific literature, professional judgment, and personal knowledge of assessors of the project area.

3.2.5.2 Review of Results

The SCM model output provides useful information in the form of AAHUs that allows the user to support project analysis and easily export the results into project management documentation. The model allows quantification of the proposed projects negative impacts on the swamps in the SNWW project area by providing an estimate of fewer HUs that will be available for fish and wildlife every year during the life of the project than will be available if the proposed action is not implemented. To obtain an estimate of compensation for losses in area units, the model can be run adding acreages in FWP conditions until the target number of AAHUs lost with the project are replaced.

3.2.5.3 Review of Model Documentation

Calculation of cumulative HUs is not well documented and may lead to user confusion when trying to determine how the calculation is done by the model. The original formula defined by the USFWS (1980) for cumulative HUs calculations is defined as follows:

$$\text{Cumulative HUs} = (T_2 - T_1) * [(A_1HSI_1 + A_2HSI_2)/3 + (A_2HSI_1 + A_1HSI_2)/6)]$$

Where, T_1 = first target year of time interval
T_2 = last target year of time interval
A_1 = area of available habitat at beginning of time interval
A_2 = area of available habitat at end of time interval
HSI_1 = HSI at beginning of time interval
HSI_2 = HSI at end of time interval
3 and 6 = constants derived from integration of HSI x Area for the interval between any two target years

The above formula is slightly different from the formula used in the SCM (spreadsheet). Reference to the original formula defined for the HEP needs to be incorporated into assessment protocols and differences among model formulae need to be explained.

There is some confusion in terms of the sources of model documentation. It will be useful for the model user to have all the related documents (i.e. introduction to WVA methodology, procedural manual, and SCM) as one updated file with a link to the model spreadsheet (if made available electronically). Although the model is considered to be transparent in terms of allowing for a relatively easy verification of calculations and outputs, the lack of integration between documents and spreadsheet makes the SCM not very user friendly when it comes to following protocols and instructions of model usage.

3.3 Model Assessment Summary

A summary of the technical assessment of the SCM as described in *Protocols of Certification of Planning Models* (Almodovar et al., 2007) in accordance with requirements specified by USACE (2005) are presented in Section 5.

4 BOTTOMLAND HARDWOOD COMMUNITY MODEL

4.1 Model Description

4.1.1 Model Applicability

The BHCM was developed by LDNR for use in quantifying impacts and mitigation for permitted activities in Louisiana's coastal zone (LDNR, 1994). It is a modification of the USFWS's HEP. The BHCM is a WVA tool and was adopted by the Habitat Workgroup to help accomplish the SNWW CIP mitigation planning objectives. It applies to forested wetlands that can support a canopy of woody vegetation of which more than 40 percent of tree species consist of oaks (*Quercus* spp.), hickories (*Carya* spp.), American elm(*Ulmus Americana*), cedar elm (*Ulmus crassifolia*), green ash (*Fraxinus pennsylvanica*), sweetgum (*Liquidambar styraciflua*), sugarberry (*Celtis laevigata*), boxelder (*Acer negundo*), common persimmon (*Diospyros virginiana*), honeylocust (*Gleditsia triacanthos*), red mulberry (*Morus rubra*), eastern cottonwood (*Populus deltoides*), black willow (*Salix nigra*), and American sycamore (*Platanus occidentalis*) (LDNR,1994).

4.1.2 Model Summary

The BHCM is a deterministic model that consists of: 1) seven variables that allow determining bottomland hardwood habitat suitability for fish and wildlife communities; 2) a SI graph for each variable; and 3) mathematical formulae that combine the SI for each variable into a single value for habitat suitability - HSI. The HSIs are established for the FWOP and FWP conditions for selected target years throughout the life of the project. By multiplying HSIs by the project area acreage at each target year, HUs are calculated. The HUs for the FWOP and FWP conditions are annualized over the project life to determine AAHUs. The difference in AAHUs between FWOP and FWP conditions represents the net benefits or impacts of project in terms of habitat quantity and quality (USFWS, 2006).

4.1.3 Model Components

The seven variables that represent bottomland hardwood habitat quality in the model are:

V_1 Tree Species Composition
V_2 Stand Maturity
V_3 Midstory/Understory
V_4 Hydrology
V_5 Size of Contiguous Forested Area
V_6 Surrounding Land Uses
V_7 Disturbance

Detail about these variables and the mathematical formulae that represent and calculate bottomland hardwood habitat quality in the model can be found in Appendix A.3.

Habitat Suitability Index Formulae

The model incorporates site-specific habitat quality features (tree species composition, forest stand structure, stand maturity, and hydrology) and landscape parameters (forest size, surrounding land use, and disturbance) in these calculations. A discussion of these factors and the formula can be found in Appendix A.3.

4.2 Model Evaluation

4.2.1 Assessment Criteria

The BHCM is a regional/local model developed by a Federal Agency different than the USACE; therefore it is subject to approval for use rather than certification (Almodovar et al., 2007). The assessment criteria of a model are based on its: **1) technical quality, 2) system quality, and 3) usability**. An assessment of applicable components of the BHCM with respect to each of the certification criteria is presented in Sections 4.2.3, 4.2.4, and 4.2.5.

A model that meets the **technical quality** criterion is one that is based on well-established contemporary science and/or theory, and is a realistic representation of the actual system. Additionally, the model needs to clearly address the analytical requirements defined, which must be supported by valid model assumptions. Technical quality is also ensured when formulae used in the model are accurate, and reflect the relationships among variables as specified in the system description. Finally, assumptions, data requirements and model outputs must be fully documented.

System quality refers to the quality of the entire system regarding model development, use and support. The quality of the system is ensured by system level functional testing of hardware and software components, including the assessment of the suitability of the software or programming language. It includes model testing and validation using test datasets, the availability of hardware and software to model users, and the third party interoperability

Usability refers to the ability to access model programs or files, the skills required for model use, data requirements and ease of availability, model's user friendliness, and usefulness of the model outputs to support project analysis. Additional components of this criterion are the availability of model documentation and technical support, and the ease of verification of model calculations and outputs.

4.2.2 Approach to Model Testing

The technical quality assessment was performed considering if the BHCM satisfies general USACE guidelines for mitigation and specific mitigation objectives for the SNWW

navigation expansion project. An analysis of wetland function description and system representation was done to assess how the BHCM integrates indicators of wetland processes for determining compensation mitigation. Review of model calculations and formulae, as well as evaluation of system quality and usability were based on direct observations that resulted from the general use and operation of the model. Telephone meetings were held with members of the modeling team from USACE and USFWS to present partial model evaluation results and to discuss specifics of the model that allowed the evaluation team to gain valuable insights into the development and application of the BHCM.

The version of the BHCM template used for review and testing was provided via electronic transfer by the USACE in March of 2008. In addition to the model template, examples of model applications which included data inputs and outputs for the SNWW project area were also provided by USACE and used for model testing and validation. Model applications for Texas and Louisiana hydrologic units (i.e. TX2 – Neches Lake Bayou, LA1 – Perry Ridge, and LA/TX1- Sabine Island) were used for testing and validation.

4.2.3 Technical Quality Assessment

The technical quality evaluation considered the theoretical basis of the BHCM, the degree to which the model represents the actual system, the validity of the assumptions used in creating the model, the ability of the model to estimate project benefits and impacts, and the suitability of the internal and external model components and accuracy of formulae and calculations.

4.2.3.1 Review of Theory and External Model Components

USACE guidance ER 1105-2-100 requires that the Nation's wetlands be restored, enhanced, replaced and/or preserved when these are affected or lost during the implementation of water and related land resources projects. The ecological benefits of mitigation should compensate for the functional loss resulting from the allowed wetland impact. Furthermore, this USACE guidance document defines compensation for an impact to a wetland as "compensating for the impact by replacing or providing substitute resources or environments. 'Replacing' means the replacement of fish and wildlife resources in-kind. 'Substitute' means the replacement of fish and wildlife resources out-of-kind." The guidance clearly states "this regulation provides the overall direction by which Corps of Engineers Civil Works projects are formulated, evaluated and selected for implementation." Within the context of these guidelines, the BHCM is theoretically sound in that it measures the suitability of bottomland hardwood habitat for fish and wildlife communities.

In the evaluation of wetland mitigation measures, a reference or a baseline wetland condition allows comparison of impacts among proposed alternatives; it allows assessing if proposed mitigation would effectively compensate for the impact, and determining if, once implemented, mitigation actions have actually compensated for impacts or losses

(Brinson and Rheinhardt, 1996). By comparing FWOP and FWP conditions for selected target years throughout the life of the mitigation initiative, the BHCM satisfies project needs for comparing alternative scenarios.

It has been mentioned that the BHCM was developed for use in quantifying impacts and mitigation for permitted activities in Louisiana's coastal zone, thus the application of the model is restricted to areas with the same type of bottomland hardwoods as those present in coastal Louisiana. Since the bottomland hardwood ecosystems in the SNWW project area belong to the same ecological regions as those in western coastal Louisiana according to Griffith et al. (2004) and Daigle et al. (2006), in general the application of the BHCM in the SNWW project area has no perceptible ecological restrictions.

The BHCM incorporates regionally appropriate protocols for quantifying habitat suitability. It is a modification of widely used USFWS's HEP models. Theoretical support for the HEP models come from ecological theories related to habitat selection, niche partitioning, and limiting factors (Barry et al., 2006). These models have been used extensively in characterizing ecosystems (Williams 1988, VanHorne and Wiens 1991, Brooks 1997, Brown et al. 2000, Store and Jokimaki 2003, Shifley et al. 2006, Van der Lee et al. 2006). However, the validity of these assumptions has been question in some instances (e.g. Van Horne and Wiens, 1991; Roloff and Kernohan, 1999; Barry et al., 2006). Variables and SI graphs of the BHCM were constructed based on those incorporated in HEP models. In the application of the model in the SNWW project area monitoring data, scientific literature, professional judgment and knowledge of the assessors of the area is used to predict changes to baseline conditions, yielding quantifications of bottomland hardwood habitat suitability without and with project scenarios.

4.2.3.2 Review of Representation of the System

The regulation used by the USACE for issuing dredge and fill permits under Section 404 of the CWA, defines wetlands as "those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas" (33 CFR 328.3(b)). The model represents the actual bottomland hardwood system through the variables that are included that make reference to presence of a specific type of vegetation (i.e. V_1, V_2, and V_3) and hydrological conditions (V_4). Although the model does not include specific information on saturated soil conditions, variables V_1, V_2, V_3, and V_4 are appropriate surrogates to describe this component of bottomland hardwood ecosystems. The model includes variables regarding landscape condition (i.e. V_5, V_6, and V_7), which provide information on landscape context; an important factor for assessing wetland mitigation needs (Gosselink et al., 1990; Zedler, 1996; NRC, 2001).

Variables in the model assess the quality of the system as fish and wildlife habitat. The model makes little or no reference to functional characteristics of bottomland hardwood plant communities or other system components (e.g. underground biomass accumulation, nutrient cycling, and biological diversity). However, habitat suitability is

assumed to be a surrogate for determining the condition of wetland components and processes not considered by the model and an assessment approach that includes the goals set for mitigation for the SNWW project area. The BHCM incorporates key variables that describe habitat suitability and includes habitat units that allow determining net losses based on multiple scenarios.

4.2.3.3 Review of Analytical Requirement

Analytical requirements associated with BHCM include its ability to identify and assess the ecological functions of bottomland hardwood ecosystems that may be affected by the improvement of SNWW navigation conditions. Additionally, analytical requirements include the ability of the model to assess compensation for damages or losses that may result from the SNWW navigation improvements. Bottomland hardwood ecological function and mitigation assessment is determined based on field and secondary data, as well as professional judgment, in accordance with an established protocol as listed in Appendix A-3. The model includes variables sensitive to changes in bottomland hardwood ecological condition that are summarized as a habitat suitability index that allows determining the ability of bottomland hardwoods to provide required habitat for fish and wildlife activities. When the suitability index is expressed in terms of the extent of the potentially affected bottomland hardwood area during the life of the project, it allows assessing compensatory mitigation requirements.

4.2.3.4 Review of Model Assumptions

The basic assumptions that guide the WVA assessment methodology and that apply to the BHCM are:

- Optimal conditions for fish and wildlife can be characterized within a given coastal wetland habitat type;
- Existing or predicted conditions can be compared to a desired condition to provide an index of habitat quality;
- The resulting HSI of a model has a linear relationship with the suitability of a coastal wetland system in providing fish and wildlife habitat;
- Coastal wetland functions and values (e.g. storm-surge protection, flood water storage, water quality, and nutrient import/export) are positively correlated with fish and wildlife habitat quality.

All the above assumptions operate under an the underlying assumption that in general, the ability of a wetland to provide suitable fish and wildlife habitat is sufficient to characterize overall wetland ecological functions, a limitation that has been noted previously.

Assumptions specific to the BHCM are:

Parameter	Description	Assumptions	Assessment
V_1	Tree Species Composition	Variable defined based on food availability to wildlife (soft mast, other edible seeds, invertebrates, and vegetation) and ability for a woody species to provide resting, foraging, breeding, nesting, and nursery habitat; The main assumptions are: 1) more production of mast and other edible seeds is better than less production, and 2) hard mast is more critical than soft mast and other edible seeds; Variable is calculated using five different classes of overstory canopy coverage.	Assumptions related to the importance of overstory canopy woody species for providing food and other activities to fish and wildlife are appropriate
V_2	Stand Maturity	For this variable it is assumed that stands of bottomland hardwoods with mature sizeable trees (> 10 years old) provide abundant food an important habitat for wildlife and that as the older/weaker trees die additional habitat is provided. The SI for this variable can be determined using the average age of canopy dominant and canopy-codominant trees or their dbh.	Assumptions are appropriate for providing suitable habitat for fish and wildlife. However, under undisturbed conditions bottomland hardwoods would be expected to present a wide range of age and size distribution that includes mature and younger trees and different age/size combinations of woody species.
V_3	Midstory/ Understory	The model assumes that midstory and understory of bottomland hardwoods are equally important in providing abundant food an adequate habitat for wildlife as well as a medium for invertebrate production; Optimal understory coverage is determined by access/availability of habitat for breeding, nesting and feeding activities of wildlife; A slow decrease in SI over 60% understory coverage and 50% midstory coverage is assumed.	Assumptions related to the importance of the midstory/understory of bottomland hardwoods are appropriate. However, the presence of undesirable species (e.g. invasive exotics, other native invasive species, and upland species) is not considered as part of the midstory/understory.

Parameter	Description	Assumptions	Assessment
V_4	Hydrology	The model assumes that the optimum hydrology for stands of bottomland hardwood is one that is essentially unaltered from natural conditions, allowing natural flooding cycles which are beneficial to vegetation and associated fish and wildlife species; The model considers 3 classes of altered water regimes and their associated SIs.	Although more classes that would allow assessing various combinations of flow/exchange and flooding duration may be desirable, in general the assumptions relative to different hydrologic scenarios are considered adequate for determining the suitability of habitat for fish and wildlife species.
V_5	Size of Contiguous Forested Area	The model assumes that larger forested tracts are less common and offer higher quality habitat than smaller tracts, and that species in greatest need of conservation are specialists in habitat use requiring large forested tracts; Tracts > 500 acres in size are considered optimal.	Assumptions are appropriate. Many species that nest, feed, or find cover in a specific habitat or habitat type are also dependent in varying degrees upon other habitats, including upland, wetland, and surface waters that are present in the surrounding landscape.
V_6	Surrounding Land Uses	The model assumes that surrounding land uses affect the wildlife value of specific bottomland hardwood tracts; The model also assumes that some types of surrounding land use are more valuable than others in providing food sources and habitat to wildlife; The model defines five types of surrounding land usually found in the study area, and assigns weighting factors which reflect their estimated potential in meeting habitat needs; The effect of surrounding land use is measured within a 0.5 mile perimeter of the bottomland hardwood tract.	Assumptions are adequate; however, it is not clear why a 0.5 mile perimeter was selected.
V_7	Disturbance	The model assumes that human-induced disturbance can displace individuals, modify home ranges,	Assumptions on distance effect and effect of type of disturbance are

Parameter	Description	Assumptions	Assessment
		interfere with reproduction, cause stress, and force animals to use important energy reserves; The model measures the effect of disturbance based on type of disturbance and distance from disturbance; the magnitude of the effect of each type of disturbance is determined by the distance to the source of disturbance.	reasonable. This variable seems redundant with V_6 as both make reference to type of disturbance/land use and distance/buffer size

4.2.3.5 Review Ability to Evaluate Risk and Uncertainty

The BHCM allows a quantitative evaluation of losses that are specific to bottomland hardwood habitat that might be affected by the SNWW navigation improvement project. Similarly, the model evaluates compensatory mitigation with a habitat unit that allows quantifying the value of habitat quantity and quality over the period of analysis.
The model does not include a direct way to perform sensitivity analysis. However, to assess how project initial conditions vary, the value of each variable was varied repeatedly while holding the other constant until a 10% change in model output was observed. Assessment results showed that the model is not particularly sensitive to any of the seven variables. Ten percent change in model output was only obtained when the most influential variables (i.e. V_1 and V_2) individually experienced a 32% change in value (Figure 3). A 10% change in model output was observed when these two variables were varied simultaneously by 18%. Since model output does not react significantly to changes in any of the input values, precision estimates of model variables are not critical and the uncertainty in model behavior is considered to be low. Model outputs responded as expected to changes in model input.

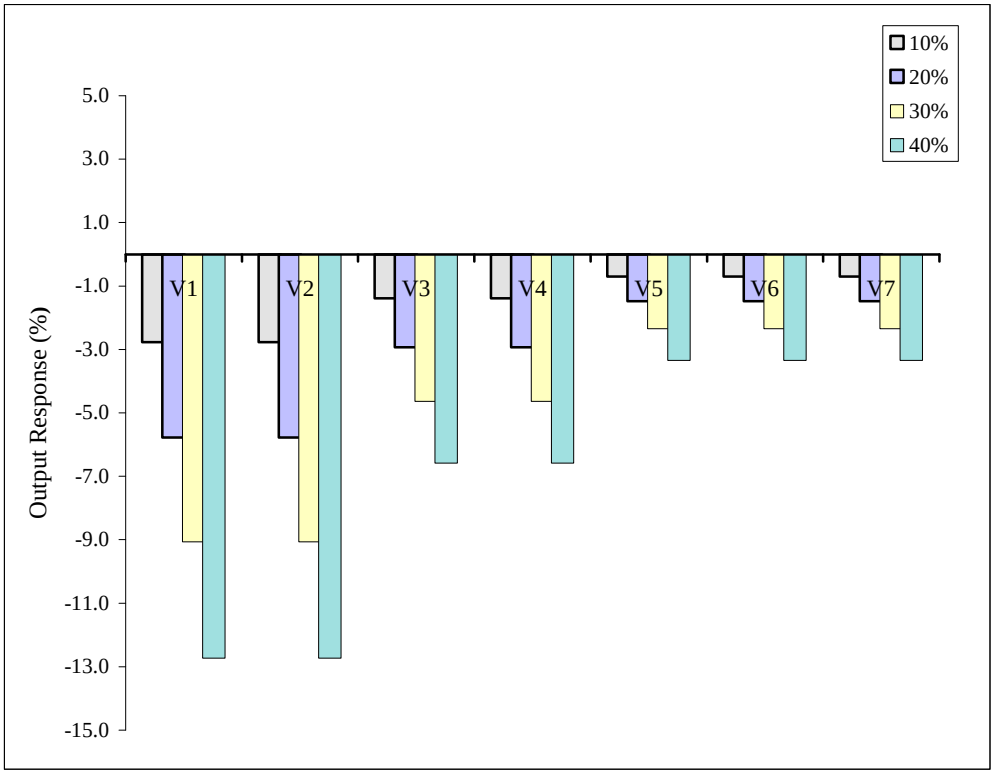

Figure 3. Changes in BHCM output with changes in input data. Variables SI value were decreased repeatedly while holding the other constant until a 10% change in output value was observed.

4.2.3.6 Review Ability to Calculate Benefits for Total Project Life

The BHCM calculates habitat units for FWOP and FWP conditions. These units are annualized over the life of the project to determine AAHUs. The impacts or benefits of the project are then quantified by comparing AAHUs between FWP and FWOP. This procedure fulfills the USACE requirement that compensation be evaluated using a unit of comparison that measures quality and quantity of habitat over time.

4.2.3.7 Review of Model Calculations/Formulae

The model is deterministic since for the same initial conditions and time period projected, they always give the same result. Formulae internal to the model were verified following the BHCM protocols as defined in Appendix A-3. The accuracy of external calculations to the model was not verified. The following internal formulae of the BHCM were verified:

- Suitability Index (SI) Formula for each variable
- Habitat Suitability Index (HSI) Formulae

If Age < 7 (or dbh < 5), then

$HSI = (SI_{V2}^4 \times SI_{V4}^2 \times SI_{V6} \times SI_{V7})^{1/8}$

If Age ≥ 7 (or dbh ≥ 5), then

$HSI = (SI_{V1}^4 \times SI_{V2}^4 \times SI_{V3}^2\ SI_{V4}2 \times SI_{V5} \times SI_{V6} \times SI_{V7})^{1/15}$

- Habitat Units (HUs) Formula
- HU = HSI x Area of available habitat
- Average Annual Habitat Units (AAHUs) Formula

$$AAHUs = \frac{\text{Sum of HUs across all years in the period of analysis}}{\text{Number of years in the life of the project}}$$

Suitability Index calculations are based on external estimates (i.e. SI graphs). These external components were not verified; however, these were assumed to be correct as they are based on established protocols of the HEP and WVA methodologies. The review of internal formulae and calculations is summarized as follows:

- Internal model formulae for determining tree species composition (V_1) and size of contiguous forested area (V_5) show an error on the logical argument; however, these do not affect model output and can be ignored. Errors can be attributed to the fact that multiple levels of functions are nested with the main function statements;

- The SI value for V_2 is not displayed in the Microsoft Excel® model template when dbh = 0 (SI = 0) although the function statement appears to be correct. This problem was not noted in the datasets used for model verification.

- SI values for understory/midstory (V_3) are displayed in cells outside the main WVA calculation tables only after entering a value for this variable. It is important to identify the cells where the SI values are displayed to avoid problems with unintentional cell modification by users;
- No additional errors were found in the remaining formula calculations or function statements.

4.2.4 System Quality

4.2.4.1 Review of Supporting Software

The BHCM is a Microsoft Excel® computer-base simple model which includes data entry or input in tables within a worksheet. Formulae within the analysis tables for FWOP and FWP conditions follow the protocols defined in Appendix A-3 and are linked to the data

entry for specific variables. Model calculations are performed based on the input values to yield the model output (AAHUs) that allow assessing project benefit/impact.

4.2.4.2 Review of Programming Accuracy

There is no computer programming associated with the BHCM. The model consists of formulae defined within an Excel spreadsheet linked to the various data entries for specific model variables. These formulae/linkages were reviewed and verified for accuracy.

Since the BHCM is Microsoft Excel® supported the data and results can be easily imported into similar software programs. Both model inputs and results can be easily made available to other users; therefore, interoperability is not a limitation. Since Excel is a spreadsheet program that can perform numerical calculations such as those required by the model, it is appropriate software for model development.

4.2.4.3 Review of Model Testing and Validation

Model testing and validation was performed by running the model using three different test datasets provided by USACE and comparing the results. Models/test datasets used were: TX2 – Neches Lake Bayou (Texas Hydro Unit), LA1 – Perry Ridge, and LA/TX1 Sabine Island. Summary of results for FWOP and FWP for each unit is presented below.

HU #	Hydrologic Unit	FWOP Net Change # Acres	FWP Net Change # Acres	Net Change in AHHUS due to Project
TX2	Neches Lake Bayou	0	0	0.53
LA1	Perry Ridge	0	0	0.01
LA/TX 1	Sabine Island	0	0	0.00

Model outputs were consistent with variable/data input as described in the accompanying documentation (LDNR, 1994). In the above examples no net change in wetland AAHUs due to the project implementation was observed as no impacts from project implementation are expected. Future conditions were determined based on scientifically-based projections, and professional judgment and knowledge of the area by the SNWW model assessment team.

4.2.5 Usability

The BHCM combines several biological and environmental protocols derived from recognized wetlands functional assessment methods (USFWS, 1980; Bartoldus, 1999; NRC, 2001). Users that have training/experience in basic ecological concepts of coastal

wetlands and coastal fish and wildlife habitat should find the BHCM easy and readily usable.

4.2.5.1 Review of Data Availability

Model inputs of baseline wetland data for V_1, V_2, V_3 and V_4 are based on field observations by the Workgroup members in the hydro-units of the project area. Baseline data for V_5, V_6, and V_7 result from interpretation of aerial photos, estimates from Geographic Information Systems, and professional knowledge of the area. Future conditions estimates for V_1, V_2, V_3 and V_4 are based on scientific literature and professional judgment. Salinity effects on bottomland hardwood habitat are incorporated into the model though V_2 based on salinity projections obtained from the H-S numerical model for the SNWW project area. The H-S model is an external component to the BHCM. Future conditions estimates for V_5, V_6, and V_7 are based on professional judgment.

4.2.5.2 Review of Results

The BHCM model output provides useful information in the form of AAHUs that allows the user to support project analysis and easily export the results into project management documentation. The model allows quantifying if the proposed project will have a negative impact on the bottomland hardwoods present in the SNWW project area by a providing an estimate of fewer HUs that will be available for fish and wildlife every year during the life of the project than will be available if the proposed action is not implemented. To obtain an estimate of compensation for losses in area units, the model can be run adding acreages in FWP conditions until the target number of AAHU's lost with the project are replaced. However, it must be noted that based on model projections no loss of hardwood is anticipated as a result of project implementation.

4.2.5.3 Review of Model Documentation

Calculation of cumulative HUs is not well document and may lead to user confusion when trying to determine how the calculation is done by the model. The original formula defined by the USFWS (1980) for cumulative HUs calculations is defined as follows:
Cumulative HUs = $(T_2 - T_1) * [(A_1HSI_1 + A_2HSI_2)/3 + (A_2HSI_1 + A_1HSI_2)/6)]$

Where, T_1 = first target year of time interval
T_2 = last target year of time interval
A_1 = area of available habitat at beginning of time interval
A_2 = area of available habitat at end of time interval
HSI_1 = HSI at beginning of time interval
HSI_2 = HSI at end of time interval
3 and 6 = constants derived from integration of HSI x Area for the interval between any two target years

The above formula is slightly different from the formula used in the BHCM Microsoft Excel® template. Reference to the original formula defined for the HEP needs to be incorporated into assessment protocols and differences among model formulae need to be explained.

There is some confusion in terms of the sources of model documentation. It will be useful from the point of view of the model users to have all the related documentations (i.e. introduction to WVA methodology, procedural manual, and BHCM) as one updated file with a link to the model spreadsheet (if made available electronically). Although the model is considered to be transparent in terms of allowing for a relatively easy verification of calculations and outputs, the lack of integration between documents and spreadsheet makes the BHCM not very user friendly when it comes to following protocols and instructions to model usage.

4.3 Model Assessment Summary

A summary of the technical assessment of the BHCM as described in *Protocols of Certification of Planning Models* (Almodovar et al., 2007) in accordance with requirements specified by USACE (2005) are presented in Section 5.

5 MODEL ASSESSMENT SUMMARY AND RECOMMENDATIONS

5.1 Emergent Marsh Community Model

A summary of the technical assessment of the EMCM as described in *Protocols of Certification of Planning Models* (Almodovar et al., 2007) in accordance with requirements specified by USACE (2005) are presented in the following table.

Assessment Criteria	Results
Technical Quality	
Theory	Theoretical approach behind the models is valid within the context of USACE guidelines; when reliable indicators that describe all the important wetland processes are not available, the use of scientifically established structural surrogates of those processes is appropriate.
Description of the system being represented by the model	Variables calculated based on established protocols provide a reasonable description of the system being represented.
Analytical requirements	The model identifies habitat structural components and assesses habitat-related ecological functional processes of marsh ecosystems that may be affected by the project. The mode allows assessing compensation for damages or losses that may result from project implementation using habitat units.
Model assumptions	Assumptions of variables specific to the model are appropriate; however, plant community composition could be a useful addition.
Risk and uncertainty	• The model allows a quantitative evaluation of losses that are specific the SNWW CIP. • The model evaluates compensatory mitigation with a habitat unit that allows quantifying suitable habitat quantity and quality for fish and wildlife over the period of analysis. • Based on the assumption that no net loss of habitat equals no net loss of function, the use of the model in the SNWW meets the goal of "no net loss" to wetlands. • The model does not include a direct way to perform sensitivity analysis; however, sensitivity analysis can be done using data tables and graphs directly in Microsoft Excel® spreadsheets or using "what if" tools available from Microsoft®.

Assessment Criteria	Results
Formulae used in the model are identified and the computations are appropriate and done correctly	• Formulae in Microsoft Excel® spreadsheet are appropriate and accurate.
System Quality	
Description of and rationale for selection of supporting software tool/programming language and hardware platform	The model consists of basic mathematical formulae, which can be appropriately computed in a Microsoft Excel® spreadsheet.
Proof that the programming was done correctly.	There is no computer programming associated with the models; however, all Microsoft Excel® formulae, logical arguments and linkages are accurate.
Description of process used to test and validate model.	Test datasets where results were known allowed comparing results; model outputs were consistent with variable/data input as described in the accompanying documentation.
Description of the ability to import data into other software analysis tools (interoperability issue).	Input data and results can be easily imported into similar software programs; model inputs and results can be easily made available to other users.
Usability	
Availability of input data necessary to support the model.	Ecological data are required. Data on baseline conditions can be easily obtained through field assessments. Future conditions are assessed using an external component (i.e. H-S model), scientific literature, professional judgment, and personal knowledge of assessors of the project area.
Formatting of output in an understandable manner.	Output is clear and understandable.
Usefulness of results to support project analysis	The model output provides useful information in the form of AAHUs that allows comparing alternatives and the assessment of benefits or impacts during the life of the project.
Ability to export results into project management documentation	Model outputs are simple and clear and can easily be exported to other documents.
Training availability	Not applicable; however, training in basic ecological concepts of coastal wetlands and coastal fish and wildlife habitat, as well as in the use of spreadsheets should be sufficient for model use.
Users documentation availability and whether it is user friendly and complete	Model is considered to be transparent in terms of allowing for a relatively easy verification of calculations and outputs. However, the following issue is identified as a source of user confusion: • Poor integration between model protocols and spreadsheet.

5.2 Swamp Community Model

A summary of the technical assessment of the SCM as described in *Protocols of Certification of Planning Models* (Almodovar et al., 2007) in accordance with requirements specified by USACE (2005) are presented in the following table.

Assessment Criteria	Results
Technical Quality	
Theory	Theoretical approach behind the SCM is valid; when reliable indicators that describe all the important wetland processes are not available, the use of scientifically established structural surrogates of those processes is appropriate.
Description of the system being represented by the model	Variables calculated based on established protocols provide a reasonable description of the system being represented.
Analytical requirements	The model identifies habitat structural components and assesses habitat-related ecological functional processes of swamp ecosystems that may be affected by the project. The mode allows assessing compensation for damages or losses that may result from project implementation using habitat units.
Model assumptions	Assumptions of variables specific to the model are appropriate; however, tree species composition may be a limiting factor.
Risk and uncertainty	• The model allows a quantitative evaluation of losses that are specific to swamp habitat that might be affected by the SNWW CIP. • The model evaluates compensatory mitigation with a habitat unit that allows quantifying suitable habitat quantity and quality for fish and wildlife over the period of analysis. • Based on the assumption that no net loss of habitat equals no net loss of function, the use of the model in the SNWW meets the goal of "no net loss" to wetlands. • The model does not include a direct way to perform sensitivity analysis; however, sensitivity analysis can be done using data tables and graphs directly in Microsoft Excel® spreadsheets or using "what if" tools available from Microsoft®.
Formulae used in the model are identified and the computations are appropriate and done correctly	Formulae in Microsoft Excel® spreadsheet are appropriate and accurate. However the following issue requires attention: • Variable 2 – Stand Maturity: the y-intercepts for

Assessment Criteria	Results
	logical statements 3, 4, and 8 in the spreadsheet does not match model protocols for any of the time periods considered (TY 0, TY 1, and TY *N*) for the FWOP and FWP scenarios.
System Quality	
Description of and rationale for selection of supporting software tool/programming language and hardware platform	The SCM consists of basic mathematical formulae, which can be appropriately computed in a Microsoft Excel® spreadsheet.
Proof that the programming was done correctly.	There is no computer programming associated with the SCM; however, all Microsoft Excel® formulae, logical arguments and linkages are accurate.
Description of process used to test and validate model.	Test datasets where results were known allowed comparing results; model outputs were consistent with variable/data input as described in the accompanying documentation.
Description of the ability to import data into other software analysis tools (interoperability issue).	Input data and results can be easily imported into similar software programs; model inputs and results can be easily made available to other users.
Usability	
Availability of input data necessary to support the model.	Ecological data on swamp ecosystems are required. Data on baseline swamp conditions can be easily obtained through field assessments. Future conditions are assessed using an external SCM component (i.e. salinity model), scientific literature, professional judgment, and personal knowledge of assessors of the project area.
Formatting of output in an understandable manner.	Output is clear and understandable.
Usefulness of results to support project analysis	The SCM model output provides useful information in the form of AAHUs that allows comparing alternatives and the assessment of benefits or impacts during the life of the project.
Ability to export results into project management documentation	Model outputs are simple and clear and can easily be exported to other documents.
Training availability	Not applicable; however, training in basic ecological concepts of coastal wetlands and coastal fish and wildlife habitat, as well as in the use of spreadsheets should be sufficient for model use.
Users documentation availability and whether it is user friendly and complete	Model is considered to be transparent in terms of allowing for a relatively easy verification of calculations and outputs. However, the following issues are identified as sources for user confusion:

Assessment Criteria	Results
	• Calculation of cumulative HUs is not well document in model protocols (original formula can be find in USFWS (1980)). • Poor integration between model protocols and spreadsheet.

5.3 Bottomland Hardwood Community Model

A summary of the technical assessment of the BHCM as described in *Protocols of Certification of Planning Models* (Almodovar et al., 2007) in accordance with requirements specified by USACE (2005) are presented in the following table.

Assessment Criteria	Results
Technical Quality	
Theory	Theoretical approach behind the BHCM is valid; when reliable indicators that describe all the important wetland processes are not available, the use of scientifically established structural surrogates of those processes is appropriate.
Description of the system being represented by the model.	In general, variables calculated based on established protocols provide a reasonable description of the system being represented.
Analytical requirements	The model identifies habitat structural components and assesses habitat-related ecological functional processes of bottomland hardwood ecosystems that may be affected by the project. The model allows assessing compensation for damages or losses that may result from project implementation using habitat units.
Model assumptions	Assumptions of variables specific to habitat suitability for wildlife are appropriate. However, some limitations are: • Tree species composition is overlooked and may be a limiting factor. • Overall tree species demographics are not considered; long-term habitat suitability depends on adequate recruitment and regeneration. • There is redundancy among variables that describe landscape context.
Risk and uncertainty	• The model allows a quantitative evaluation of losses that are specific to bottomland hardwood habitat that might be affected by the SNWW CIP. • The model evaluates compensatory mitigation with a habitat unit that allows quantifying suitable habitat quantity and quality for wildlife over the period of

Assessment Criteria	Results
	analysis. • Based on the assumption that no net loss of habitat equals no net loss of function, the use of the model in the SNWW meets the goal of "no net loss" to wetlands. • The model does not include a direct way to perform sensitivity analysis.
Formulae used in the model are identified and the computations are appropriate and done correctly	Formulae in Microsoft Excel® spreadsheet are appropriate and accurate. However the following issues require attention: • The SI value for V_2 is not displayed in the Microsoft Excel® model template when dbh = 0 (SI = 0); • SI values for understory/midstory (V_3) are displayed in cells outside the main WVA calculation tables only after entering a value for this variable exposing them to unintentional modification by users.
System Quality	
Description of and rationale for selection of supporting software tool/programming language and hardware platform	The BHCM consists of basic mathematical formulae, which can be appropriately computed in Microsoft Excel® spreadsheet.
Proof that the programming was done correctly.	There is no computer programming associated with the BHCM; however, all Microsoft Excel® formulae, logical arguments and linkages are accurate.
Description of process used to test and validate model.	Test datasets where results were known allowed comparing results; model outputs were consistent with variable/data input as described in the accompanying documentation.
Description of the ability to import data into other software analysis tools (interoperability issue).	Input data and results can be easily imported into similar software programs; model inputs and results can be easily made available to other users.
Usability	
Availability of input data necessary to support the model.	Ecological data on bottomland hardwood ecosystems are required. Data on present bottomland hardwood conditions can be easily obtained through field visits. Future assessment conditions are assessed mainly using external BHCM components (i.e. salinity model), scientific literature, professional judgment, and personal

Assessment Criteria	Results
	knowledge of assessors of the project area.
Formatting of output in an understandable manner.	Output is clear and understandable.
Usefulness of results to support project analysis	The BHCM model output provides useful information in the form of AAHUs that allows comparing of alternatives and the assessment of benefits or impacts during the life of the project
Ability to export results into project management documentation	Model outputs are simple and clear and can easily be exported to other documents.
Training availability	Not applicable; however, training in basic ecological concepts of coastal wetlands and coastal fish and wildlife habitat, as well as in the use of spreadsheets should be sufficient for model use.
Users documentation availability and whether it is user friendly and complete	Model is considered to be transparent in terms of allowing for a relatively easy verification of calculations and outputs. However, the following issues are identified as sources for user confusion: • Calculation of cumulative HUs is not well document in model protocols (original formula can be find in USFWS (1980). • Poor integration between model protocols and spreadsheet.

5.4 Recommendations

Specific Recommendations for Model Improvement:

1. A standard quality control mechanism of the model is recommended to secure integrity of the formulae/calculations. Cells in Excel® spreadsheet containing formulae and logical arguments should be locked to prevent unintentional modification by users.

2. It is recommended that if the model is going to be made available to users in an electronic format, links be established between the model protocols and spreadsheets for improve its user friendliness.

General Comments

The WVA is susceptible to temporal or spatial variability; its use outside the project area is not recommended without model recalibration. In addition to the recalibration of existing variables the following is also recommended:

a) Consideration should be given to include information on overall plant community composition. This might be particularly important where invasive species are a big concern.
b) Consideration should be given to include a variable that provides information on landscape context. Disturbances inside the site and outside may be equally important in affecting the condition of wetlands.
c) Weighting factors for variables need to be reviewed. Additionally, project specific hydrology should be considered as a tool to evaluate wetlands' structure and processes when applying the model to different systems.
d) Redundancy among variables that describe landscape context needs to be tested. Variables that are providing similar information should be considered for elimination.

3. The WVA methodology operates under the underlying assumption that in general, the ability of a wetland to provide suitable fish and wildlife habitat is sufficient to characterize overall wetland ecological function. Although the use of surrogates has been suggested as a valid approach, and this approach does satisfy current USACE guidelines, it is recommended that in assessing compensatory mitigation an effort is made to account for other ecological processes and functions in order to provide a more robust measure of wetland function.

4. The WVA models collectively can be used to provide estimates of specific habitat types applicable to each individual model (e.g., SCM and EMCM). The user is cautioned that the habitat units from each model are not equivalent, and we have not asked nor commented on suitable factors for exchanging habitat units from the various models.

References

Almodovar, L., D. Nolton, B. Carlson, J. Walaszek, and B. Frechione. 2007. Protocols for certification of planning models. Planning Models Improvement Program. 24 pp.

Bartoldus, C. C. 1999. A comprehensive review of wetland assessment procedures: a guide for wetland practitioners. Environmental Concern Inc., St. Michaels, MD. 196 pp.

Barry, D., R. A. Fischer, K. W. Hoffman, T. Barry, E. G. Zimmerman, and K. L. Dickson. 2006. Assessment of habitat values for indicator species and avian communities in a riparian forest. Southern Naturalist 5:295-310.

Brinson, M. M. and R. Rheinhardt. 1996. The role of reference wetlands in functional assessment and mitigation. Ecological Applications 6:69-76.

Brooks, R. P. 1997. Improving habitat suitability index models. Wildlife Society Bulletin 25:163-167.

Brown, S. K., K. R. Buja, S. H. Jury, M. E. Monaco, and A. Banner. 2000. Habitat suitability index models for eight fish and invertebrate species in Casco and Sheepscot Bays, Maine. North American Journal of Fisheries Management 20:408–435.

Conner, W. H. and M. A. Buford. 1998. Southern deepwater swamps. Pages 261-287. *In* M. G. Messina and W. H. Conner (eds.) Southern forested wetlands. Lewis Publishers, Boca Raton, FL.

Conner, W. H. and L. W. Inabinette. 2003. Tree growth in three South Carolina (USA) swamps after Hurricane Hugo: 1991–2001. Forest Ecology and Management 182:371–380.

Conner, W.H., K.W. McLeod, and J.K. McCarron. 1997. Flooding and salinity effects on growth and survival of four common forested wetland species. Wetlands Ecology and Management 5:99-109.

Daigle, J. J., G. E. Griffith, J. M. Omernik, P. L. Faulkner, R.P. McCulloh, L. R. Handley, L. M. Smith, and S. S. Chapman. 2006. Ecoregions of Louisiana (color poster with map, descriptive text, summary tables, and photographs): Reston, Virginia, U.S. Geological Survey (map scale 1:1,000,000).

Gosselink, J. G., G. P. Shaffer, L. C. Lee, D. M. Burdick, D. L. Childers, N. C. Leibowitz, S. C. Hamilton, R. Boumans, D. Cushman, S. Fields, M. Koch, and J. M. Visser. 1990. Landscape conservation in a forested wetland watershed: can we manage cumulative impacts? BioScience 40:588-600.

Griffith, G. E., S. A. Bryce, J. M. Omernik, J. A. Comstock, A. C. Rogers, B. Harrison, S. L. Hatch, and D. Bezanson. 2004. Ecoregions of Texas (color poster with map,

descriptive text, and photographs): Reston, Virginia, U.S. Geological Survey (map scale 1:2,500,000).

Hamby, D. M. 1994. A review of techniques for parameter sensitivity analysis of environmental models. Environmental Monitoring and Assessment 32:135-154.

Jackson, L. J., A. S. Trebitz, and K. L. Cottingham. 2000. An introduction to the practice of ecological modeling. BioScience 50:694-706.

McLeod, K. W., J. K. McCarron, and W. H. Conner. 1996. Effects of flooding and salinity on photosynthesis and water relations of four Southeastern Coastal Plain forest species. Wetlands Ecology and Management 4:31-42.

Louisiana Department of Natural Resources (LDNR). 1994. Habitat assessments models for fresh swamp and bottomland hardwoods within the Louisiana coastal zone. Louisiana Department of Natural Resources, Baton Rouge, Louisiana. 10 pp. & appendices.

Mitsch, W. J. and J. G. Gosselink. 2000. Wetlands. John Wiley & Sons, Inc., Third Edition, New York.

National Research Council (NRC). 2001. Compensating for wetland losses under the Clean Water Act. National Academy Press, Washington, D.C.

Roloff, G. J. and B. J. Kernohan. 1999. Evaluating reliability of habitat suitability index models . Wildlife Society Bulletin 27:973-985.

Shifley, S. R., F. R. Thompson, W. D. Dijak, M. A. Larson, and J. J. Millspaugh. 2006. Simulated effects of forest management alternatives on landscape structure and habitat suitability in the Midwestern United States. Forest Ecology and Management 229:361-377.

Store, R., and J. Jokimaki. 2003. A GIS-based multi-scale approach to habitat suitability modeling. Ecological Modelling 169:1-15.

U.S. Army Corps of Engineers (USACE). 2000. Planning guidance notebook. ER 1105-2-100. Department of the Army, Washington DC. 712 pp.

U.S. Army Corps of Engineers (USACE). 2005. Planning Models Improvement Program: model certification. EC 1105-2-407. Department of the Army, U.S. Army Corps of Engineers, Washington, D.C. 11 pp.

U.S. Army Corps of Engineers (USACE). 2007. Draft Environmental Impact Statement for Sabine-Neches Waterway Channel Improvement Project Southeast Texas and Southwest Louisiana. Appendix C, Ecological Modeling Report Sabine-Neches Waterway, Texas and Louisiana Channel Improvement Project. 452 pp. + Appendix (181 pp.)

U.S. Fish and Wildlife Service (USFWS). 1980. Habitat Evaluation Procedures (HEP). ESM 102, Division of Ecological Services, Department of the Interior, Washington DC. 130 pp.

U.S. Fish and Wildlife Service (USFWS). 2002. Coastal Wetlands Planning, Protection and Restoration Act, Wetland Value Assessment Methodology, Swamp Community Model. Prepared by Environmental Work Group, CWPPRA Technical Committee. USFWS, Lafayette, Louisiana.

U.S. Fish and Wildlife Service (USFWS). 2006. Coastal Wetlands Planning, Protection and Restoration Act, Wetland Value Assessment Methodology, Introduction. Prepared by Environmental Work Group, CWPPRA Technical Committee. USFWS, Lafayette, Louisiana.

Van der Lee, G. E. M., D. T. Van der Molen, H. F. P. Van den Boogaard, and H. Van der Klis. 2006. Uncertainty analysis of a spatial habitat suitability model and implications for ecological management of water bodies. Landscape Ecology 21:1019-1032.

Van Horne, B. and J. A. Wiens. 1991. Forest bird habitat suitability models and the development of general habitat models. U.S. Fish and Wildl. Serv., Fish and Wildl. Res. 8. 31 pp.

Williams, G. L. 1988. An assessment of HEP (Habitat Evaluation Procedures) applications to Bureau of Reclamation projects. Wildlife Society Bulletin 16:437-447.

Zedler, J. B. 1996. Ecological issues in wetland mitigation: introduction to the forum. Ecological Applications 6:33-37.

Appendix A: Model Components and Formulae

A.1 Emergent Marsh Community Models

V_1 Percent of the wetland covered by emergent vegetation

Persistent emergent vegetation provides foraging, resting, and breeding habitat for a variety of coastal fish and wildlife species. Detritus from coastal marshes also provides a source of mineral and organic nourishment for organisms at the base of the food chain. In this model, an area that is 100 percent shallow water is assumed to have minimal habitat suitability (SI=0.1). For all marsh types, optimal vegetative coverage is assumed to be 100 percent (SI=1.0). This assumption diverges from the general biological understanding that optimum cover falls in the 60 percent - 80 percent range. Selection of 100 percent marsh cover as the optimal habitat condition is based upon several factors. Loss of emergent coastal marsh is a serious existing condition in the study area and it is assumed that this loss will continue due to relative sea-level rise (USDC-NOAA, 2006). Existing and potentially accelerated marsh loss associated with channel deepening has been identified as one of the highest concerns by resource agencies and the general public. Mitigation measures should, therefore, maximize emergent marsh creation, maintenance, and protection.

V_1 Line Formula

All marsh types

$$SI = (0.009 \times \%) + 0.1$$

V_2 Percent of the open water covered by submerged aquatic vegetation

Submerged aquatic vegetation (SAV) is defined in this model as any of the diverse array of floating-leaved and submerged aquatic plants that are typically found in the SNWW study area. Seagrasses, included in the SAV designation, are flowering plants that grow entirely underwater. SAV coverage is included as an important marsh variable because it provides important food and cover to a wide variety of fish and wildlife. SAVs provide a refuge from predation and because of this protection, densities of many invertebrates (infaunal and epifaunal) and small fishes are greater in SAVs than in nearby unvegetated areas. SAVs and seagrasses provide additional benefits by stabilizing sediments and filtering water. SAVs and seagrasses tolerate or require a wide range of salinities. Polyhaline species (18-30 ppt) species found in the study area include widgeon grass (*Ruppia maritima*) and turtle grass (*Thalassia testudinum*). Mesohaline species (5-18 ppt) typically found in the SNWW study area include Eurasian watermilfoil (*Myriophyllum spicatum*), and freshwater eelgrass (*Vallisneria americanum*).

Fresh and intermediate marshes, in particular, often support diverse communities of submerged and floating-leaved vegetation. Open water with no aquatics within a fresh or intermediate marsh is assumed to have low suitability (SI = 0.1). Optimal conditions

are assumed when 100 percent of the open water is dominated by aquatic vegetation (SI = 1.0). Brackish marshes can also support aquatic plants that provide food and cover for several species of fish and wildlife. Although amounts are generally less than that which occur in fresh or intermediate marshes, certain species such as widgeon-grass, coontail, and milfoil can be abundant under some conditions and widgeon grass, in particular, is an important food source for waterfowl. The SI graph for brackish marsh is identical to the fresh/intermediate model.

Low salinity saline marshes may also contain beds of widgeon grass, which is able to tolerate a wide range of salinities. However, open water areas in saline marshes generally contain sparse aquatic vegetation and are primarily important as nursery areas for marine organisms. In order to reflect the importance of saline open water areas to marine organisms, a saline marsh with no aquatic vegetation is assigned an SI = 0.3. Optimal coverage by aquatic plants is assumed to be 100 percent.

V_2 Line Formulae

Fresh/intermediate and brackish marsh

$$SI = (0.009 \times \%) + 0.1$$

Saline marsh

$$SI = (0.007 \times \%) + .3$$

V_3 Marsh edge and interspersion

This variable takes into account the relative amount of marsh to open water, and the degree to which open water is dispersed throughout the marsh. Interspersion is an important characteristic for freshwater and estuarine fish and shellfish nursery and foraging habitat in all marsh types. The marsh/open water edge provides cover for post-larval and juvenile organisms. Smaller, isolated ponds are less turbid and contain more aquatic vegetation, thereby providing more suitable waterfowl habitat. Conversely, a large degree of interspersion is assumed indicative of marsh degradation, as solid marsh converts to ever larger areas of open water. If the entire area is solid marsh, or marsh with natural stream courses and tidal channels, Class 1 interspersion is assigned (SI=1.0). If the entire project area is open water, Class 5 interspersion is assigned (SI=0.1).

The SI for V_3 is not calculated with a line formula. Classes 1 through 5 are assigned by comparing marsh edge and interspersion to photographic examples for each class provided in Appendix A of the EMCM (USFWS, 2002d).

V_4 Percent of open water areas less than or equal to 1.5 ft deep

Deeper water is assumed to be less biologically productive than shallow water because sunlight, oxygen, and temperature are reduced as depth increases. Shallow water also provides better bottom access for waterfowl, better foraging habitat for wading birds, and more favorable conditions for the growth of aquatic vegetation. SIs for shallow water are calculated differently for fresh/intermediate, brackish and saline marshes. Optimal shallow water conditions in fresh/intermediate marsh are assumed when 80-90

percent of the open water is equal to or less than 1.5 ft deep. It is assumed that brackish marshes generally contain deeper open water areas because of tidal scouring and therefore lower percentages of shallow water receive a higher SI than in fresh/intermediate marsh. The SI for saline marsh is similar to that of brackish marsh, with one difference. The SI for 100 percent shallow water is slightly less than that for brackish marsh, reflecting the importance of deeper tidal channels for estuarine organism access into saline marshes.

V_4 Line Formulae

Fresh/intermediate marsh

If $0 \leq \% < 80$, then SI = (0.01125 x %) + 0.1

If $80 \leq \% \leq 90$, then SI = 1.0

If $\% > 90$, then SI = (-0.04 x %) + 4.6

Brackish marsh

If $0 \leq \% < 70$, then SI = (0.01286 x %) + 0.1

If $70 \leq \% \leq 80$, then SI = 1.0

If $\% > 80$, then SI = (-0.02 x %) + 2.6

Saline marsh

If $0 \leq \% < 70$, then SI = (0.01286 x %) + 0.1

If $70 \leq \% \leq 80$, then SI = 1.0

If $\% > 80$, then SI = (-0.025 x %) + 3.0

V_5 Salinity

Salinity is one of the most important factors affecting coastal land loss. Salinity projections affect all of the other EMCM variables with the exception of aquatic organism access. For fresh/intermediate marshes and swamp, the mean high salinity (calculated as a roaming mean of the highest 33 percent consecutive salinity readings) during the growing season is used. For brackish and saline marshes, average annual salinity is used. Optimum salinity ranges assumed by the model for the various habitat types are as follows: swamp and bottomland hardwood (≤ 1 ppt), fresh marsh (≤ 2 ppt), intermediate marsh (≤ 4 ppt), brackish marsh (≤ 10 ppt), and saline marsh (≥ 9 and ≤ 21 ppt).

V_5 Line Formulae

Fresh marsh

If $0 \leq ppt \leq 2$, then SI =1.0

If $2 < ppt \leq 4$, then SI =(-0.4 x ppt) + 1.8

If $4 < ppt \leq 5$, then SI =(-0.1 x ppt) + 0.6

Intermediate marsh

If $0 \leq ppt \leq 4$, then SI =1.0

If $4 < ppt \leq 8$, then SI =(-0.2 x ppt) + 1.8

Brackish marsh
If $0 \leq ppt \leq 10$, then SI =1.0
If ppt > 10, then SI =(-0.15 x ppt) + 2.5

Saline marsh
If $9 \leq ppt \leq 21$, then SI =1.0
If ppt > 21, then SI =(-0.067 x ppt) + 2.4

V_6 Aquatic organism access

Access by estuarine-dependent fishes and shellfishes, as well as other aquatic organisms, is important in assessing the quality of marsh systems. It is assumed that a high degree of surface hydrologic connectivity with adjacent systems provides high organism access, as well as providing greater nutrient exchange. The SI is calculated by determining an Access Value which is based on an interaction between the wetland area accessible to aquatic organisms during normal tidal fluctuations and the type of man-made structures (if any) blocking access channels (USFWS, 2002d). Access ratings for specific structures, developed by the Louisiana EnvWG, were adopted for the SNWW application. Optimal conditions are assumed when the entire wetland area is accessible and access points are unobstructed. Brackish and saline marshes are assumed to be more important than fresh/intermediate marshes as habitat for estuarine-dependent fish and shellfish.

V_6 Line Formulae

Fresh marsh
SI= (0.7 x Access Value) + 0.3
Intermediate marsh
SI= (0.8 x Access Value) + 0.2
Brackish and saline marsh
SI= (0.9 x Access Value) + 0.1

Habitat Suitability Index Formulae

All of the variable suitability indices (SI) for a specific marsh type (i.e. fresh/intermediate, brackish, or saline) are combined in a mathematical formula, the Habitat Suitability Index or HSI, which represents the composite habitat quality of the wetland being evaluated. Within each HSI formula, specific variables can be weighted to increase the relative importance of that variable over others in the formula. The HSI formulae were the same as those used by the CWPPRA EnvWG.

The primary focus of the SNWW application of the WVA model is the preservation of vegetated wetlands, but it is also recognized that some marsh restoration or protection strategies could have an adverse effect on the access of aquatic organisms. Therefore, variables V_1 (Percent Emergent Vegetation), V_2 (Percent SAV), and V_6 (Aquatic Organism Access) are grouped together and weighted greater than the remaining variables. For all marsh models, V_1 receives the greatest weighting; however, the relative weights of V_1,

V_2, and V_6 vary by marsh model to reflect different levels of importance between the marsh types.

The EMCM employs a split model format to account for the value of both marsh and open water habitats. Two HSI formulae are calculated for each marsh type – one for emergent marsh habitat and one for open water habitat. The HSI formula for emergent marsh contains only those variables that are important for evaluating its habitat quality (V_1, V_3, V_5, and V_6). The HSI formula for open water habitat contains only those variables important to that habitat component (V_2, V_3, V_4, V_5, and V_6).

Fresh / Intermediate Marsh HSI

Emergent Marsh HSI =

$$\frac{\left(3.5 \times \left(SIV_1^{5} \times SIV_6^{1}\right)^{(1/6)}\right) + \frac{(SIV3 + SIV5)}{2}}{4.5}$$

Open Water HSI =

$$\frac{\left(3.5 \times \left(SIV_2^{3} \times SIV_6^{1}\right)^{(1/4)}\right) + \frac{(SIV3 + SIV4 + SIV5)}{3}}{4.5}$$

Brackish Marsh HSI

Emergent Marsh HSI =

$$\frac{\left(3.5 \times \left(SIV_1^{5} \times SIV_6^{1.5}\right)^{(1/6.5)}\right) + \frac{(SIV3 + SIV5)}{2}}{4.5}$$

Open Water HSI =

$$\frac{\left(3.5 \times \left(SIV_2^{3} \times SIV_6^{2}\right)^{(1/5)}\right) + \frac{(SIV3 + SIV4 + SIV5)}{3}}{4.5}$$

Saline Marsh HSI

$$\text{Emergent Marsh HSI} = \frac{\left(3.5 \times \left(SIV_1^{\,3} \times SIV_6^{\,1}\right)^{(1/4)}\right) + \frac{(SIV3 + SIV5)}{2}}{4.5}$$

$$\text{Open Water HSI} = \frac{\left(3.5 \times \left(SIV_2^{\,1} \times SIV_6^{\,2.5}\right)^{(1/3.5)}\right) + \frac{(SIV3 + SIV4 + SIV5)}{3}}{4.5}$$

Since the EMCM is split into emergent marsh and open water components, an HSI is calculated for both. Net AAHUs, determined for both components, must be combined to determine total net benefits. In the weighted formulae for determining net AAHUs for each marsh type (below), AAHUs for emergent marsh are weighted higher than open water AAHUs to reflect the ICT's emphasis on marsh restoration/protection over open water habitat.

Fresh/Intermediate Marsh: $\frac{2.1\ (\text{Emergent Marsh AAHUs}) + \text{Open Water AAHUs}}{3.1}$

Brackish Marsh: $\frac{2.6\ (\text{Emergent Marsh AAHUs}) + \text{Open Water AAHUs}}{3.6}$

Saline Marsh: $3.5\ (\text{Emergent Marsh AAHUs}) + \text{Open Water AAHUs}$

A.2 Swamp Community Model

V_1 Stand Structure

This variable (V_1) refers to the ability for a swamp to provide resting, foraging, breeding, nesting, and nursery habitat for vertebrates and invertebrates. Three structure components of swamps are evaluated: herbaceous vegetation, scrub-shrub/midstory cover, and overstory canopy. A site with the lowest suitability presents limited amount of all three stand structure components while a site with the highest suitability presents significant amount of all three stand structure components (USFWS, 2002). The SI for V_1 is calculated using six possible combinations of the relative coverage of the structure components as shown below.

	Overstory Closure		Scrub-shrub/ Midstory Cover		Herbaceous Cover	Suitability Index (SI)
Class 1	<33%					0.1
Class 2	33%<50%	and	<33%	and	<33%	0.2
Class 3	33%<50%	and	>33%	or	>33%	0.4
Class 4	50%-75%	and	>33%	or	>33%	0.6
Class 5	33%<50%	and	>33%	and	>33%	0.8
Class 6	≥50%	and	>33%	and	>33%	1.0
			OR			
	≥75%	and	>33%	or	>33%	1.0

V_2 Stand Maturity

Stand age and stand density are combined to score this variable (V_2). For defining stand maturity it is assumed that swamps with mature sizeable trees provide important habitat for wildlife and invertebrates including snags and nesting cavities. Additionally, as the older, stronger trees establish themselves in the canopy, weaker trees die and provide additional habitat. Sites are most suitable when the average diameter-at-breast height (dbh) of canopy-dominant and canopy-codominant trees is above 16 inches for bald cypress and above 12 inches for tupelo gum and other species (USFWS, 2002). Stand density, measured in terms of basal area (BA), allows evaluation of mature swamps that present an overstory with a few widely-scattered, mature bald cypress but that fail to provide many important habitat components of a mature swamp ecosystem, including a suitable number of trees for nesting, foraging, and other habitat functions (USFWS, 2002).

The SI for V_2 is calculated separately for bald cypress and tupelo gum associations using a line formula and multiplied by a factor depending on stand density as follows.

Suitability Index Line Formulae for baldcypress

If dbh = 0 then SI = 0.0
If 0 < dbh $\leq$ 1 then SI = 0.01 x dbh
If 1 < dbh $\leq$ 4 then SI = (0.013 x dbh) - 0.003
If 4 < dbh $\leq$ 7 then SI = (0.017 x dbh) - 0.017
If 7 < dbh $\leq$ 9 then SI = (0.1 x dbh) - 0.6
If 9 < dbh $\leq$ 11 then SI = (0.15 x dbh) - 1.05
If 11 < dbh $\leq$ 13 then SI = (0.1 x dbh) - 0.5
If 13 < dbh $\leq$ 16 then SI= (0.067 x dbh) - 0.067
If dbh > 16 then SI = 1.0

Suitability Index Line Formulae for tupelo gum associations

If dbh = 0 then SI = 0.0
If 0 < dbh $\leq$ 1 then SI = 0.01 x dbh
If 1 < dbh $\leq$ 2 then SI = (0.04 x dbh) - 0.03
If 2 < dbh $\leq$ 4 then SI = 0.025 x dbh
If 4 < dbh $\leq$ 6 then SI = (0.1 x dbh) - 0.3
If 6 < dbh $\leq$ 8 then SI = (0.15 x dbh) - 0.6
If 8 < dbh $\leq$ 12 then SI = (0.1 x dbh) - 0.2
If dbh > 12 then SI = 1.0

Stand Density Factors

If open (BA < 40 ft^2), then 0.2
If moderately open (40 $ft^2 \leq$ BA $\leq$ 80 ft^2), then 0.4
If moderate (81 $ft^2 \leq$ BA $\leq$ 120 ft^2), then 0.6
If moderately dense (121 $ft^2 \leq$ BA $\leq$ 160 ft^2), then 0.8
If dense (BA >160 ft^2), then 1.0

V_3 Water Regime

This variable (V_3) considers the duration and amount of water flow/exchange. The optimal water regime is assumed to be seasonal flooding with abundant and consistent riverine/tidal input and water flow-through. Seasonal flooding with periodic drying cycles is assumed to contribute to increased nutrient, increased vertical structure complexity, and increased recruitment of dominant overstory trees. Optimal water flow-through maximizes fish and wildlife habitat use. Temporary flooding is also assumed to be desirable. Habitat suitability is assumed to decrease as water exchange between the swamp and adjacent systems is reduced. The combination of permanently flooded conditions and no water exchange is assumed to be the least desirable. Under these conditions and warm temperatures, water quality can be affected reducing fish and crawfish production (USFWS, 2002).

Four flow/exchange and four flooding duration categories are used to characterize the water regime. The SI for V_3 is assigned according to the various combinations of the flow/exchange and flooding duration categories as shown below.

		Flow/Exchange			
		High	Moderate	Low	None
Flooding Duration	Seasonal	1.00	0.85	0.70	0.50
	Temporary	0.9	0.75	0.65	0.40
	Semi- Permanent	0.75	0.65	0.45	0.25
	Permanent	0.65	0.45	0.30	0.10

V_4 Mean High Salinity during the Growing Season

For this variable (V_4) mean high salinity during the growing season (March 1st to October 31st) is defined as the average of the upper 33 percent of salinity measurements taken during the specified period of record (USFWS, 2002). Baldcypress may tolerate some degree of salinity; however other swamp species such as tupelo gum and many herbaceous species are salinity-sensitive. Thus, optimal habitat suitability is assumed to occur at mean high salinities less than 1.0 ppt. and to decrease rapidly at mean high salinities above 1.0 ppt. The SI for V_4 is calculated using a line formula as follows:

<u>Line Formulae</u>

If $0 \leq ppt \leq 1.0$, then $SI = 1.0$
If $1.0 < ppt < 3.0$, then $SI = (-0.45 \times ppt) + 1.45$
If $ppt \geq 3.0$, then $SI = 0.1$

Habitat Suitability Index Formula

All of the variable suitability indices are combined in a mathematical formula to calculate the HSI, which represents the composite habitat quality. Variables V_1 and V_3 (stand structure and water regime) are considered the most important variables in characterizing swamp habitat quality and therefore are weighted heavier than other variables (USFWS, 2002). Variable V_4 (salinity) is considered to be least important. The HSI is defined as:

$$HSI = (SI\ V_1^3 \times SI\ V_2^{2.5} \times SI\ V_3^3 \times SI\ V_4^{1.5})^{1/10}$$

A.3 Bottomland Hardwood Community Model

V_1 Tree Species Composition

Bottomland hardwoods provide a variety or mast, other edible seeds and tree buds to their associated wildlife. The BHCM model assumes that 1) more production of mast and other edible seeds is better than less, and that 2) because of its availability during late fall and winter and high energy content, hard mast is more critical than soft mast and other edible seeds (LDNR, 1994). Hard mast producing species include oaks, pecan, and other hickories, while soft mast and other edible seeds producers include red maple, sugarberry, green ash, boxelder, common persimmon, sweetgum, honeylocust, red mulberry, bald cypress, tupelo-gum, American elm and cedar elm (LDNR, 1994). The SI for this variable is calculated using 5 classes of the percentage of the overstory that contains mast producing trees, and the percentage of hard mast producers in the canopy. Classes and associated SI are shown below.

	Description	SI
Class 1	< 25% mast or other edible seed producing trees in overstory	0.2
Class 2	25% to 50% mast or other edible seed producing trees in overstory; hard mast producers < 10% of canopy	0.4
Class 3	25% to 50% mast or other edible seed producing trees in overstory; hard mast producers > 10% of canopy	0.6
Class 4	> 50% mast or other edible seed producing trees in overstory; hard mast producers < 20% of canopy	0.8
Class 5	> 50% mast or other edible seed producing trees in overstory; hard mast producers > 20% of canopy	1.0

V_2 Stand Maturity

Mature stands of bottomland hardwoods provide more hard and soft mast, other edible seeds, and buds than younger stands. In addition to food production, bottomland hardwoods also provide important wildlife requirements including snags, nesting cavities, as well as medium for invertebrate production. Additionally, as stronger mature trees establish themselves in the canopy, they out-compete weaker trees that when they die, provide additional habitat (i.e. snags and downed tree tops). The average age of canopy-dominant and canopy-codominant trees or the average tree diameter at breast height (dbh) are used for calculating the SI for this variable.

<u>Suitability Index Line Formulae when Tree Age is known</u>

If age = 0 then SI = 0
If 0 < age $\leq$ 3 then SI = 0.0033 x age
If 3 < age $\leq$ 7 then SI = (0.01 x age) - 0.02

If 7 < age $\leq$ 10 then SI = (0.017 x age) - 0.07
If 10 < age $\leq$ 20 then SI = (0.02 x age) - 0.1
If 20 < age $\leq$ 30 then SI = (0.03 x age) - 0.3
If 30 < age $\leq$ 50 then SI = 0.02 x age
If age > 50 then SI = 1.0.

Suitability Index Line Formulae based on Tree DBH

If dbh = 0 then SI = 0
If 0 < dbh $\leq$ 5 then SI = 0.01 x dbh
If 5 < dbh $\leq$ 8 then SI = (0.017 x dbh) - 0.035
If 8 < dbh $\leq$ 11 then SI = (0.067 x dbh) - 0.43
If 11 < dbh $\leq$ 14 then SI = (0.1 x dbh) - 0.8
If 14 < dbh $\leq$ 20 then SI = (0.067 x dbh) - 0.338
If dbh > 20 then SI = 1.0.

V_3 Midstory/Understory

Midstory and understory vegetation of bottomland hardwoods provide to wildlife food sources (i.e. hard/soft mast, other edible seeds, vegetation, invertebrates) and other important habitat (i.e. resting, foraging, nesting, breeding, and nursery activities). The understory and midstory SIs are calculated separately and equally weighted (averaged) in determining the SI for this variable. The model assumes that a midstory/understory is present when stand maturity is greater than 7 years (or dbh is greater than 5 inches). The model also assumes that the value of understory coverage increases as it increases between 0 and 30 percent. Optimal understory coverage is achieved between 30 and 60 percent. The SI slightly decreases when understory coverage exceeds 60 percent, based upon the assumptions that denser understory limits wildlife access and is less desirable for breeding, nesting, and feeding activities.

Suitability Index Line Formulae for Understory Coverage

If understory % = 0 then SI = 0.1
If 0 < un. % $\leq$ 30 then SI = (0.03 x un. %) + 0.1
If 30 < un. % ≤ 60 then SI = 1.0
If un. % > 60 then SI = (-0.01 x un. %) + 1.6

Suitability Index Line Formulae for Midstory Coverage

If midstory % = 0 then SI = 0.1
If 0 < mid. % $\leq$ 20 then SI = (0.045 x mid. %) + 0.1
If 20 < mid. % ≤ 50 then SI = 1.0
If mid. % > 50 then SI = (-0.01 x mid. %) + 1.5

V_4 Hydrology

The model assumes that the optimum hydrology for bottomland hardwood stands is one that is essentially undisturbed; it allows natural wetting and drying cycles which are

beneficial to vegetation and associated fish and wildlife species. For stands with efficient forced drainage, it is assumed that the vegetation provides some habitat value, but water-dependent wildlife are excluded and fisheries production is not allowed. For stands with a moderately lowered water table, the vegetation provides excellent habitat for many wildlife species and temporary habitat for water-dependent wildlife, but fish are excluded. For stands with a raised water table, habitat for fish and water-dependent wildlife is assumed to be equivalent to an unaltered system, but habitat to other wildlife is limited since vegetation components can be adversely impacted. Classes and associated SI are assigned according to the various classes as shown below.

	Description	SI
Class 1	Forced drainage system which efficiently removes water from the surface year round.	0.1
Class 2	Water table lowered relative to ground level so as to significantly reduce period of inundation or water table raised so as to cause extended inundation or impoundment.	0.5
Class 3	Hydrology essentially unaltered (small levees and/or ditches that do not significantly affect water regime can be present).	1.0

V_5 Size of Contiguous Forested Area

The main assumptions for this variable are that 1) larger forested tracts are less common and offer higher quality habitat than smaller tracts, and that 2) species in greatest need of conservation are specialists in habitat use requiring large forested tracts. Even though forest edge and diversity are important, the model assumes that edge habitat species are highly mobile and occur in substantial numbers because of the increase in forest fragmentation. Additionally, edge habitat species are generalists in habitat use and are capable of existing in larger tracts. Optimal tracts are those greater than 500 acres in size. Five forest tract classes are used in this variable and associated SI are assigned according to these classes as shown below.

	Description	SI
Class 1	0 to 5 acres	0.2
Class 2	5.1 to 20 acres	0.4
Class 3	20.1 to 100 acres	0.6
Class 4	100.1 to 500 acres	0.8
Class 5	> 500 acres	1.0

V_6 Surrounding Land Uses

The model assumes that adjacent lands to bottomland hardwood tracts are of value to wildlife since they provide important habitat (e.g. temporary escape or resting cover, seasonal or diurnal food sources, connecting corridors to other desirable habitats). However, wildlife values differently the various types of surrounding land uses of

bottomland hardwood tracts depending on their ability to provide suitable habitat. The model defines five types of surrounding land use and assigns weighting factors which reflect their estimated potential in meeting specific needs and to serve as corridors between more desirable habitats. The percent of the area occupied by each land use type within a 0.5 mile perimeter of the bottomland hardwood tract is used to assess habitat suitability. Land use classes, weighting factors and final SI calculation are shown below.

Land Use	Weighting Factor	Percent of 0.5 Mile Circle	Weighted Percent
Bottomland hardwood, other forested areas, marsh habitat, etc.	1.0	x	=
Abandoned agriculture, overgrown fields, dense cover, etc.	0.6	x	=
Pasture, hayfields, etc.	0.4	x	=
Active agriculture.	0.2	x	=
Non-habitat: linear, residential, commercial, industrial development, etc.	0.0	x	=
			Total/100 = SI

V_7 Disturbance

The model assumes that human-induced disturbance can displace individuals, modify home ranges, interfere with reproduction, cause stress, and force animals to use important energy reserves. The effect of disturbance is dependent on the distance to disturbance and on the type of disturbance. These factors are evaluated separately and then combined to obtain a single SI value as shown below.

Distance Classes		SI
Class 1	0 to 50 ft	1
Class 2	50.1 to 500 ft	2
Class 3	> 500 ft	3

Type Classes		SI
Class 1	Constant / Major. (Major highways, industrial, commercial, major navigation)	1
Class 2	Frequent / Moderate. (Residential development, moderately used roads, waterways commonly used by small to mid-sized boats.)	2
Class 3	Seasonal / Intermittent. (Agriculture, aquaculture.)	3
Class 4	Insignificant. (Lightly used roads and waterways, individual homes, levees, rights of way.)	4

Combined SI for Disturbance

		Type Class			
		1	2	3	4
Distance Class	1	0.01	0.26	0.41	1.0
	2	0.26	0.50	0.65	1.0
	3	1.0	1.0	1.0	1.0

Habitat Suitability Index Formulae

The model incorporates site-specific habitat quality features (tree species composition, forest stand structure, stand maturity, and hydrology) and landscape parameters (forest size, surrounding land use, and disturbance) in these calculations. Because the primary application of this model is to quantify the loss of ecological values due to changes in the site-specific conditions, variables which are likely to be affected by these changes (V_1, V_2, V_3, and V_4) are considered more important than the landscape variables. Of the site specific variables, Variables V_1 and V_2 are considered equal and of greater importance than the other variables; they are weighted to the power of four. Variable V_3 and V_4 are weighted to the power of two. The "landscape" variables (V_5, V_6, and V_7) are not weighted (LDNR, 1994).

Several factors influence the HSI formulae. The suitability index for V_1 and V_3 are a function of hard and soft mast production. Until the trees reach hard mast-bearing age (approx. 7 years of age), V_1 and V_3 do not affect the value of the site. Therefore, V_1 and V_3 are not incorporated into HSI formulae until the trees reach approximately 7 years of age (dbh ≥ 5 inches). Variable V_5 assigns a greater value to larger contiguous forested tracts than to edge and diversity. In keeping with that approach, seedlings and saplings present at a forest regeneration site are not yet part of the contiguous forested area. Therefore, V_5 is not incorporated into HSI formulae until dbh ≥ 5 inches (LDNR, 1994). The HSI formulae for bottomland hardwood are:

1. If Age < 7 (or dbh < 5), then

$$HSI = (SI\ V_2^4 \times SI\ V_4^2 \times SI\ V_6 \times SI\ V_7)^{1/8}$$

2. If Age ≥ 7 (or dbh ≥ 5), then

$$HSI = (SI\ V_1^4 \times SI\ V_2^4 \times SI\ V_3^2 \times SI\ V_4^2 \times SI\ V_5 \times SI\ V_6 \times SI\ V_7)^{1/15}$$